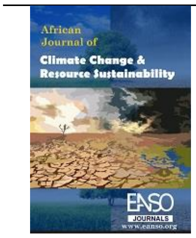

African Journal of Climate Change and Resource Sustainability
ajccrs.eanso.org
Volume 3, Issue 1, 2024
Print ISSN: 790-962X | Online ISSN: 790-9638
Title DOI: https://doi.org/10.37284/2790-9638

EAST AFRICAN NATURE & SCIENCE ORGANIZATION

Original Article

Climate Change Projections in the Upper Awash River Basin of Ethiopia Using Statistical Downscaling Model

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Article DOI: https://doi.org/10.37284/ajccrs.3.1.2064

Date Published:

29 July 2024

Keywords:

Scenario, Global Climate Model, Temperature, Precipitation.

ABSTRACT

Climate change is becoming a major threat to the economic development of developing countries such as Ethiopia. Therefore, understanding the long-term variation and change of climate variables is crucial in developing a plan for sustainable development. This study aimed to project and analyze future climate change in the Upper Awash Basin (UARB) using a statistical downscaling model. Daily data was used every 30-year interval from the second generation of the Earth System Model (CanESM2) under three Representative Concentration Pathways (RCPs). The observed maximum and minimum temperature and precipitation values are a good simulation of the modeled data during the calibration and validation periods using the Pearson coefficient(R), the correlation coefficient(R2), and the Nash-Sutcliffe efficiency (NSE). The downscaled results showed that the mean maximum temperature of upper Awash river basin is likely to increase in the range of 0.32– 0.77°C for RCP4.5 in the 2050s (2041–2070) and 0.43-1.16°C in 2080s (2071–2099), whereas under the worst emission scenario (RCP8.5), the mean maximum temperature of the study area will increase in between 0.52-0.96°C in 2050s and 1.27-2.19°C in 2080s respectively. In the high emission scenario RCP 8.5, the monthly mean maximum temperature increases by 0.5 to 20c in the mid and end of the century. Under medium and high emission scenarios of the far-future period (2080s), the mean annual precipitation will increase by 10.2% and 21.5% compared to the reference period. In both RCP 4.5 and RCP 8.5, rainfall in the Bega/dry season is expected to increase in the 2050s and 2080s while Belg's (February–May) in all emission scenarios for all periods. Whereas in the RCP 4.5 and 8.5 emission scenarios, the Kiremit season is expected to increase in the 2050s and 2080s by 4.6 and 13.9%, respectively. In general, the increase in temperature could worsen the environmental conditions in warm seasons; and an increase in precipitation in the Kiremt season is expected to bring a likely risk of flooding.

APA CITATION

Cherinet, A. & G/Yesus, M. (2024). Climate Change Projections in the Upper Awash River Basin of Ethiopia Using Statistical Downscaling Model *African Journal of Climate Change and Resource Sustainability*, *3*(1), 215-225. https://doi.org/10.37284/ajccrs.3.1.2064.

CHICAGO CITATION

Cherinet, Abirham and Marta G/Yesus. 2024. “Climate Change Projections in the Upper Awash River Basin of Ethiopia Using Statistical Downscaling Model”, *African Journal of Climate Change and Resource Sustainability* 3 (1), 215-225. https://doi.org/10.37284/ajccrs.3.1.2064.

HARVARD CITATION

Cherinet, A. & G/Yesus, M. (2024) “Climate Change Projections in the Upper Awash River Basin of Ethiopia Using Statistical Downscaling Model”, *African Journal of Climate Change and Resource Sustainability,* 3(1), pp. 215-225. Doi: 10.37284/ajccrs.3.1.2064.

IEEE CITATION

A. Cherinet & M. G/Yesus “Climate Change Projections in the Upper Awash River Basin of Ethiopia Using Statistical Downscaling Model”, AJCCRS, vol. 3, no. 1, pp. 215-225, Jul. 2064.

MLA CITATION

Cherinet, Abirham & Marta G/Yesus. “Climate Change Projections in the Upper Awash River Basin of Ethiopia Using Statistical Downscaling Model”. *African Journal of Climate Change and Resource Sustainability*, Vol. 3, no. 1, Jul. 2024, pp. 215-225, doi:10.37284/ajccrs.3.2064.

