Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Climate Change Scenario Analysis for Baro-Akobo River Basin, Southwestern Ethiopia

TERESSA NEGASSA MULETA (terneg@gmail.com)
Budapest University of Technology and Economics

Research

Keywords: A1B emission scenario, Baro-Akobo River Basin, Climate change, Climate scenario, General circulation model, Regional climate model

Posted Date: November 20th, 2020

DOI: https://doi.org/10.21203/rs.3.rs-110962/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Version of Record: A version of this preprint was published on March 26th, 2021. See the published version at https://doi.org/10.1186/s40068-021-00225-5.

Climate Change Scenario Analysis for Baro-Akobo River Basin, Southwestern Ethiopia

Teressa Negassa Muleta[1]*

[1]Department of Sanitary and Environmental Engineering, Budapest University of Technology and Economics, Budapest, Hungary

*Correspondence: Email: teressa.negassa.muleta@epito.bme.hu; Mob.: +36203225372

Abstract

Background

Relatively few studies have addressed water management and adaptation measures in the face of changing water balances due to climate change. Projection of the future climate variables is done using General Circulation Model (GCM). But GCM cannot capture finer scale forcing variables at regional and basin levels. Hence Regional Climate Model (RCM) downscaled data for A1B emission scenario is bias corrected at basin level using observed data. The current study has developed future climate trends using the bias corrected RCM output data for Baro-Akobo River Basin with the basic objective of producing informative data for sustainable water resource development and management in the basin.

Result

The projected future climate shows an increasing trend for both maximum and minimum temperatures; however, for the case of precipitation it doesn't manifest a systematic increasing or decreasing trend in the next century. The projected mean annual temperature increases from the baseline period by an amount of 1^{o}C and 3.5^{o}C respectively, in 2040s and 2090s. Similarly, evapotranspiration has been found to increase to an extent of 25% over the basin. The precipitation experiences a mean annual decrease by 1.8% in 2040s and increases by 1.8% in 2090s over the basin for the A1B emission scenario.

Conclusion

Irrespective of whether there is a trend or not, it can be concluded from these results that considerable change in climate is expected to happen over the basin as per the A1B emission scenario. In addition to quantitative change, the results of this study have depicted a considerable climate change in terms of timing and frequency and hence calls for an attention on the possible future risks of sustainable water resources development and management in the basin.

Key Words: A1B emission scenario, Baro-Akobo River Basin, Climate change, Climate scenario, General circulation model, Regional climate model

Background

The planning and management of basin scale water resources systems has historically relied on assuming stationary hydrologic conditions. This approach assumes that past hydrologic conditions are sufficient to guide the future operation and planning of water resources systems and infrastructures. This assumption is nowadays threatened by climate change and the notion that both climate and hydrology will evolve in the future.

There are now strong evidences, which show that the earth's climate is changing mainly as a result of the increasing concentration of greenhouse gases in the atmosphere that are emitted from various human activities. According to the Series Assessment Reports of the Intergovernmental Panel on Climate Change (IPCC, 2007), warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level.

These climatic variables directly affect runoff levels and stream flows which in turn determine the amount of water available for hydroelectric generation. Water resource planning based on the concept of a stationary climate is increasingly considered inadequate for sustainable water resources management (Mohamed, 2015). So far, water resource issues have not been adequately addressed in climate change analyses and climate policy formulations in Baro-Akobo River basin. Hence projection of possible climate change over the basin is of paramount importance for operation and planning of water resource projects in the basin for sustainable development (Jones, 1999). In fact, according to the IPCC's latest findings, global average temperatures will probably raise a further 1.1 to 6.4 ºC (2.0 to 11.5 ºF) (IPCC, 2018) this century, depending on the extent of continued greenhouse gas emissions. Developing countries in general and least developed

countries like Ethiopia in particular are more vulnerable to the adverse impacts of climate variability and change.

In Ethiopia, the report by (NAPA, 2007) (Getachew B., 2018), has shown that there has been a warming trend in the annual minimum temperature over the past 55 years (1951-2006) using 40 stations from the country. According to this report the annual minimum temperature has been increasing by about 0.37^0C every ten years. However, hardly few studies have addressed water management and adaptation measures in the face of changing water balances due to climate change in Ethiopia. In contrast, over the last few years, the literature on adaptation to climate change has expanded considerably worldwide. Studies such as (Schneider, Easterling, & Mearns, 2000) have drawn lessons from adaptation to climatic variability or extreme events, whereas others have focused on how adaptation can reduce vulnerability to climate change. (Brekke, et al., 2009), presented a flexible methodology for conducting climate change risk assessments involving reservoir operations. (Li, Xu, Chen, & Simonovic, 2009) and (Deepashree & Mujumdar, 2010) investigated potential impacts of future climate change on stream flow and reservoir operation performance in a Northern American Prairie watershed.

Climate Models

Climate models are mathematical representations of the climate system, expressed as computer codes and run on powerful computers. General circulation models (GCMs) are tools designed to simulate time series of climate variables globally, accounting for effects of greenhouse gases in the atmosphere. They attempt to represent the physical processes in the atmosphere, ocean, cryosphere and land surface. They are currently the most credible tools available for simulating the response of the global climate system to increasing greenhouse gas concentrations, and to

provide estimates of climate variables (e.g. air temperature, precipitation, wind speed, pressure, etc.) on a global scale. GCMs demonstrate a significant skill at the continental and hemispheric spatial scales and incorporate a large proportion of the complexity of the global system; they are, however, inherently unable to represent local sub grid-scale features and dynamics, which are of interest to a hydrologist. Accuracy of GCMs in general decreases from climate-related variables such as wind, temperature, humidity and air pressure to hydrologic variables such as precipitation, evapotranspiration, runoff and soil moisture, which are also simulated by GCMs. These limitations of the GCMs restrict the direct use of their output in hydrology.

Models are routinely and extensively assessed by comparing their simulations with observations of the atmosphere, ocean, cryosphere and land surface. There is considerable confidence that Atmosphere-Ocean General Circulation Models (AOGCMs) provide credible quantitative estimates of future climate change, particularly at continental and larger scales adapted from (IPCC, 2007). Even given the limitations and uncertainties associated with modelling, global circulation models and regional climate models can be applied usefully to identify a range of uncertainties allowing strategic policy-making for adaptation.

A number of research centers around the world have developed their own versions of GCMs, but all predictions contain uncertainties. For example, because future emissions of greenhouse gases are unknown, numerous emissions scenarios have been developed; therefore, different scenarios will obviously produce different results. However, the largest uncertainty arises from the models themselves. Even if each of the different GCMs uses the same emissions scenario, they will give quite different predictions due to the different ways they represent aspects of the climate system (Robert & colin, 2007).

Limited Area Models (LAMs) and Regional Climate Models (RCMs)

Poor performances of GCMs at local and regional scales have led to the development of limited area models. The use of AOGCMs is limited in projecting climate change at the regional and sub-regional level (Feyissa, Zeleke, Bewket, & Gebremariam, 2018), because significant differences in climate occur at a scale below the resolution of the AOGCMs (about 300km by 300km). Recently, (Dickinson, Errico, Giorgi, & Bates, 1989), described the development of a nested general circulation model (GCM)-limited area model (LAM) framework for simulation of regional climates. The nested modeling technique consists of using a course resolution GCM to carry out simulations of global climate and then employing the GCM output to derive a high-resolution LAM over an area of interest. This is a one-way nesting technique in which the circulations produced by the LAM do not feedback into GCM. The basic idea is that the GCM can provide the correct large-scale circulation response to global climate forcing, and the LAM can describe the effect of the sub-GCM grid-scale forcing, due for example to large bodies of water, surface vegetation characteristics, or complex topography and coastlines that may significantly influence the characteristics of local climates.

The main thrust for the development of the nested modeling technique derives from growing interest in predicting regional effects of global climate changes. Indeed, current GCMs are too coarse to resolve local forcing, and due to limitations, both in computational resources and representation of relevant physical processes, it may be several years before high resolution GCM simulations become feasible. The nested modeling approach to high resolution regional climate simulation offers two main advantages. The first is the availability of both coarse resolution GCMs that have proven successful in reproducing the basic features of large-scale atmospheric circulations (Dinckison & Rougher, 1986) and high-resolution LAMs that are capable of

describing a wide range of mesoscale phenomena (Anthes, Kuo, Baumhefner, Errico, & Bettge, 1985). The second is the relative simplicity and effectiveness of the one-way nesting technique (Dickinson, Errico, Giorgi, & Bates, 1989)).

Climate Scenarios

A climate scenario is a plausible representation of future climate that has been constructed for explicit use in investigating the potential impacts of anthropogenic climate change (IPCC, 2001). The climate change scenarios should be assessed according to consistency with global projections, physical plausibility, applicability in impact assessments and representativeness (Hulme, 1998). Climate change scenarios for impact assessment can be developed in three major techniques; analogue, synthetic and GCM-based climate change scenarios as follows:

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). 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.

Synthetic/Arbitrary Scenario: 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 $+2^0$C. 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.

GCMs Scenario: GCMs are the only credible tools currently available for simulating the response of the global climate system to increasing greenhouse gas concentrations. 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 and to apply changes derived from GCM information (i.e. the scenarios) to these observed data.

The Emission Scenarios

Future greenhouse gas (GHG) emissions are the product of very complex dynamic systems, determined by driving forces such as demographic development, socio-economic development, and technological change. Their future evolution is highly uncertain. Scenarios are alternative images of how the future might unfold and are an appropriate tool with which to analyze how driving forces may influence future emission outcomes and to assess the associated uncertainties. They assist in climate change analysis, including climate modeling and the assessment of impacts, adaptation, and mitigation. The possibility that any single emissions path will occur as described in scenarios is highly uncertain. The main driving forces of future greenhouse gas trajectories will continue to be demographic change, social and economic development, and the rate and direction of technological change (IPCC, 2000).

According to IPCC Working Group III Special Report on Emission Scenario (SRES), four different narrative storylines were developed to describe consistently the relationships between emission driving forces and their evolution. Each storyline represents different demographic,

social, economic, technological, and environmental developments. The four storylines are defined as follows:

(1) The A1 storyline and scenario family describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system. The three A1 groups are distinguished by their technological emphasis: fossil intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B). Balanced is defined as not relying too heavily on one particular energy source, on the assumption that similar improvement rates apply to all energy supply and end use technologies.

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

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

(4) The B2 storyline and scenario family describes a world in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is a world with continuously

increasing global population at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented toward environmental protection and social equity, it focuses on local and regional levels.

Downscaling (Regionalization) Techniques

The term "downscaling" has been adopted in literature to describe a set of techniques that relate the local and regional scale climate variables to the large scale atmospheric and oceanic forcing variables. It bridges the gap between what the current GCMs are able to provide and the information users require. In the context of hydrology, it is a method to project the hydrologic variables (e.g. rainfall and stream flow) at a smaller scale based on large scale climatological variables (e.g. mean sea level pressure) simulated by a GCM.

Spatial downscaling

The spatial resolution of GCMs remains quite coarse typically in the range of about 3° or 4° in latitude and 4° to 10° in longitude. At that scale, the regional and local detail of the climate is lost. Hence, spatial downscaling is the simplest method adopted by hydrologists that interpolate the GCM outputs on to a finer grid, more appropriate for the study (Barrow, Hulme, & Semenov, 1996; Conway & Hulme, 1996; Smith & G, 1997).

Statistical Downscaling

Another approach to downscaling is statistical downscaling, in which, regional or local information about a hydrologic variable is derived by first determining a statistical model which relates large scale climate variables (or predictors) to regional or local scale hydrologic variables

(or predictands). Then the large-scale output of a GCM simulation is fed into this statistical model to estimate the corresponding local or regional hydrologic characteristics.

There are three implicit assumptions involved in statistical downscaling: first, the predictors are variables of relevance and are realistically modeled by the GCM; second, the empirical relationship is also valid under altered climatic conditions and third, the predictors employed fully represent the climate change signal. As it is difficult to guarantee these assumptions, they remain the main weakness of this technique. Statistical downscaling methods can be further classified into weather generators, weather typing and transfer functions based on the use of different statistical tools.

Dynamic Downscaling

The third option is the dynamical downscaling approach in which a fine, at a much smaller space-scale (e.g. 0.5° by 0.5°), computational grid over a limited domain is nested within the coarse grid of a GCM. Regional-scale limited-area models (LAMs) use GCM outputs as the boundary conditions to calculate estimates at a detailed scale, but these so-called 'regional nested models' are computationally expensive (Hewitson & Crane, 1996). Moreover, LAMs are dependent upon the veracity of the GCM grid-point data that are used to drive the boundary conditions of the region (Wilby & Wigley, 1997). Compared with statistical downscaling, the spatial patterns produced are more homogeneous, but not necessarily more realistic (Cubash, von Storch, Waszkewitz, & Zorita, 1996; Mearns, Bogardi, Giorgi, Matyasovzky, & Palecki, 1999).

A major drawback of dynamic downscaling, which restricts its use in climate change impact studies, is its complicated design and high computational cost. Moreover, dynamic downscaling is

inflexible in the sense that expanding the region or moving to a slightly different region requires redoing the entire experiment.

Materials and Methods

Description of the study area

The Baro-Akobo River Basin lies in the South-Western part of Ethiopia between latitudes 5° and 10°North and longitudes 33° and 36° East. In the west the basin boundary forms an international boundary with Sudan. The basin covers parts of the Benshangul-Gumuz, Gambella, Oromia and SNNP administrative regions.

With a total drainage area of about 76,000sq.km, the Baro-Akobo River basin ranks number eight of the 12 major river basins in Ethiopia. Both Baro and Akobo rivers border with Sudan in their downstream sections and merge to form the Sobat River, which is a major tributary of White Nile. Neighboring river basins in Ethiopia are the Abay river basin in the north and the Omo-Gibe river basin in the south-east.

The Baro-Akobo river basin has a lowest elevation of about 390 m and highest elevation of about 3244 m. The total mean annual flow from the river basins is estimated to be 23.6 BCM. As a consequence of regular flooding, the lowland areas are mainly used as pastures for grazing and no major water resources development has taken place to-date.

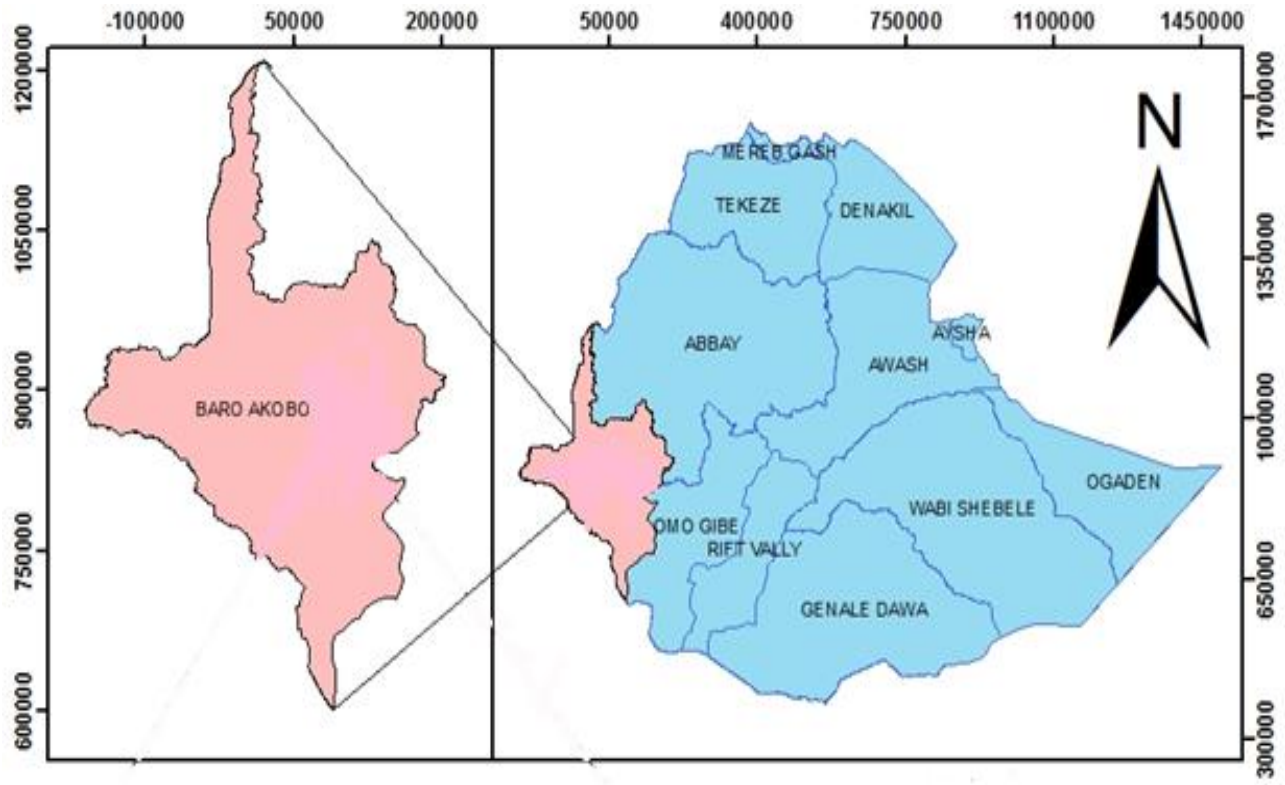


Fig. 1 Location map of Baro-Aakobo river basin relative to Ethiopian river basins

Data collection and processing

Spatial data such as Digital Elevation Model (DEM) of 90m*90m, and Ethio-River basin shape files in the basin were collected from Ministry of Water Resource (MoWR). Moreover, land use/landcover and soil data were obtained from Ministry of Agriculture (MoA). Available meteorological data including precipitation, minimum and maximum temperature, relative humidity, sunshine duration, and wind speed were collected from National Meteorology Agency (NMA). These data were obtained for 11- meteorological stations at daily time step in the basin. The data covers a duration of about 30-years (1989 to 2018) for precipitation and temperature whereas it is limited to 10-years' data for the remaining meteorological variables.

In general, in this study, observed data has been used for two purposes: first it is used to develop bias correction factors to adjust mid-term and long-term forecasted RCM data; second it is used as a base line data to determine the change in climate forcing variables in to the future. To this end different data processing techniques: data screening, trend test, stationery test, F-& t-tests; test for relative consistency and homogeneity are all applied to assure observation data quality.

Mean-Areal Precipitation (MAP) Depth Computations

There are many ways of deriving the areal precipitation over a catchment from rain gauge measurements including: Arithmetic Mean, Thiessen Polygon, Isohyetal, grid Point, Percent Normal, Hypsometric, etc. (Chow, Maidment, & Mays, 1988). Choice of methods requires judgment in consideration of quality and nature of the data, and the importance, use and required precision of the result. Accordingly, the Thiessen Polygon method was applied to determine the areal average precipitation over the sub basins. In this method, weights are given to all the measuring gauges on the basis of their areal coverage of the watershed, thus eliminating the discrepancies in their spacing over the basins. For the purpose, HEC_GeoHMS utility - for construction of Thiessen Polygons and meteorological function in the model - for assigning gage weight was used in this study. Similar procedure is followed to calculate other basin areal meteorological data (e.g. ETo data) and areal data of RCM GCPs meteorological data.

The areal rainfall $\bar{R}$ is given by:

$$\bar{R} = \sum_{i=1}^{n} \frac{a_i R_i}{A} = \sum_{i=1}^{n} w_i R_i \quad \ldots\ldots (1)$$

Where R_i are the rainfall measurements at n rain gauges; a_i is polygon area; w_i is gauge areal weight and A is the total area of the catchment.

Potential Evapotranspiration

A large number of empirical or semi-empirical equations have been developed for assessing reference/potential evapotranspiration from meteorological data. Numerous researchers have analyzed the performance of the various calculation methods for different locations. As a result of an Expert Consultation held in May 1990, the FAO Penman-Monteith method is now recommended as the standard method for the definition and computation of the potential evapotranspiration when the standard meteorological variables including air temperature, relative humidity and sunshine hours are available (Allen, Smith, Pereira, Raes, & Wright, 1998).

In this study, the Potential evapotranspiration is calculated by ET_O calculator software that uses the relatively accurate and consistent performance of the Penman-Monteith approach in both arid and humid climates. ETo for the basin is determined based on the four basic climatic data – temperature (Tmax, Tmean & Tmin), mean relative humidity, wind speed at 2m above soil surface and the actual sunshine duration.

The FAO Penman-Monteith equation (Allen, Smith, Pereira, Raes, & Wright, 1998)) is given by:

$$\boldsymbol{ET_o} = \frac{\mathbf{0.408}\Delta(\boldsymbol{R_n}-\boldsymbol{G})+\boldsymbol{\gamma}\frac{\mathbf{900}}{\boldsymbol{T}+\mathbf{273}}\boldsymbol{u_2}(\boldsymbol{e_s}-\boldsymbol{e_a})}{\Delta+\boldsymbol{\gamma}(\mathbf{1}+\mathbf{0.34}\boldsymbol{u_2})} \quad \ldots\ldots\ldots\

e_s = saturation vapour pressure [kPa],

e_a = actual vapour pressure [kPa],

e_s-e_a = saturation vapour pressure deficit [kPa],

Δ = slope vapour pressure curve [kPa $°C^{-1}$],

γ = psychrometric constant [kPa $°C^{-1}$].

Baseline Climate

Baseline climate information is important to characterize the prevailing conditions and its thorough analysis is valuable to examine the possible impacts of climate change on a particular exposure unit. It can also be used as a reference with which the results of any climate change studies can be compared. The choice of baseline period has often been governed by availability of the required climate data.

According to World Meteorological Organization (WMO), the baseline period also called reference period generally corresponds to the current 30 years normal period. A 30-year period is used by WMO to define the average climate of a site or region, and scenarios of climate change are also generally based on 30-year means.

RCM Data

Regional grid climate data that has been dynamically downscaled by RCM Version 3.1 from general Circulation model (GCM) for A1B emission scenario was obtained from International Water Management Institute (IWMI). These are gridded meteorological time-series data of precipitation; maximum, mean, and minimum temperature; wind speed; relative humidity; and potential evapotranspiration at a grid center point (GCP) spatial resolution of 0.5^o by 0.5^o (i.e.

55km by 55km). GCPs that fall in and nearby the Baro-Akobo River Basin are selected for the study. The data cover three ten years' period: base period (2000s i.e. 2001 – 2010), mid-term forecast (2040s i.e. 2041-2050) and long-term forecast (2090s i.e. 2091-20100) meteorological time-series data. These data are bias corrected based on bias correction factors developed for the base period observed before making use of them for trend analysis

Bias Correction for RCM Output

This method is used to 'adjust' the mean, variance and/or distribution of RCM climate data. All models have inadequacies due to such factors as resolution, differing internal dynamics, and model parameterizations, so different climate models can respond differently to the same inputs. Bias correction addresses this. Generally, this method is applied to generate modelled time series data.

Particularly, bias correction is usually needed as climate models often provide biased representations of observed times series due to systematic model errors caused by imperfect conceptualization, discretization and spatial averaging within grid cells. Typical biases are the occurrence of too many wet days with low-intensity rain or incorrect estimation of extreme temperature in RCM simulations (Ines & Hansen, 2006). A bias in RCM-simulated variables can lead to unrealistic hydrological simulations of river runoff. Thus, application of bias-correction methods is recommended (Wilby, et al., 2000).

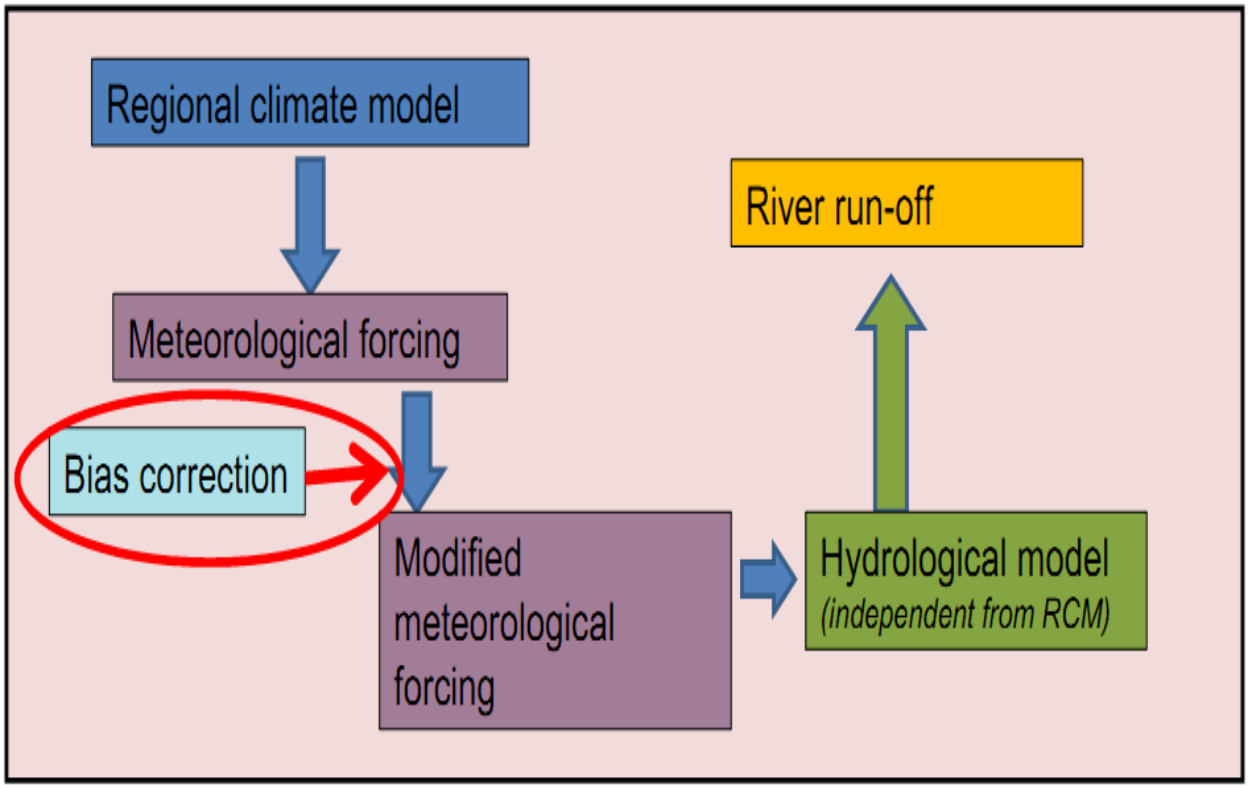


Fig. 2 Conceptual framework for bias correction

The term ‘bias correction’ describes the process of scaling climate model output in order to account for systematic errors in the climate models. The basic principle is that biases between simulated climate time series and observations are identified and then used to correct both control and scenario runs. A main assumption is that the same bias correction applies to control and scenario conditions. Several techniques are available to create an interface for translating RCM output variables to hydrological models. For instance, precipitation and temperature can be bias-corrected by applying one of the following methods: Precipitation threshold, Scaling approach, linear transformation, Power transformation, Distribution transfer, Precipitation model and Empirical correction methods.

In this work a Power Transformation method of bias correction is applied for precipitation whereas linear transformation method is used to correct temperature. In each case of bias correction attempt is made to match the most important statistics (coefficient of variation, mean and standard deviation) on a scale of 30 days.

Precipitation Bias Correction: Power Transformation Method

The method is selected based on its relative simplicity and application result by (Leander & Buishand, 2007) for a Meuse basin study. They found that adjusting both the biases in the mean and variability, the method leads to a better reproduction of observed extreme daily and multi-day precipitation amounts than the commonly used linear scaling correction.

In this nonlinear correction each daily precipitation amount P is transformed to a corrected P^* using:

$$\boldsymbol{P^* = a * P^b} \ldots\ldots\ldots\

Then the parameter "a" is determined such that the mean of the transformed daily values corresponds with the observed mean. At the end, each block of 30days has got its own "a" and "b" parameter, which are the same for each year.