INTRODUCTION

Climate change is a major threat to the planet in the twenty-first century. It is anticipated to accelerate worldwide in the coming decades, resulting in more heat waves, longer warm seasons, and shorter cold seasons (IPCC 2014, 2019, 2021). Without significant reductions in CO2 and other greenhouse gas emissions in the next few decades, global warming of 1.5 to 2°C will surpass the target (IPCC, 2021). Climate change also impacts rainfall patterns (IPCC, 2019, 2021; Ranasinghe et al, 2021). On a global scale, extreme daily precipitation events are projected to intensify by approximately 7% for every 1°C increase in global warming. In high latitudes, precipitation is expected to increase, while in the subtropics, it is expected to decrease. Changes in monsoon precipitation are likely to vary across regions (IPCC, 2021).

According to a high-emission scenario, East African countries, and particularly Ethiopia, will see rising temperatures; mean monthly temperature variations are expected to increase by 1°C by the 2050s and by 3°C by the end of the century (Gebrechorkos et al, 2019; World Bank, 2021). Temperature increases in Ethiopia are anticipated through the end of the century under all emission scenarios. The future precipitation trends of Ethiopia remain highly uncertain due to its high level of inter-annual variability (World Bank, 2021; Belay et al., 2021; Temesgen, 2021). Based on projected patterns, there could be a 20 percent reduction in spring and summer rainfall in the southern and central regions. While the north is expected to see an overall decrease in rainfall, the southwest and southeast are expected to see an increase (World Bank 2021). It is anticipated that the country's overall warming trends will worsen the already noted decrease in precipitation, thereby exacerbating the water stress. In addition to increasing the strain on water resources, warmer temperatures will accelerate evapotranspiration and lessen the benefits of higher rainfall in some parts of East Africa (Berhanu and Beyene 2015; World Bank 2021).

Global climate models (GCMs) have become the main tool for obtaining information about climate across various spatial and temporal dimensions (Eden & Widmann, 2014; Vimal et al, 2014). However, GCMs have limitations in capturing sub-grid-scale features and their outputs are still prone to biases (Hui et al. 2019). Moreover, they have a finite capacity to study hydrological and physical atmospheric processes at the regional level (Chia Ying Lee and Suzana Camargo, 2020; Eum et al., 2020). Regional climate change has gained significant attention due to the increasing economic losses caused by weather and climate-related disasters (Fan, Jiang, and Gou 2021). In the last 20 years, researchers have developed various statistical downscaling methods (SDSM) for regional climate change applications (Chen et al., 2012; Tavakol-Davani et al., 2013). SDSM is a common tool that combines regression methods and a weather generator (Wilby et al., 2002). It has been widely used and proven reliable for downscaling air surface temperature, evaporation, and precipitation (Yang., 2020; Hassan et al., 2013; Liu et al., 2017; Zia et al., 2011).

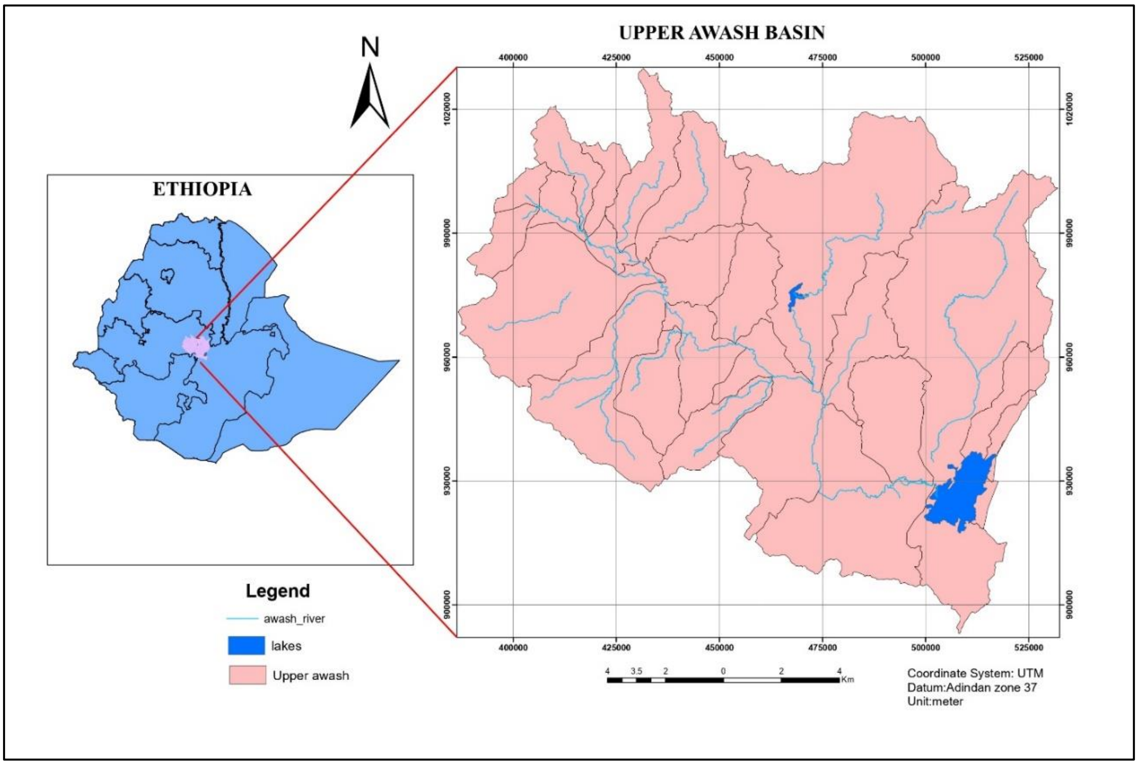
In this study, we utilize the statistical downscaling model (SDSM) method to analyze future climate scenarios. This method applies multiple linear regression to downscale Global Climate Model (GCM) outputs from a global scale to a local scale (Wilby et al. 2014). Therefore, the main objective of this study is to statistically downscale and generate climate scenarios for future maximum and minimum temperatures, as well as precipitation in the study area. We consider low (RCP 2.6), medium (RCP 4.5), and high (RCP 8.5) representative concentration pathways for the periods of the 200s, 2050s, and 2080s.