Temperature Bias Correction: Linear Transformation Method

The correction of temperature only involves shifting and scaling to adjust the mean and variance (Leander & Buishand, 2007). Hence, for correcting the daily temperature a linear transformation technique is applied. For the basin, the corrected daily temperature T_{corr} was obtained as:

$$\boldsymbol{T_{corr} = aT_{un} + b} \quad \ldots\ldots\ldots\

Table 1 Tabular values of correction factors (a & b) used for bias correction

Block/ Month	Rainfall		Max. Temperature		Min. Temperature		Remark
	A	b	a	b	A	B	
1	0.87923	1.3772	1.280508	-10.6803	0.813285	2.36216	Applied to 2040s & 2090s, too
2	1.35417	1.3361	0.874778	0.92537	0.841106	1.56176	Applied to 2040s & 2090s, too
3	1.19540	1.0213	1.113515	-5.73073	0.848638	1.50895	Applied to 2040s & 2090s, too
4	1.20722	1.0392	0.852145	0.96488	1.113072	-2.38138	Applied to 2040s & 2090s, too
5	1.58491	0.8936	0.932835	-0.61999	0.869765	1.34674	Applied to 2040s & 2090s, too
6	1.78547	0.8545	0.997172	-2.00923	1.607555	-9.10642	Applied to 2040s & 2090s, too
7	1.40889	0.8847	0.912689	0.03128	2.254962	-18.3513	Applied to 2040s & 2090s, too
8	1.89014	0.7863	0.763058	3.43765	0.871869	1.01038	Applied to 2040s & 2090s, too
9	1.28142	0.9810	0.875447	1.02377	0.647856	4.25011	Applied to 2040s & 2090s, too
10	0.94100	1.1642	0.681786	5.67126	0.502335	6.303634	Applied to 2040s & 2090s, too
11	0.61127	1.2509	0.531221	9.96134	0.373821	7.98661	Applied to 2040s & 2090s, too
12	1.46763	1.3667	0.876526	0.91229	0.250886	9.22550	Applied to 2040s & 2090s, too

The developed correction factors “a” & “b” are applied to the RCM output data and compared with the observed data to show the inherited biases in RCM. Once again, the comparison was made between bias corrected RCM, uncorrected RCM and observed data to validate the effectiveness of the factors a & b to make use of them in the climate change scenario development. These are shown below with illustrative figures: precipitation (**Fig.3**), maximum temperature (**Fig. 4**) and minimum temperature (**Fig. 5**).

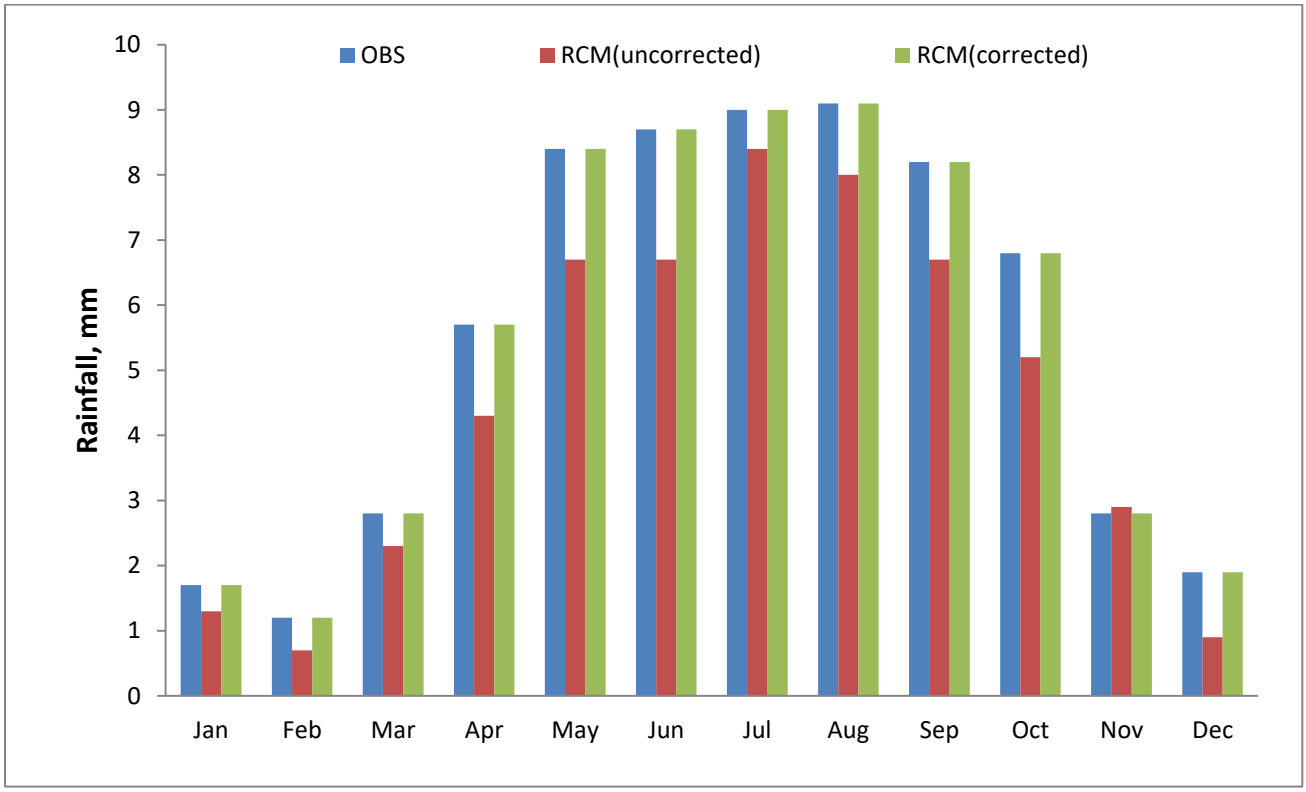


Fig.3 Comparison of bias corrected and uncorrected RCM precipitation data on the monthly basis

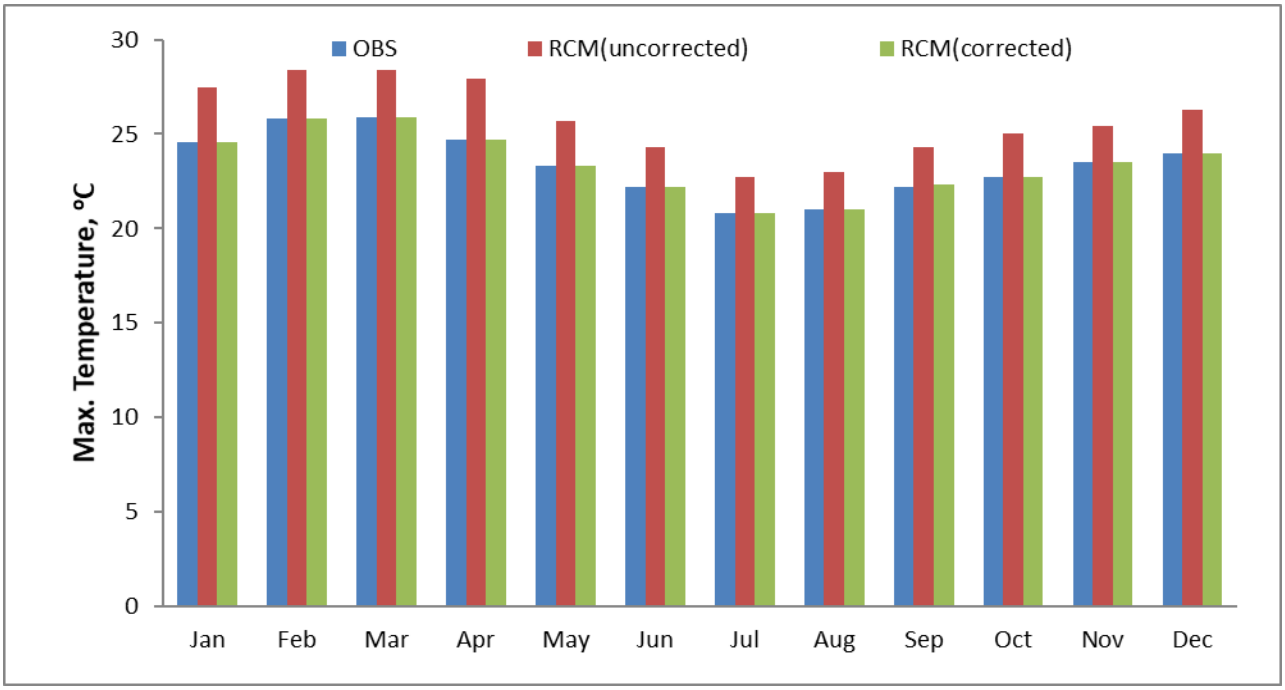


Fig. 4 Comparison of bias corrected and uncorrected RCM data of maximum temperature on the monthly basis

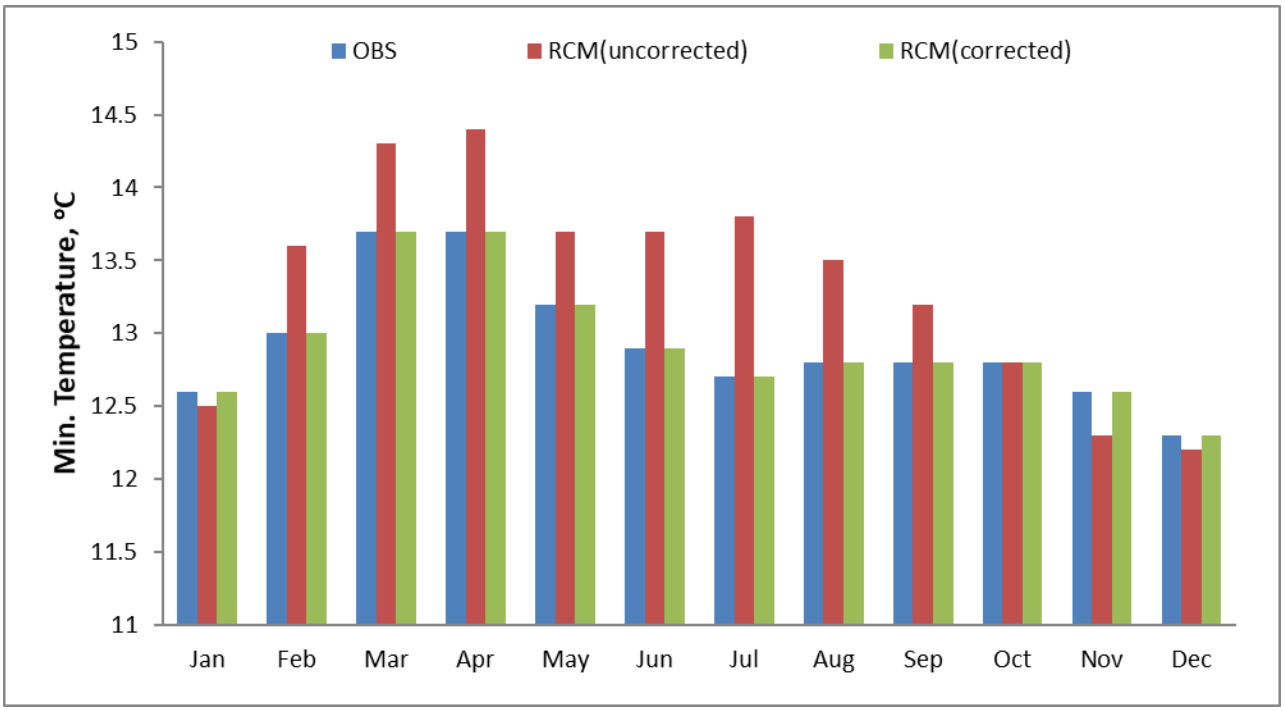


Fig. 5 Comparison of bias corrected and uncorrected RCM data of minimum temperature on the monthly basis

The results show that still considerable biases inherited from GCM are prevailing in the RCM outputs for basin level application. Furthermore, it can be observed from **Fig.3** that the RCM and hence GCM has mainly under estimated the precipitation over the basin as it might be local wind and vapor pressure conditions. In the contrary, the regional climate model has generally overestimated the maximum and minimum temperatures over the basin as illustrated by **Fig. 4** & **Fig. 5**. These variations and biases in the model outputs are of course expected owed to locally sensitive climatic variables and the complex topography of the country to be generalized at regional or continental scales.

Climate Change Scenario

In this study, the future climate change scenarios for the 2040s and the 2090s have been assessed in comparison with the base period of the 2000s for three climatic variables – temperature, precipitation, and evapo-transpiration as presented below.

Temperature Scenario

Both the projected maximum and minimum temperatures have generally shown an increase trend for A1B emission scenario in both future time of 2040s and 2090s (**Fig. 6**). Comparatively, monthly and seasonal temperature flux in both maximum and minimum temperatures is more considerable than the annual changes.

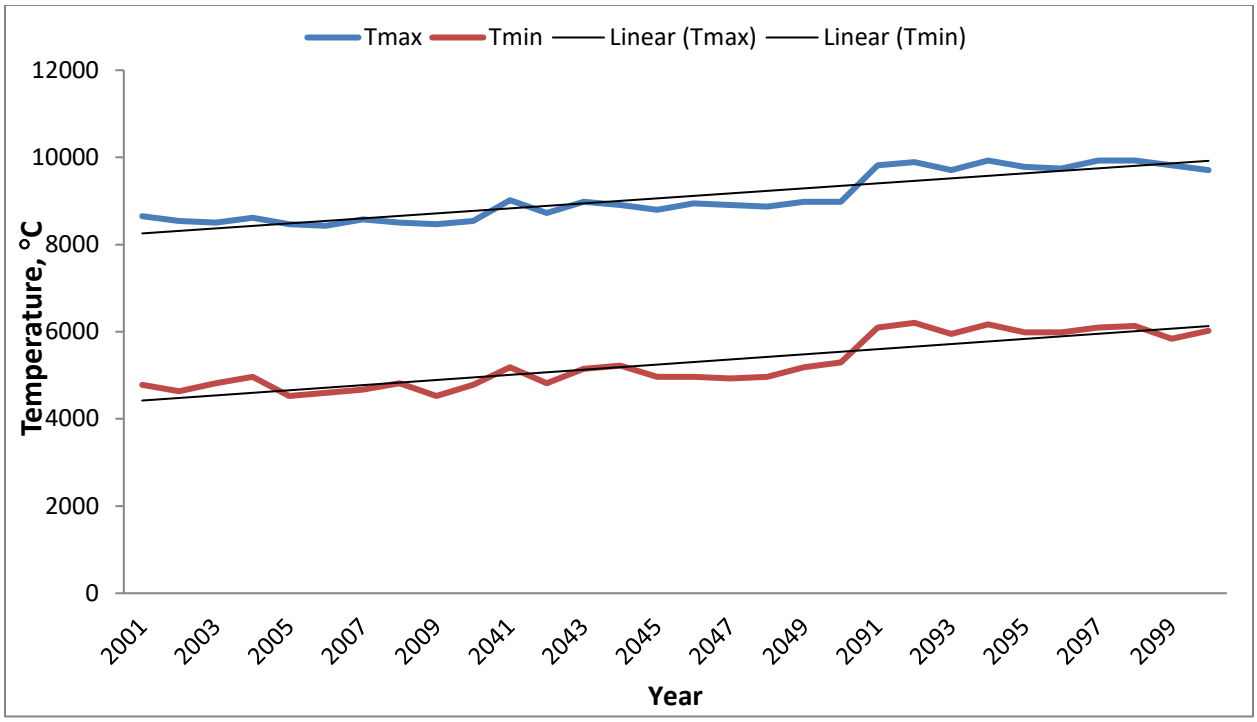


Fig. 6 Projected maximum and minimum annual temperature trends

Future projection of maximum temperatures has shown large temperature fluxes in the month of January for both 2040s and 2090s forecasts that has resulted in a temperature rise of 2.5°C and 5.1°C respectively as compared to the base period. On the other hand, minimum temperature flux will be higher in the month of July for both mid-term and long-term forecasts that experiences a temperature rise of 2.5°C and 5.8°C respectively as shown in **Fig. 7** below. Generally, the projected maximum and minimum temperature changes in future for the A1B emission scenario is within the range projected by IPCC which indicated that the average temperature rise to be in the range of 1.4-5.8°C towards the end of this century.

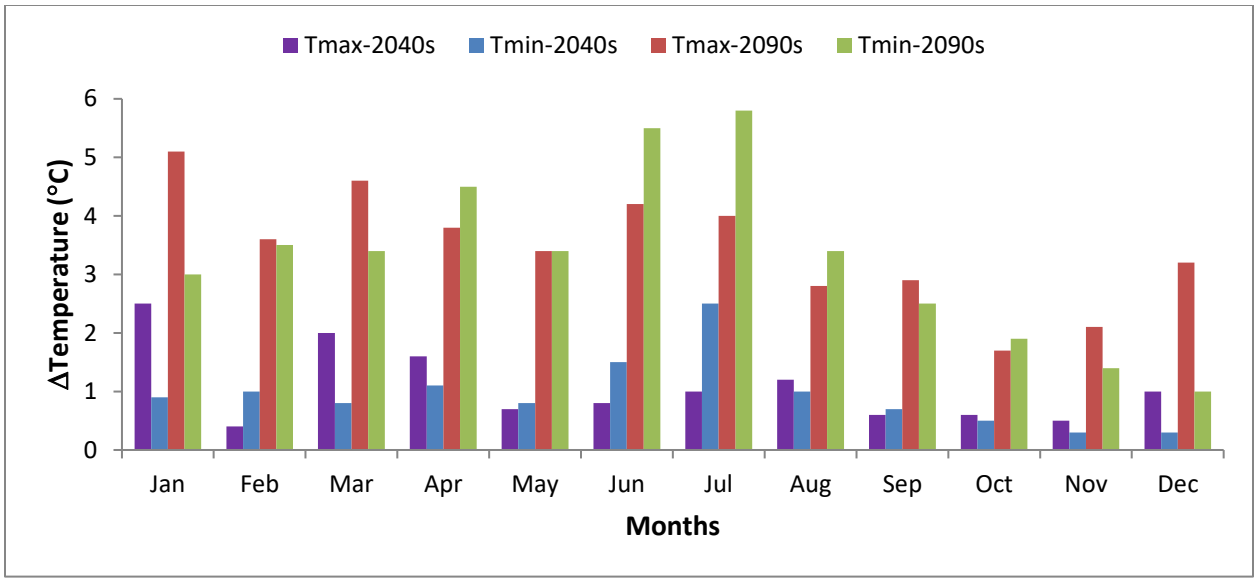


Fig. 7 Future Mean Monthly max. & min. temperature fluxes compared to base period

Precipitation Scenario

In contrast to temperature, projection of rainfall did not manifest a systematic increase or decrease in all future time horizon for A1B global emission scenario (**Fig. 8**, **Fig. 9** & **Fig. 10**).

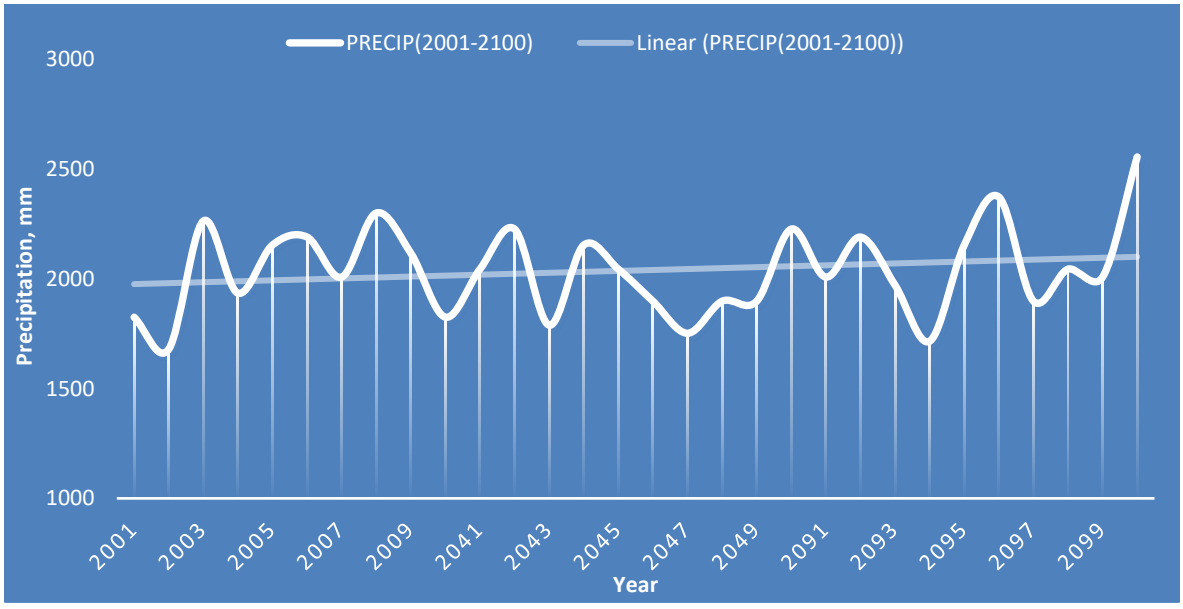


Fig. 8 Projected annual precipitation trend in general (2001 through 2100) for A1B scenario

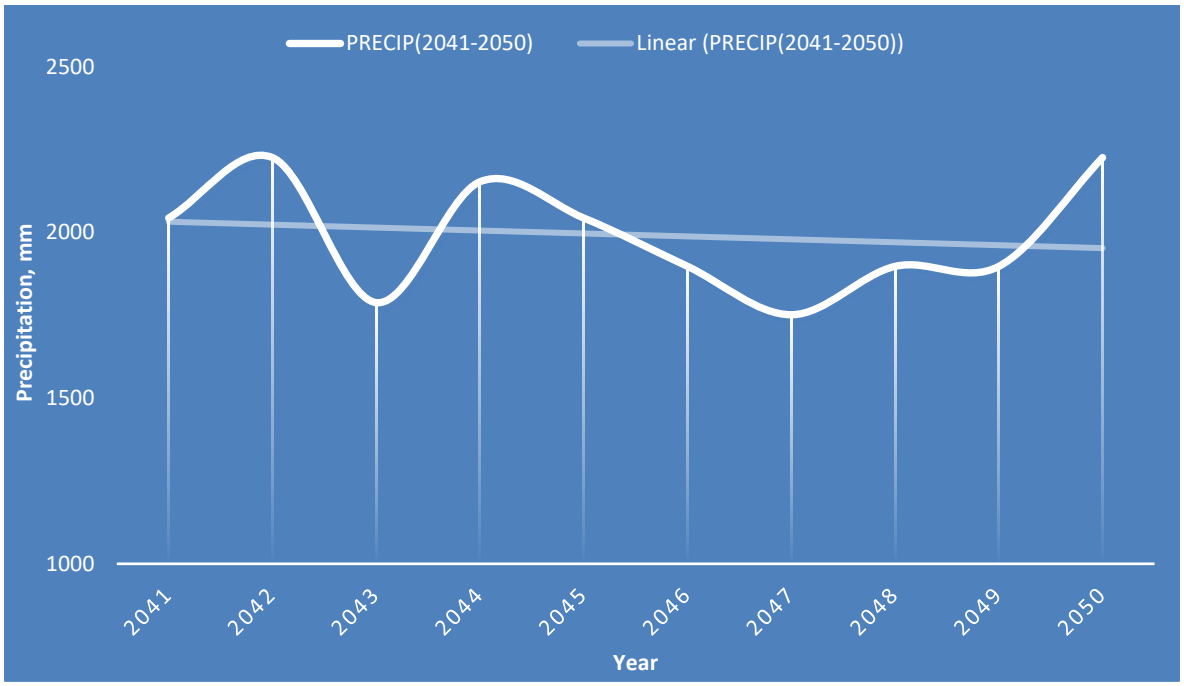


Fig. 9 Projected annual precipitation trend in the mid-term (2041 through 2050) for A1B scenario



Fig. 10 Projected annual precipitation trend in the long-term (2091 through 2100) for A1B scenario

However, similar to that of minimum and maximum temperature, future projection of rainfall has shown considerable change on seasonal and monthly levels as compared to the annual changes (**Fig. 11**). For instance, the rainfall will experience a reduction of up to 29% in January and rises up to 42% in February for future 2040s. Likewise a precipitation decreases of up to 24% in January and a rise up to 47% in December has been predicted for the 2090s A1B global emission scenario.

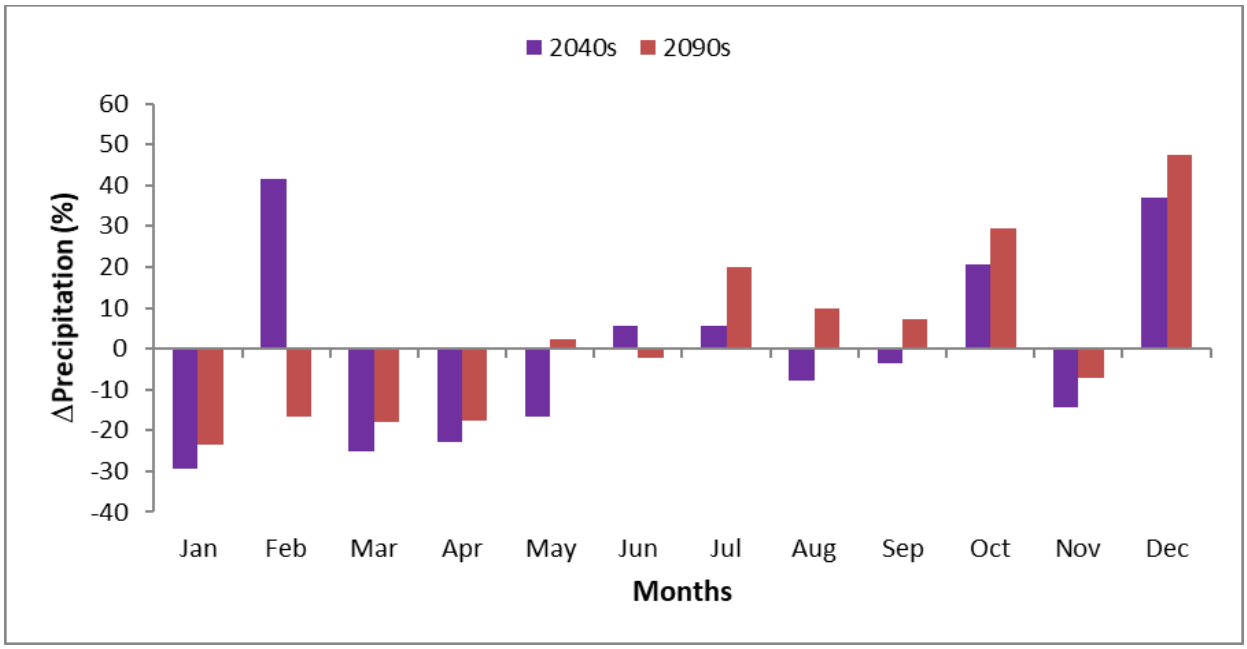


Fig. 11: Percentage monthly projected precipitation changes compared to the base period

In general, the precipitation experiences a mean annual decrease to an extent of 1.8% by 2040s and an increase of in1.8% 2090s over the basin for the A1B emission scenario. Typically, a relative rainfall reduction is expected in the winter and spring seasons accompanied by an increase in precipitation for the rainy summer and autumn seasons, in most cases, that most probably exacerbate weather extremes that would results in reservoir level decrease and flooding as per this study.

Evapo-transpiration Scenario

Relative to the current condition, the average annual evapo-transpiration over the Baro-Akobo basin shows increasing trends in both short-term (2040s) and long-term (2090s) forecasts for the A1B scenario (**Fig. 12**). Very similar to that of temperature, evapotranspiration fluxes on monthly and seasonal basis is more pronounced too as illustrated here below (fig. 13).