MATERIALS AND METHODS

Study Area Description

The Upper Awash River Basin is located in the North West Rift Valley of Ethiopia and has an area of around 11,430 km^2. The river rises on the high plateau near Ginchi town, west of Addis Ababa, at an altitude of more than 3000 m. The total length of the main course of the river is 336 km. The climate of the basin varies from humid subtropical to semiarid. Based on data from meteorological stations from 1983 to 2014 obtained from the National Meteorological Agency of Ethiopia, the mean maximum annual temperature ranges from 23.3 to 28.0°C, while the mean annual minimum temperature ranges from 9.5 to 13.3°C. The basin receives most of its precipitation in two main seasons, spring and summer. Spring, which is locally named Bulg, is a short rainy season from March to May. Summer, known locally as Kiremt, is the main rain and crop-growing season and extends from June to September. Hombole and Tulu Bolo receive over 60% of their annual total rainfall in summer and 20% in spring. The other four stations receive more than 40% in summer and 30% in spring. The mean annual rainfall ranges from 600 mm at the Hombole meteorological station to 1094 mm at the Ginchi station.

Fig. 1. Map of the upper Awash basin with the locations of the stations.



Data Collection

To identify the most dominant predictors and develop the most accurate future climate scenarios, we collected merged daily precipitation and maximum and minimum temperature station data from the National Meteorological Agency (NMA) of Ethiopia for the years 1983 to 2016. We used large-scale climate variables (predictors) for the current climate and future scenarios under the RCPs, which are available from the Canadian Climate Data and Scenarios. To downscale the output from a GCM, we used SDSM, which creates a statistical relationship between small-scale climate variables (predictand) and large-scale climate variables (predictors) using a multiple linear regression model. SDSM has been used for numerous meteorological, hydrological, and environmental analyses in various geographical locations, including Africa, Europe, North America, and Asia (Barrow 2002).

Data Analysis

Observed daily precipitation, maximum and minimum temperature data from 6 stations and 26 predictors are used from the NCEP (National Centers for Environmental Prediction) reanalysis data, and CanESM2 (second-generation Canadian Earth System Model) is used for the downscaling process calibration, validation, and future projections. The future projection is based on CanESM2 predictors and different representative concentration pathways (RCP). The fifth assessment report used a new set of RCP scenarios based on anthropogenic forcing scenarios for the latest climate model simulations conducted within the framework of the CMIP5. Integrated Assessment Models (IAMs), which frequently contain economic, demographic, energy, and simple climatic components, have been used to construct RCPs. The RCPs should contain data on all radiative forcing elements (emissions of greenhouse gases, air pollutants, and land use) required as input for atmospheric chemistry and climate modeling (van Vuuren et al. 2011). SDSM carried out seven key tasks including data quality control and transformation, screening variables, model calibration, frequency analyses, statistical analysis, scenario generation, and graphing of climate data to perform the downscaling and future projections (Wilby et al. 2014). After checking the data quality screening of the variables is done to select the appropriate downscaling predictors. The selection of predictors is based on the correlation matrix, partial correlation, P-value, and scatter plot.