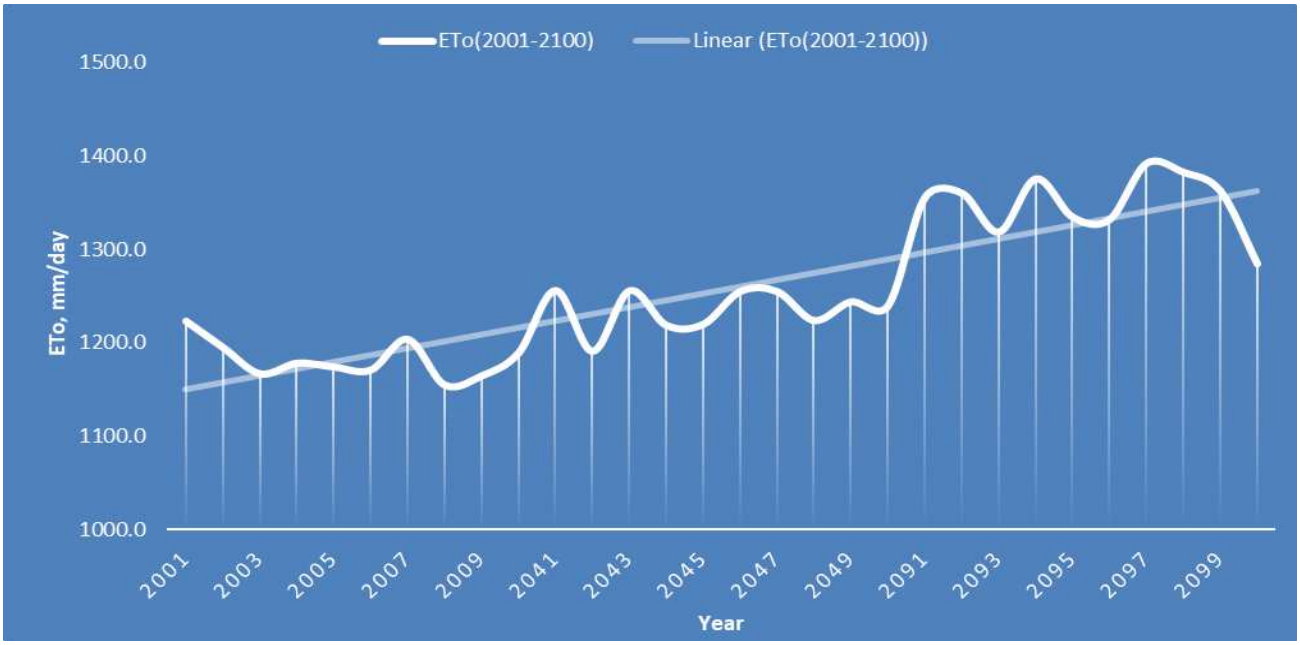


Fig. 12 Projected mean annual evapotranspiration trend for A1B emission scenario

According to this study, evapotranspiration has been found to increase to an extent of 25% in the month of July (**Fig. 13**). The very exception here is that evapotranspiration tends to decrease only in the month of February for the 2040s projection with about 5%. Seasonal wise, it has been observed that considerable evapotranspiration fluxes in summer season for the 2090s forecast and no as such observable seasonal variation in evapotranspiration changes has been shown for the case of 2040s prediction.

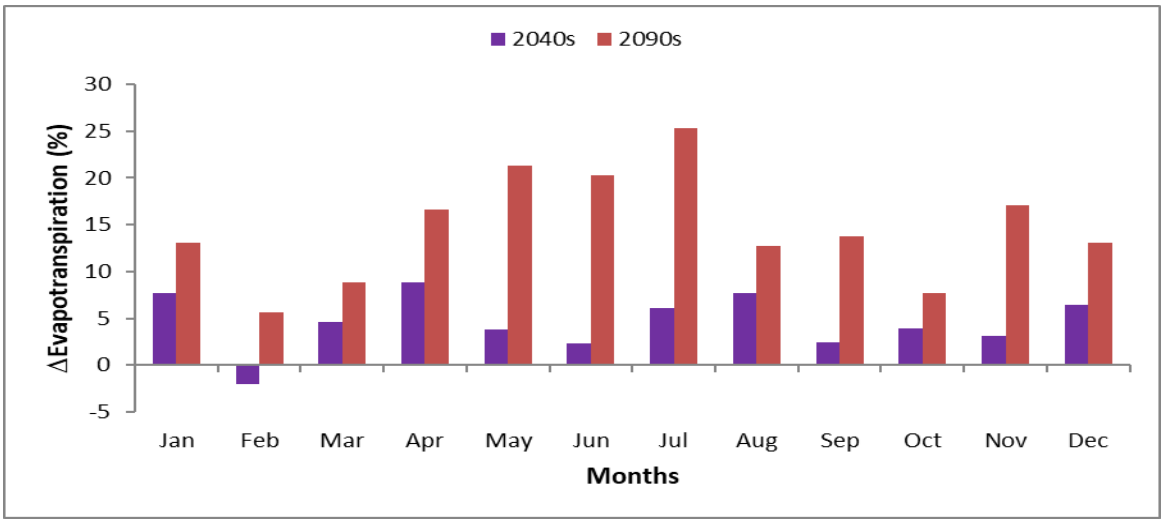


Fig. 13 Percentage changes in the projected evapotranspiration as compared to the base period

Conclusions

Nature, especially climate, is not easy to be exactly forecasted even with the advanced technologies of the 21st century. Human beings, at a larger scale, are still in the hands of climatic influences, where extreme events of floods and droughts keep on endangering many lives all over the world. The study has involved model outputs to generate future climate change scenarios and laid basic information of the possible climate change impacts on the water resources of the basin.

The result of climate projection reveals that the RCM has very good ability in replicating the historical maximum and minimum temperature for the observed period; but manifested poor replication and trend in the case of precipitation which is, of course, true across all climate models in any scenario yet applied.

Generally, the projected maximum and minimum temperature have shown an increasing trend for the next century. The projected precipitation has not manifested a general trend in the future scenarios; rather it has shown a decreasing trend in the mid-term forecast (2040s) and an increasing

trend in the late century (2090s) for the A1B emission scenario. Irrespective of whether there is a trend or not, we can conclude from these results that considerable change in climate is expected to happen over the basin as per the A1B emission scenario. The results manifested also the most likely occurrence of extremes both in temperature and precipitation. Beyond quantitative implications, the results have also manifested a considerable climate change in terms of timing and frequency. This truly warns and calls for an attention on the possible future risks of sustainable water resources development and management in the basin.

This study has involved a number of models and model outputs where each possessed a certain level of uncertainty. Hence, the results of this study should be taken with care and be considered as indicative of the likely future rather than accurate predictions. It is believed that the results of this study give a clue and increase awareness on the possible future risks of climate change. Hence, such studies are recommended to be extended to other basins of the nation for sustainable water resource development.

List of Abbreviation

AOGCMs: Atmosphere-Ocean General Circulation Models

CV: Coefficient of Variation

DEM: Digital Elevation Model

ETo: Reference Evapotranspiration

FAO: Food and Agricultural Organization

GCM: Global Climate Model

GCP: Grid Center Point

GHG: Greenhouse Gas

HEC-GeoHMS: Hydrologic Engineering Center Geospatial Hydrologic Modeling System

IWMI: International Water Management Institute

IPCC: Intergovernmental Panel for Climate Change

LAMs: Limited area models

MAP: Mean Areal Precipitation

MoA: Ministry of Agriculture

MoWR: Ministry of Water Resources

NMA: National Meteorological Agency

NAPA: National Adaptation Programme of Action

Obs: Observed

SRES: Special Report on Emission Scenario

RCM: Regional Climate Model

WMO: World Meteorological Organization

Ethics approval and consent to participate

Not Applicable

Consent for publication

Not Applicable

Availability of data and materials

The datasets used and/or analyzed during the current study are included as much as possible and also available from the corresponding author up on request.

Competing interests

The author declares that there is no any competing interest

Funding

This study was not funded by any grant

Author's contributions

TN solely performed all the Conceptualization, study design, statistical analysis of results, data interpretation, and writing the manuscript.

Acknowledgement

It is my pleasure to express my special heartfelt thanks and appreciation to my advisor **Dr. Knolmar Marcell**, an Assistant Professor at the Department of Sanitary and Environmental Engineering, Budapest University of Technology and Economics, Budapest, Hungary for his valuable support in draft review and editing of the manuscript and his all-round advisory support. I would like to extend my gratitude to **Dr. Solomon Seyoum**, a director general for International Water Management Institute at Ethiopia for his excellent support in providing GCM data and his guidance on how to bias correct the data. I am also highly indebted to all organizations and Institutes those provided me with important data & materials mainly Ministry of Water and

Energy, National Metrological Agency, International Water Management Institute and Ministry of Agriculture.

Author's information

Affiliations

TN is a doctoral student at the department of Sanitary and Environmental Engineering, Budapest University of Technology and Economics, Budapest, Hungary.

References

Allen, R., Smith, M., Pereira, L., Raes, D., & Wright, J. (1998). *Crop evapotranspiration-Guidelines for computing crop water requirements-FAO Irrigation and drainage paper 56.* FAO.

Anthes, R., Kuo, Y., Baumhefner, D., Errico, R., & Bettge, T. (1985). Predictability of Mesoscale Atmospheric Motions. *Advances in Geophysics*, 159-202.

Barrow, E., Hulme, M., & Semenov, M. (1996). Effect of using different methods in the construction of climate change scenarios: examples for Europe. *Climate Research 7*, 195-211.

Brekke, L., Maurer, E., Anderson, J., Dettinger, M., Townsely, E., Harrison, A., . . . Pruitt, T. (2009). Assessing reservoir operations risk under climate change. *Water Resour. Res*, 45.

Chow, V., Maidment, D., & Mays, L. (1988). *Applied Hydrology.* New York: McGraw-Hill Book Company.

Conway, D., & Hulme, M. (1996). The impacts of climate variability and future climate change in the Nile Basin on Water Resources in Egypt. *Water Resources Development 12(3)*, 277-296.

Cubash, U., von Storch, H., Waszkewitz, J., & Zorita, E. (1996). Estimates of climate change in Southern Europe derived from dynamical climate model output. *Climate Research 7*, 129-149.

Deepashree, R., & Mujumdar, P. (2010). Reservoir performance under uncertainty in hydrologic impacts of climate change. *Advances in Water Resources*, 312–326.

Dickinson, R., Errico, R., Giorgi, F., & Bates, G. (1989). A regional climate model for the western United States. *Climate change*, 383-422.

Dinckison, R., & Rougher, S. (1986). Venus Mesosphere and Thermosphere: Heat-Budget and Thermal Structure. *Journal of Geophysical Research-Space Physics*, 70-80.

Feyissa G, Zeleke G, Bewket W, Gebremariam E (2018). Downscaling of future temperature and precipitation extremes in Addis Ababa under climate change. Nature, MDPI 6:58

Getachew B (2018) Trend analysis of temperature and rainfall in south Gonder zone, Ethiopia. J Degraded Mining Lands Manag. ISSN: 2339–076X (p); 2502–2458 (e), 5(2): 1111–1125. https://doi.org/https://doi.org/10.15243/jdmlm.2018.052.1111

Hewitson, B., & Crane, R. (1996). Climate downscaling: techniques and application. *Climate Research 7*, 85-95.

Hulme, M. a. (1998). A climate change scenario for the Tropics . *climate change*, 145-176.

Ines, A., & Hansen, J. (2006). Bias correction of daily GCM rainfall for crop simulation studies. *Agricultural and Forest Meteorology*, 44-53.

IPCC. (2000). *Emission Scenarios: A special Report of Working Group III of the IPCC.* Cambridge: Cambridge University Press.

IPCC. (2001). *Climate Change 2001: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Third Assessment Report of the IPCC.* Cambridge: Cambridge University Press.

IPCC. (2007). *Impacts, Adaptation and Vulnerability: Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* United Kingdom: Cambridge University Press, Cambridge.

IPCC. (2018). *Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways.* Switzerland.

Jones, J. A. (1999). *Climate change and sustainable water resources: placing the threat of global warming in perspective.* Hydrol. Sci. J.

Leander, R., & Buishand, T. (2007). Resampling of regional climate model output for the simulation of extreme river flows. *Journal of Hydrology*, 487-496.

Li, L., Xu, H., Chen, X., & Simonovic, S. (2009). Streamflow forcast and reservoir operation performance assessment under climate change. *Water Resour. manag*.

Mearns, L., Bogardi, I., Giorgi, F., Matyasovzky, I., & Palecki, M. (1999). Comparison of climate change scenarios generated from regional climate model experiments and statistical downscaling. *Journal of Geophysical Research 104(D6)*, 6603-6621.

Mohamed, H. (2015, May). *Impact of Climate Change on Water Resources in the Nile Basin and Adaptation measures in Egypt.* Retrieved July 25, 2020, from Researchgate Web site: https://www.researchgate.net/publication/277330599

NAPA. (2007). *Preparation of National Adaptation Programme of Action (NAPA) of Ethiopia.* Addis Abeba.

Robert, K., & colin, H. (2007). *A Review of Climate Change and its Potential Impacts on Water Resources in the UK.* UK: Official Publication of the European Water Association (EWA).

Schneider, S., Easterling, W., & Mearns, L. (2000). Adaptation: Sensitivity to Natural Variability, Agent assumptions and Dynamic Climate Changes. *Climate Change 2000, 45*, 203-221.

Smith, J., & G, P. (1997). Regional Climate change scenariosfor vulnerability and adaptation assessments. *Climate Change 36*, 3-21.

Wilby, R., & Wigley, T. (1997). Downscaling general circulation model output: a review of methods and limitations. *Progress in Physical Geography 21(4)*, 530-548.

Wilby, R., Hay, L., Gutowski Jr., W., Arritt, R., Takle, E., Pan, Z., . . . Clark, M. (2000). Hydrological responses to dynamically and statistically downscaled climate model output. *Geophysical Research Letters*.

Figures

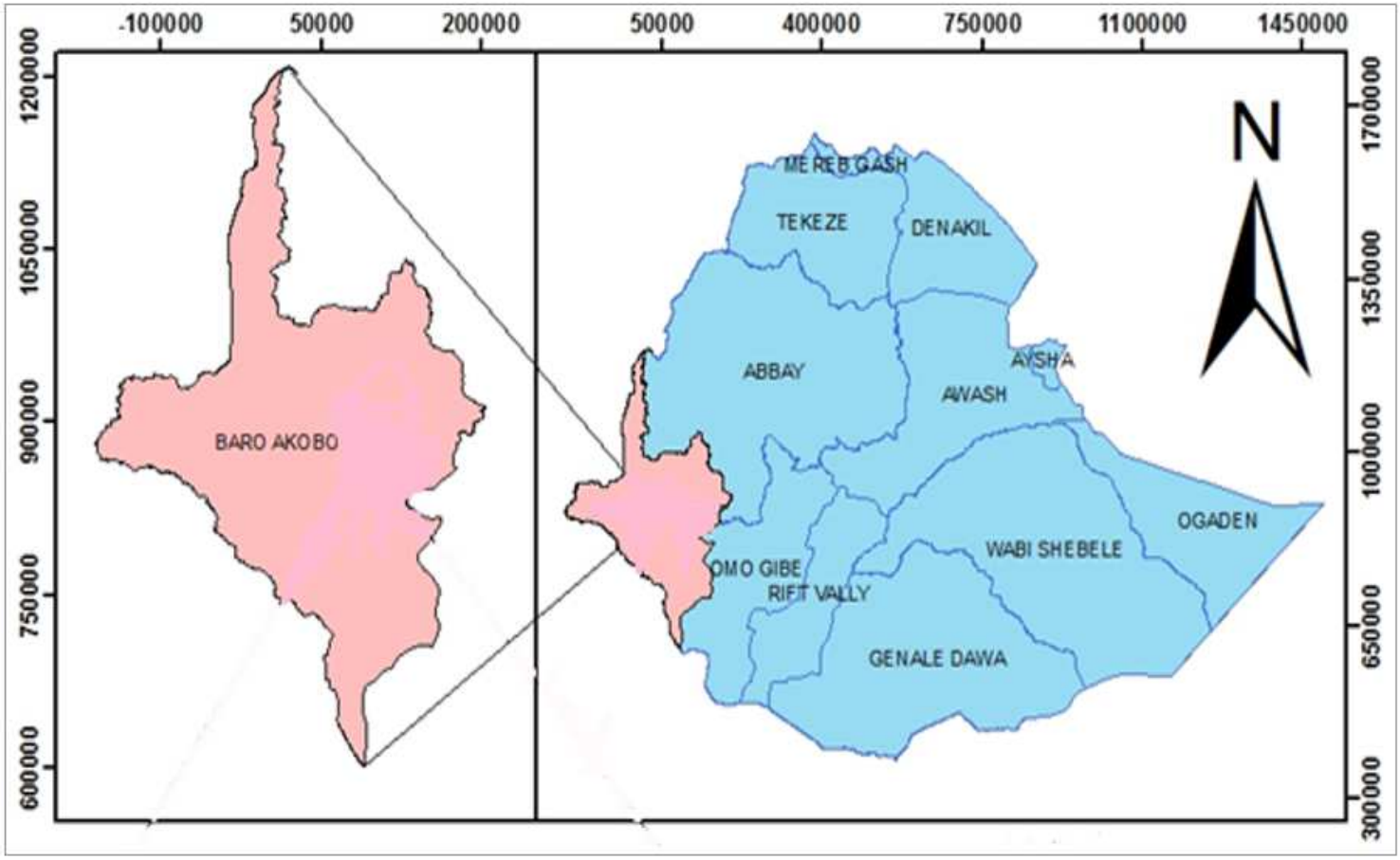


Figure 1

Location map of Baro-Aakobo river basin relative to Ethiopian river basins

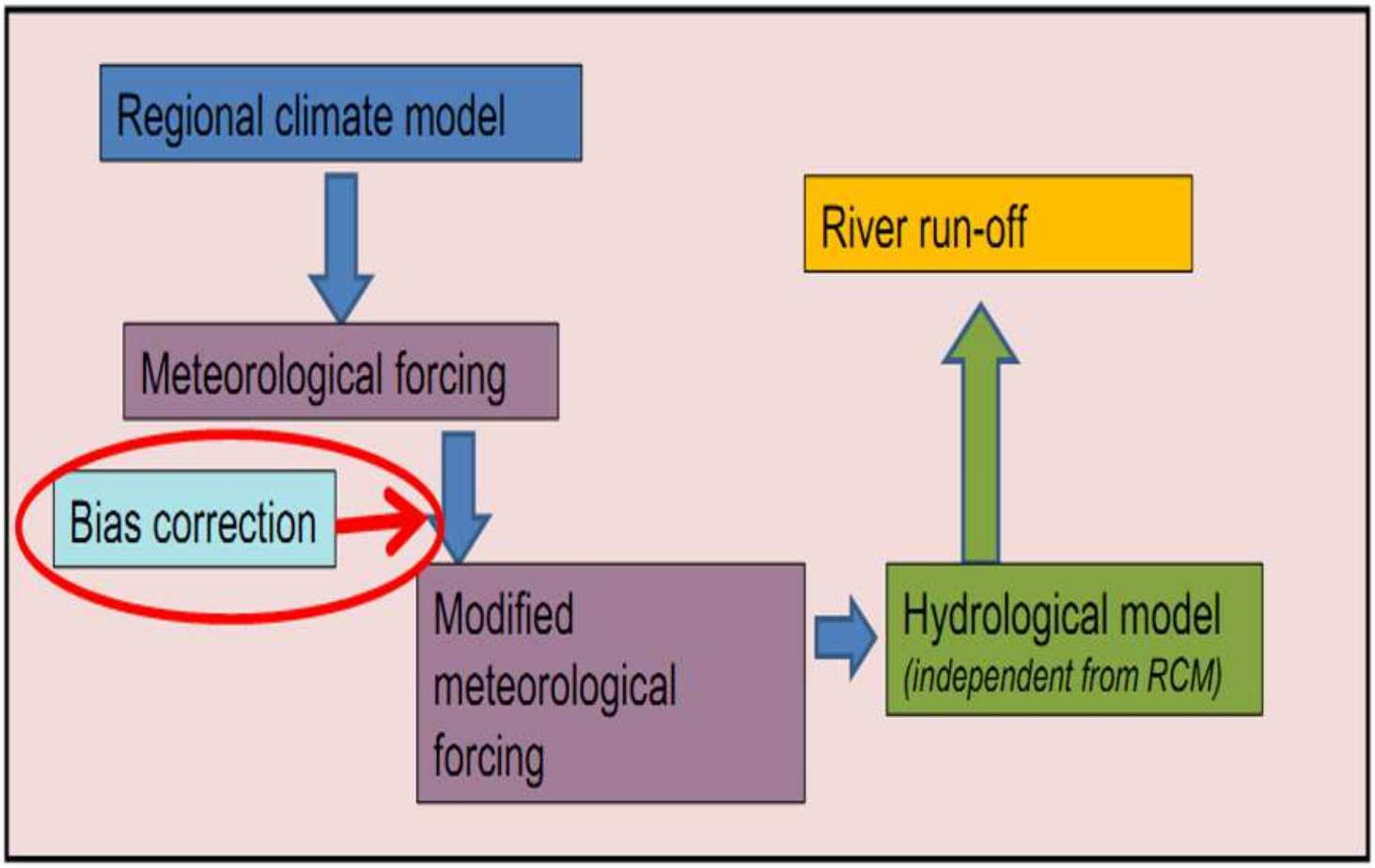


Figure 2

Conceptual framework for bias correction

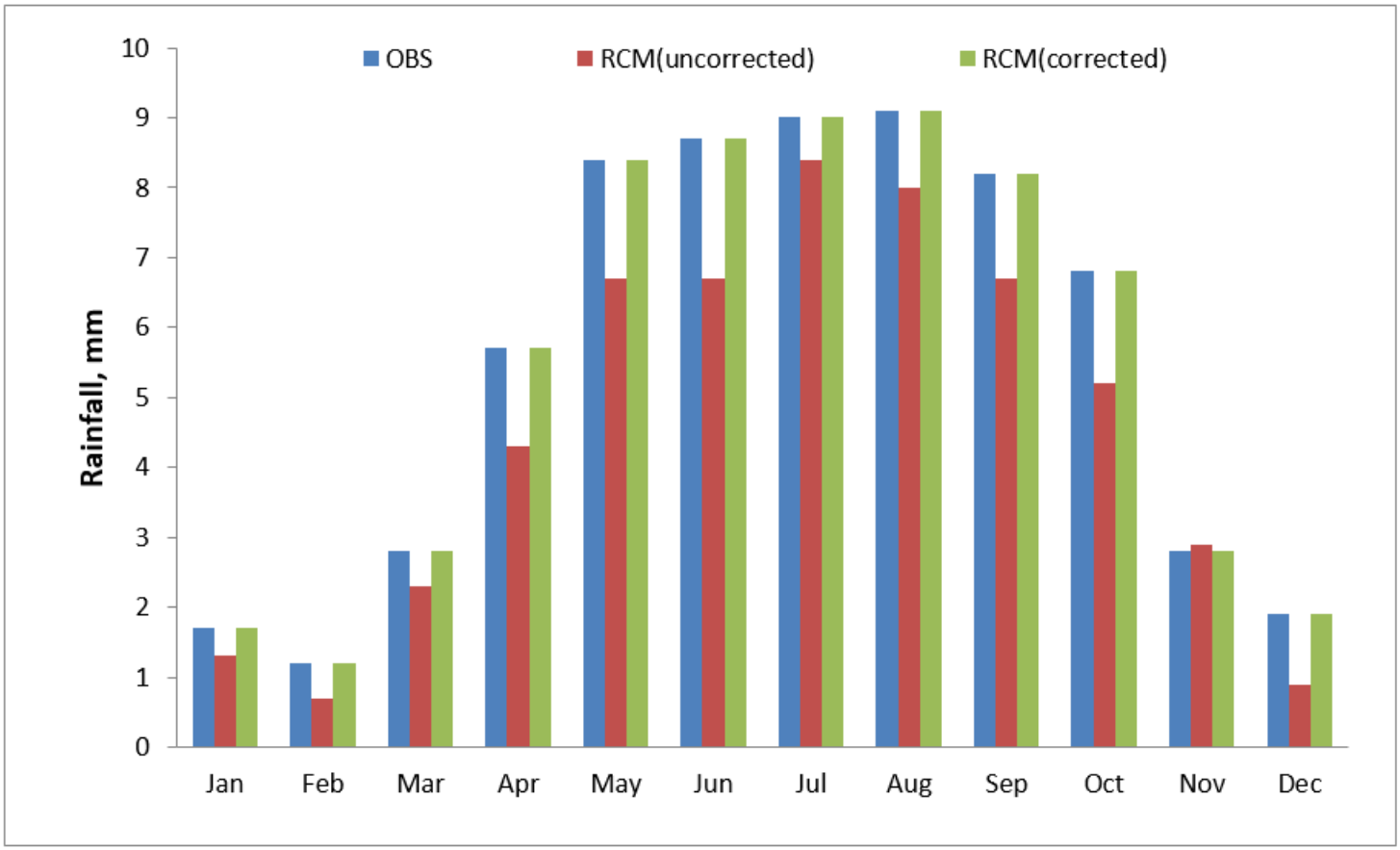


Figure 3

Comparison of bias corrected and uncorrected RCM precipitation data on the monthly basis

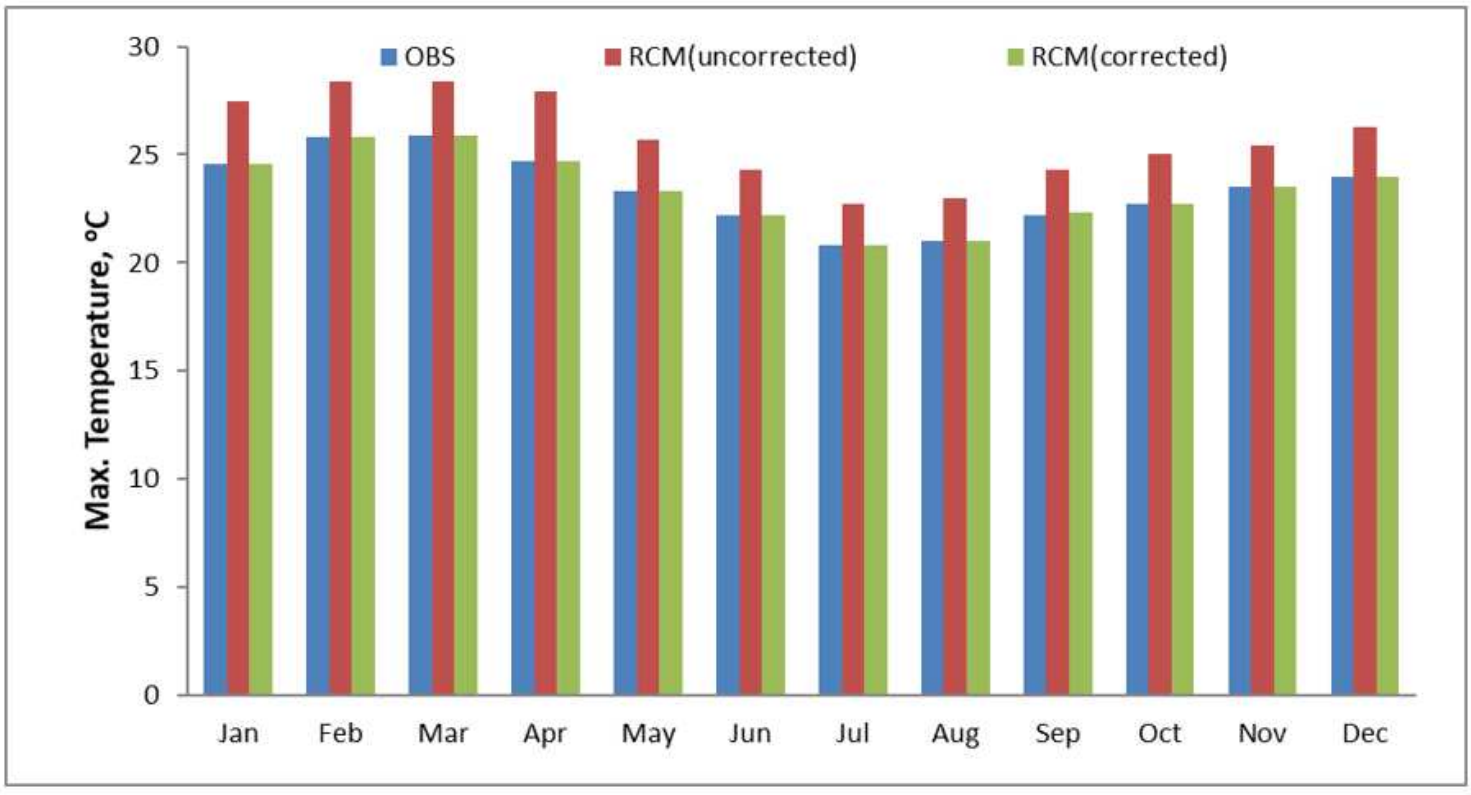


Figure 4

Comparison of bias corrected and uncorrected RCM data of maximum temperature on the monthly basis