Model Calibration

The model is calibrated under unconditional(temperature) and conditional(precipitation) processes every month using the chosen predictors for each predictand. The model was calibrated from 1983 to 2000, and it is currently utilized to generate future scenarios using the CanESM2 predictors found in RCP2.6, RCP4.5, and RCP8.5. The root mean square error (RMSE), Nash-Sutcliffe Coefficient (NSE), and coefficient of determination (R2), were used to assess the model's performance (RE). The R2 value is typically employed as a measure of the degree of correlation between observed and simulated values. NSE shows how closely the line fits the plot of real versus simulated values. Higher R2 and NSE values and lower RMSE values are recommended for evaluation purposes. (Behera et al. 2016) The model generates up to 20 or more ensembles of daily time series using the identified best-performing predictors, and its output is the mean of the ensembles used for simulating each scenario for 2020’s 2050 and 2080’s.

RESULT & DISCUSSIONS

Model Calibration and Validation

To simulate future climate variables such as rainfall and temperature, the statistical downscaling model (SDSM) was calibrated and validated. Daily precipitation, daily maximum, and minimum temperature are used to downscale the current (1983–2016) and future scenarios (2011–2100) under three Representative Concentration Pathways (RCP 2.6, RCP 4.5, and RCP 8.5). The performance of the model is evaluated using the coefficient of determination (R^2), Root Mean Square Error (RMSE), and Nash Sutcliffe model Evaluation (NSE).

Table 1 Model performance evaluation

Calibration	**Stations**	**Precipitation**			**Maximum Temperature**			**Minimum Temperature**		
		R^2	RMSE	NSE	R^2	RMSE	NSE	R^2	RMSE	NSE
	Alemtena	0.73	0.96	0.7	0.74	0.98	0.55	0.9	0.68	0.84
	Guder	0.97	0.69	0.93	0.89	0.5	0.7	0.55	1.43	0.52
	Holleta	0.91	0.9	0.86	0.92	0.55	0.83	0.59	0.93	0.56
Validation	Alemtena	0.8	0.89	0.75	0.78	1.06	0.55	0.9	0.68	0.84
	Guder	0.97	0.68	0.94	0.87	0.6	0.51	0.6	1.36	0.53
	Holleta	0.91	0.9	0.86	0.97	0.68	0.8	0.61	0.88	0.58

As shown in Table 1, the model calibration shows high values of R^2 (> 0.70, 0.70, 0.50) for precipitation, maximum temperature, and minimum temperature, respectively, in all stations. The Root mean square is (> 0.65, 0.50, 0.65) and the Nash Sutcliffe model evaluation is also (> 0.70, 0.50, 0.50) for precipitation, maximum temperature, and minimum temperature. During the model evaluation, the highest R^2, RMSE, and NSE are shown in Guder, Holleta, and Alemtena stations for precipitation, maximum temperature, and minimum temperature respectively.