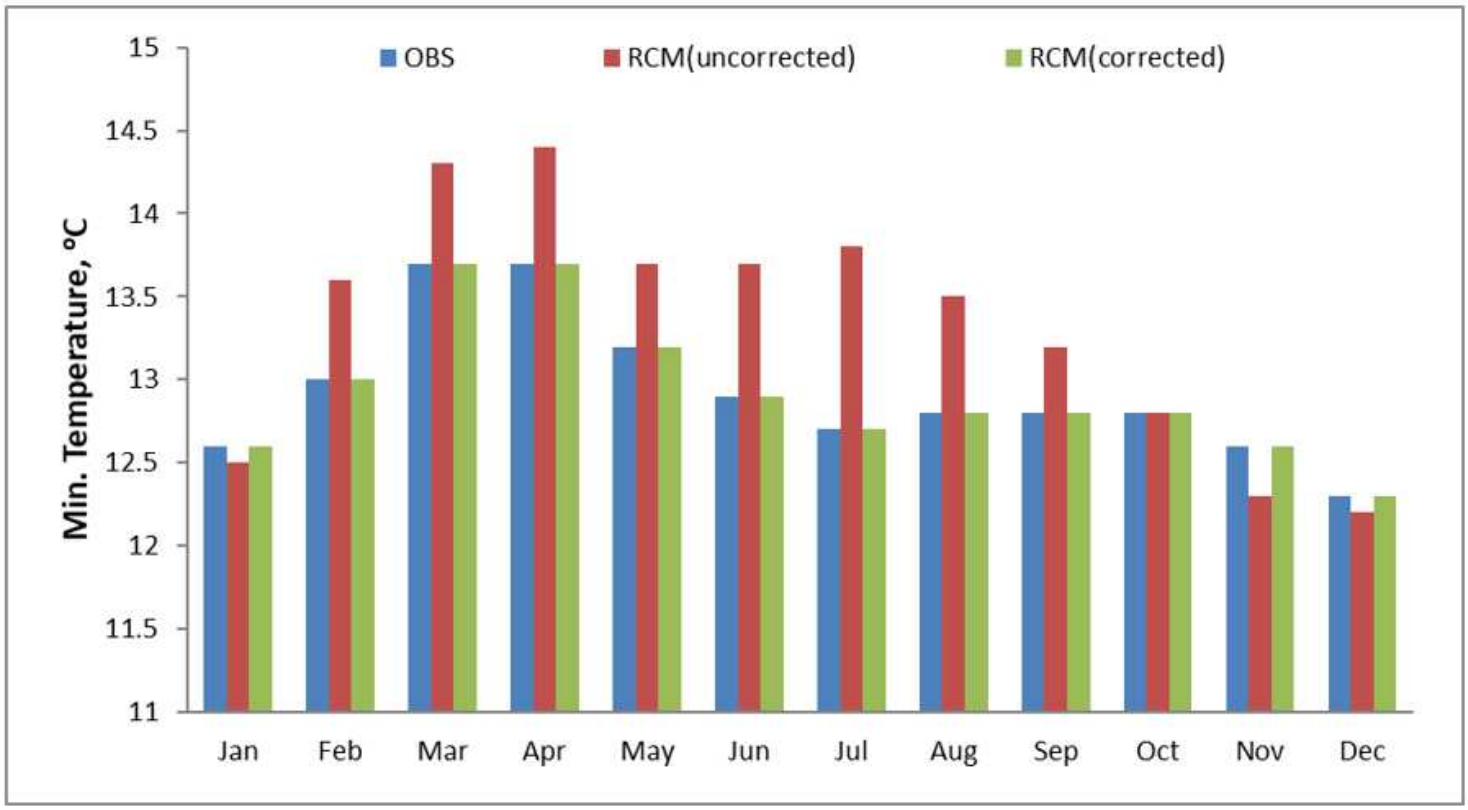


Figure 5

Comparison of bias corrected and uncorrected RCM data of minimum temperature on the monthly basis

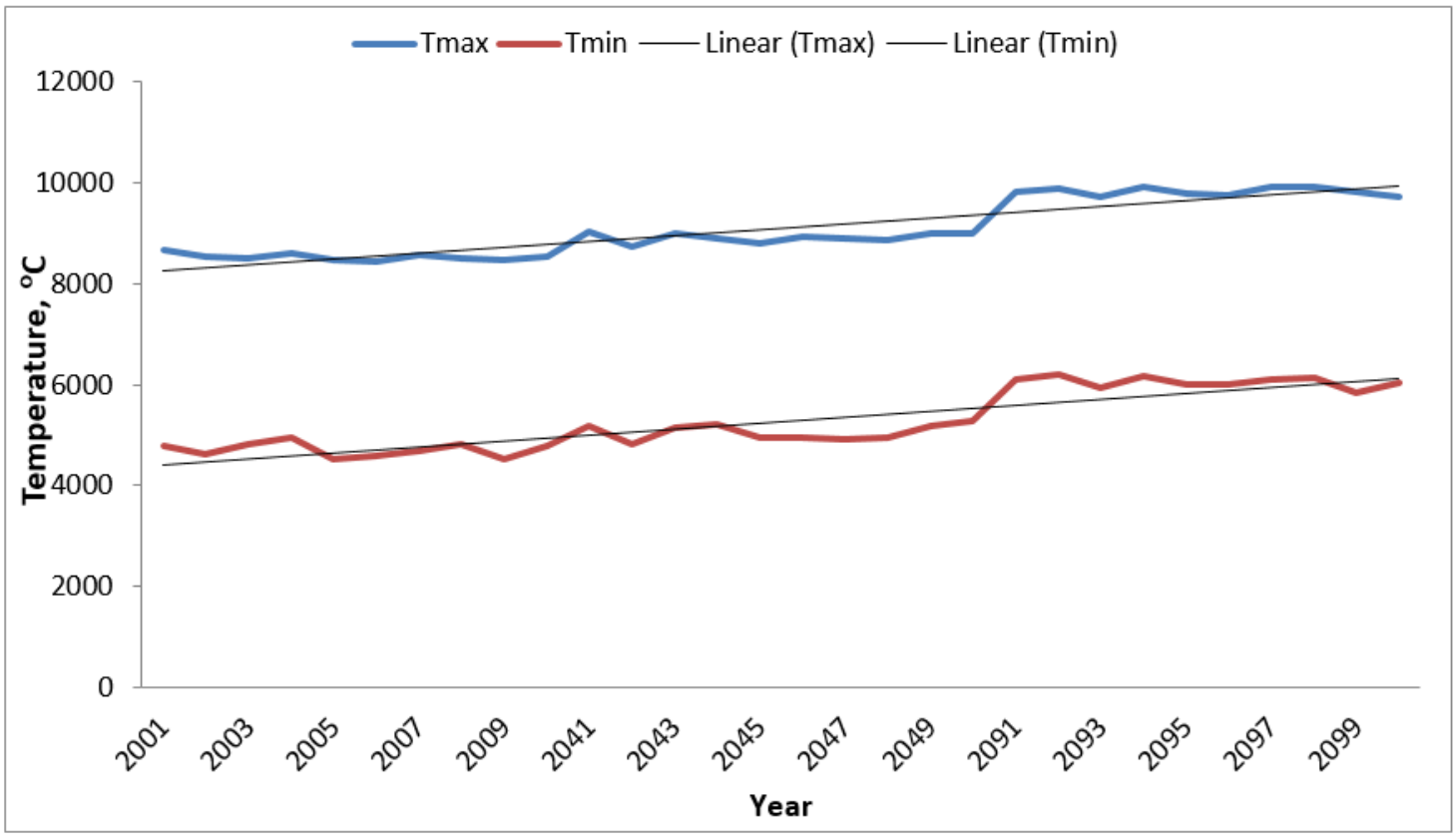


Figure 6

Projected maximum and minimum annual temperature trends

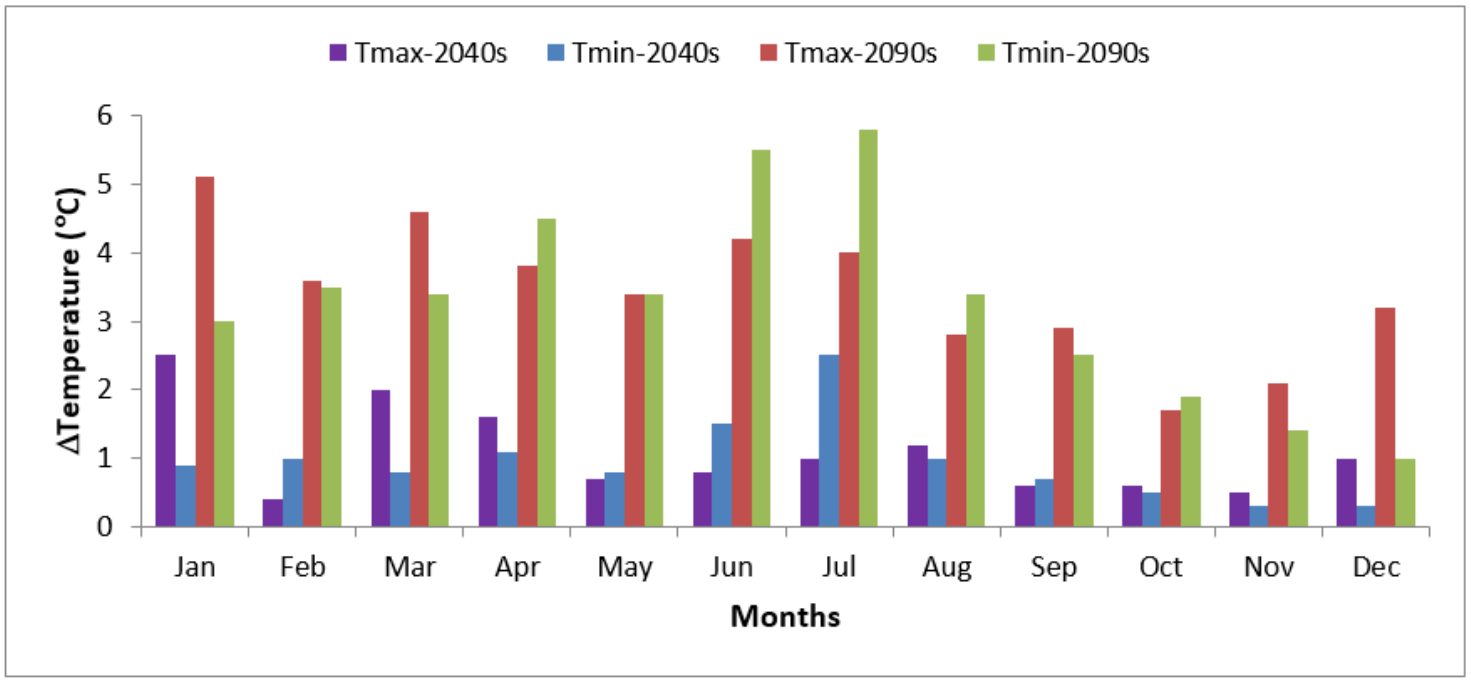


Figure 7

Future Mean Monthly max. & min. temperature fluxes compared to base period

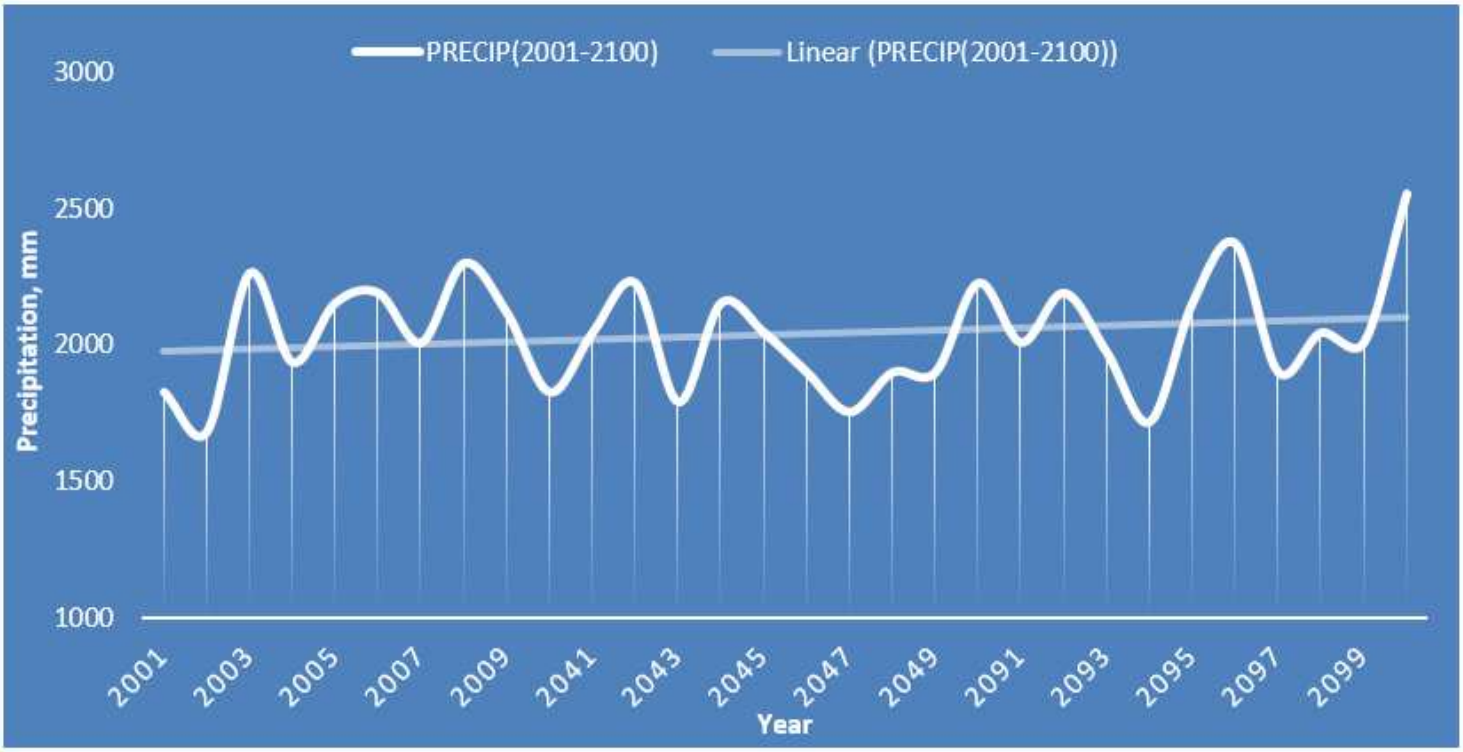


Figure 8

Projected annual precipitation trend in general (2001 through 2100) for A1B scenario

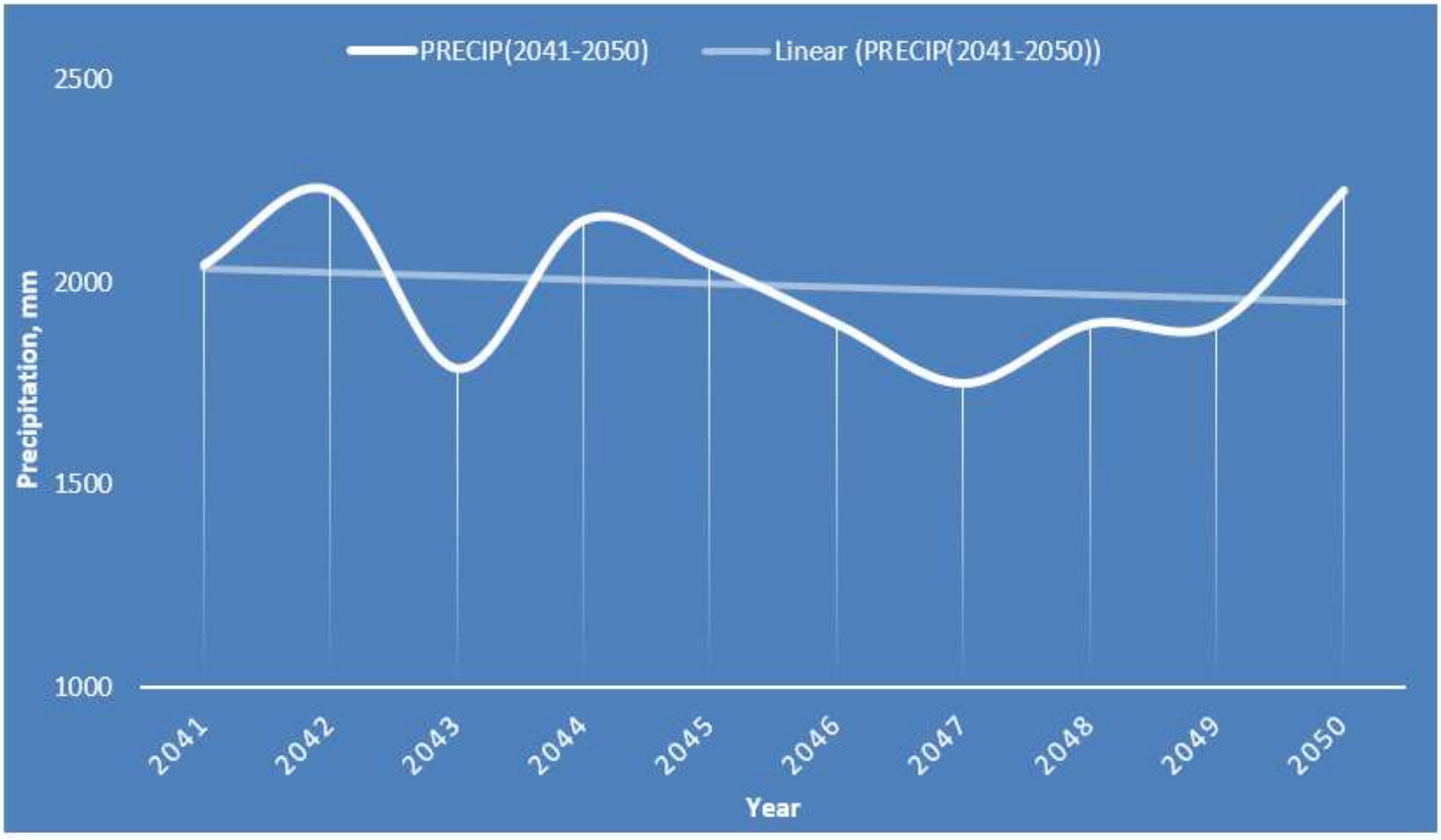


Figure 9

Projected annual precipitation trend in the mid-term (2041 through 2050) for A1B scenario

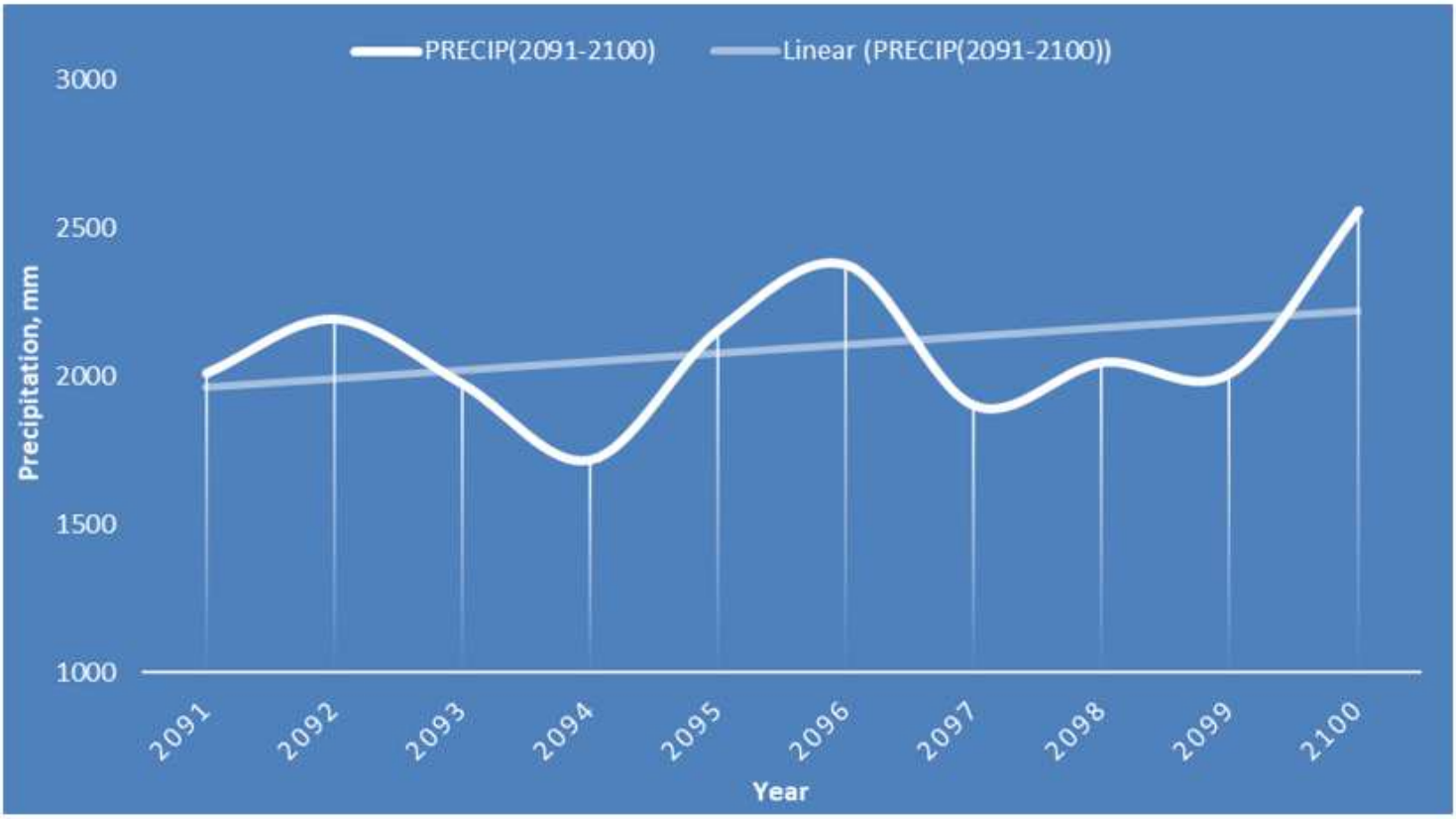


Figure 10

Projected annual precipitation trend in the long-term (2091 through 2100) for A1B scenario

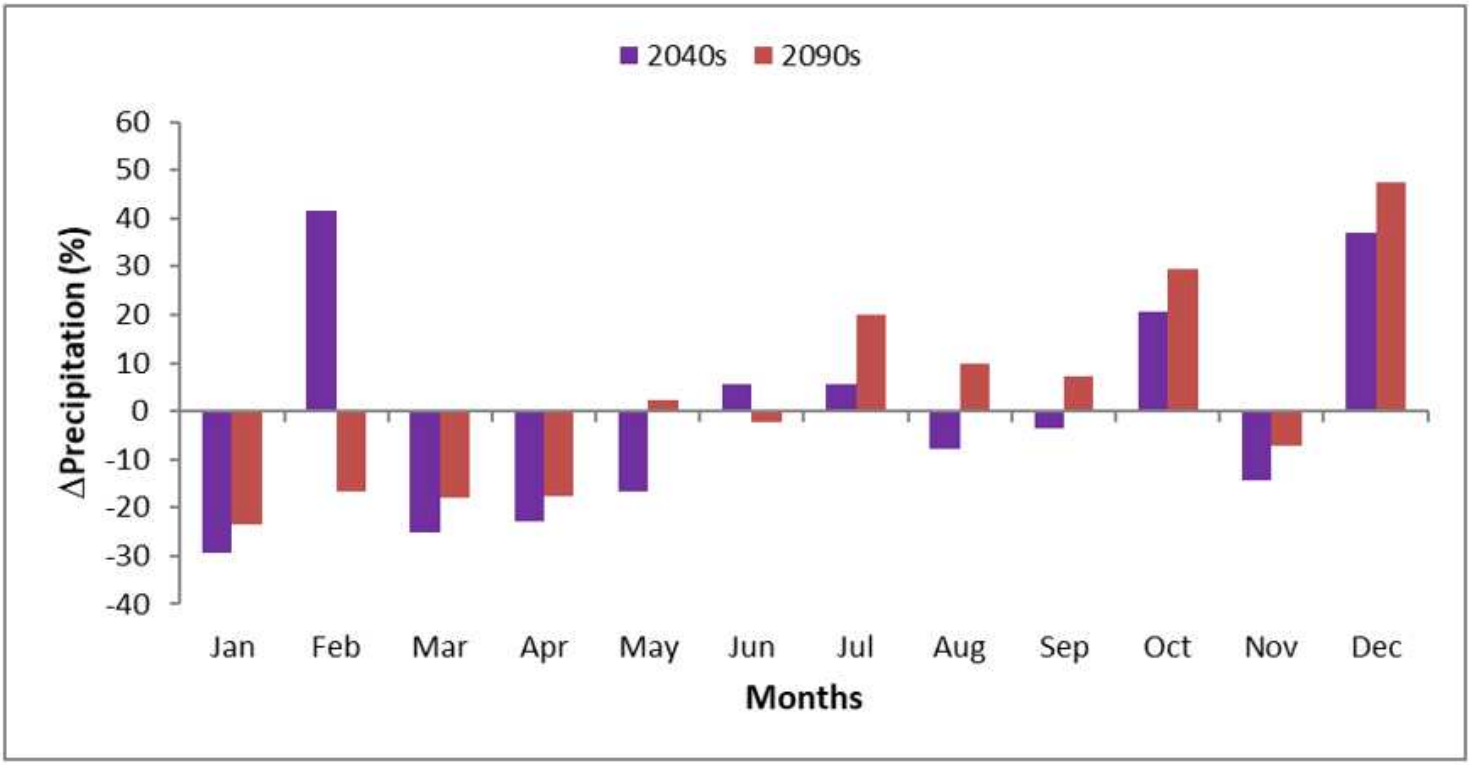


Figure 11

Percentage monthly projected precipitation changes compared to the base period



Figure 12

Projected mean annual evapotranspiration trend for A1B emission scenario

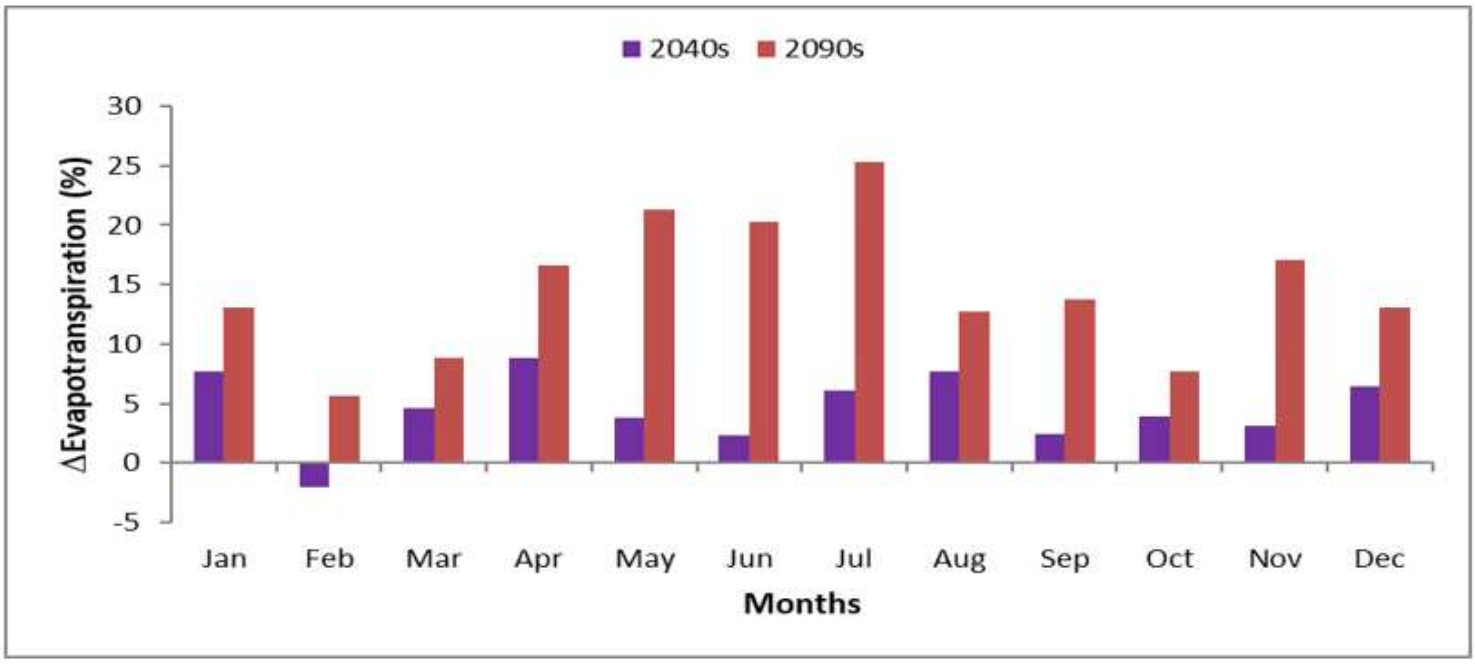


Figure 13

Percentage changes in the projected evapotranspiration as compared to the base period