Fig1 Guder Precipitation Calibration 1983-2000

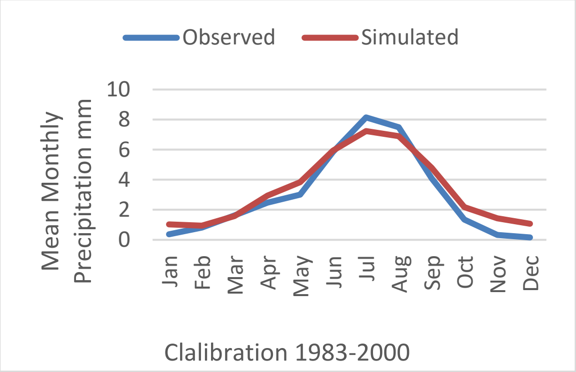


Fig 2 Guder Precipitation Validation 2002-2016

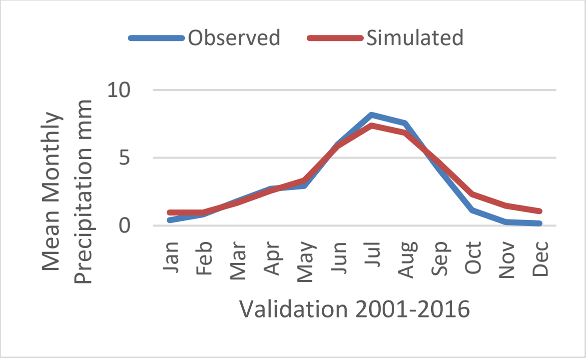


Fig3 Holleta Maximum Temperature Calibration 1983-2000

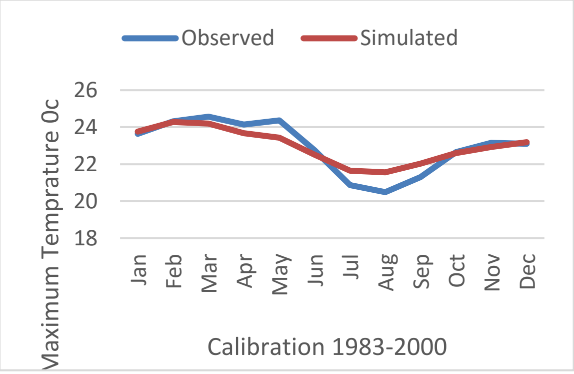


Fig 4 Holleta Maximum Temperature Validation 2002-2016

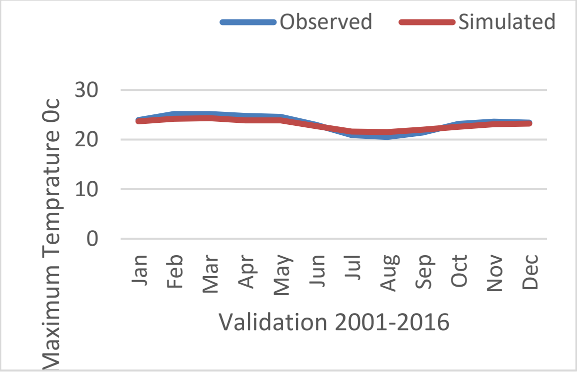


Fig5. Alemtena Station Minimum Temperature Calibration 1983-2000

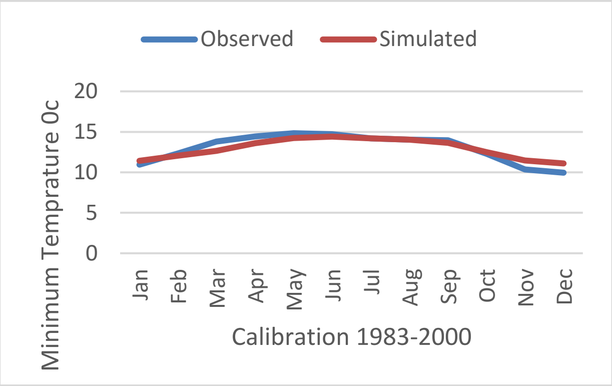
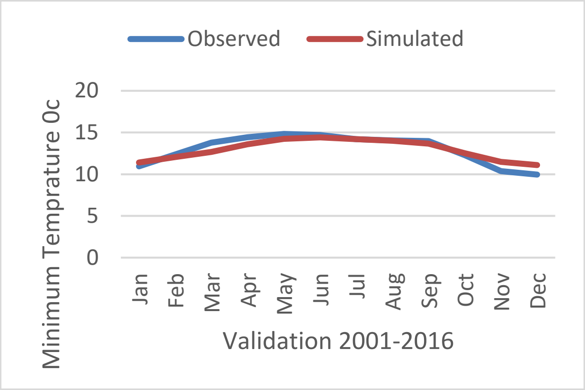


Fig6. Alemtena Station Minimum Temperature Validation 2002-2016



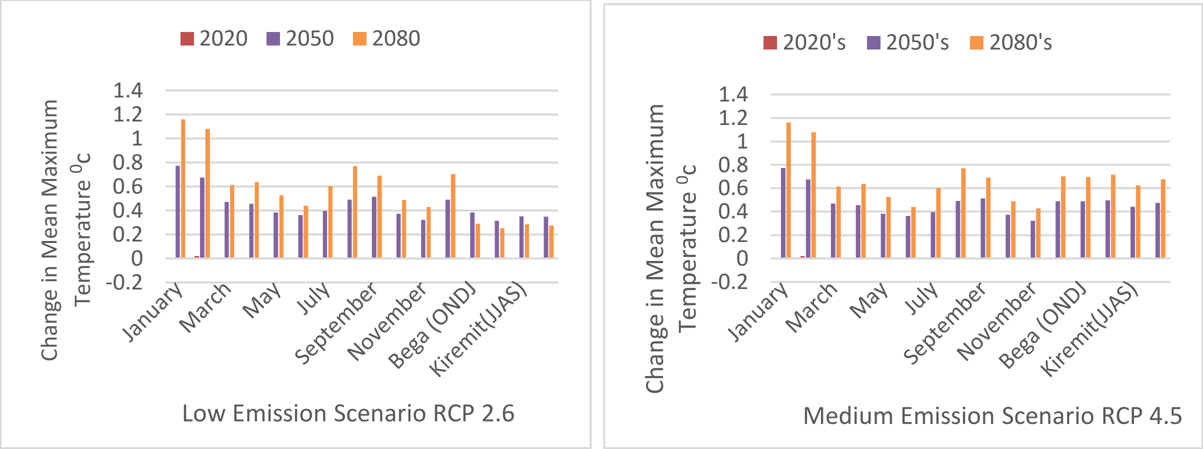
Future Climate Scenarios

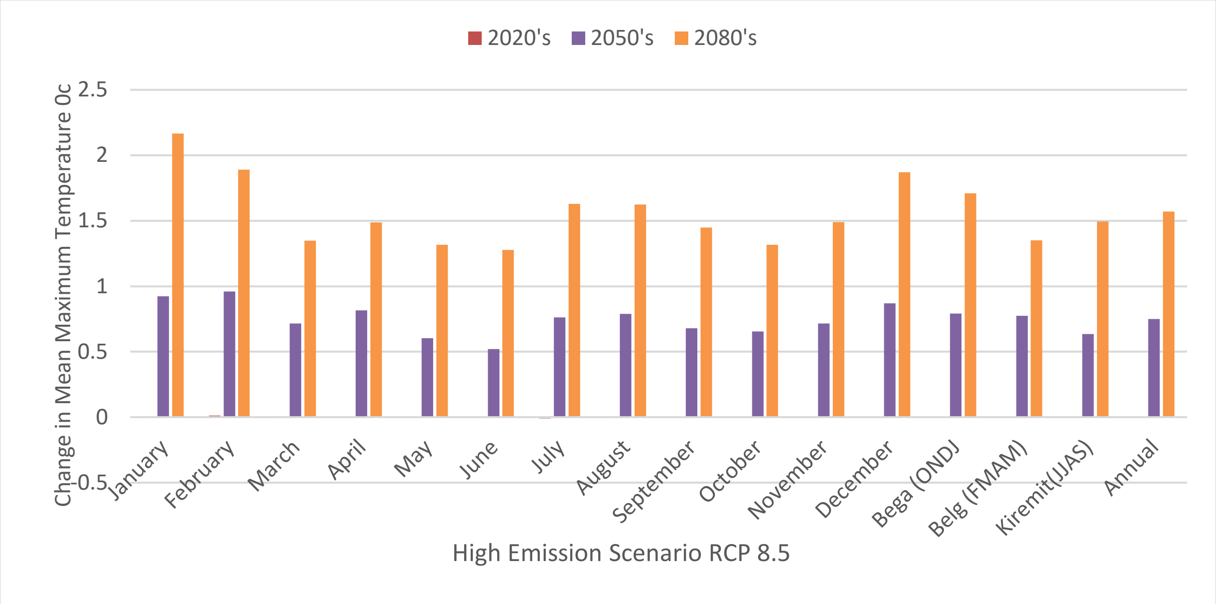
The model output generates 20 ensembles of daily precipitation and temperature, and to consider the characteristics of these ensembles, we averaged out the values of all 20 ensembles. The analysis is based on the WMO time as the 2020s (2011–2040), 2050s (2041–2070), and 2080s (2071–2100).

Maximum Temperature

The result showed an increasing trend in average monthly, annual, and seasonal temperatures in the 2050s and 2080s, whereas the average annual maximum temperature has not shown a significant change during the 2020s. Under the low emission scenario, the mean annual maximum temperature is projected to rise by 0.35 and 0.28^{0}c in the 2050s and 2080s, respectively. The medium emission scenario also shows a 0.47 and 0.68^{0}c increase in mean annual maximum temperature in the 2050s and 2080s, respectively. The highest mean annual maximum temperature change is projected to increase by 0.75 and 1.57^{0}c in the 2050s and 2080s under the high emission scenario. The projected monthly mean maximum temperature increases range between 0.3 to 1^{0}c under the low emission RCP 2.6 and medium emission RCP 4.5 scenarios in the 2050s and 2080s. In the high emission scenario RCP 8.5, the monthly mean maximum temperature increases by 0.5 to 2^{0}c in the mid and end of the century. The results show that for low, medium, and high emission scenarios, the projected seasonal changes in mean maximum temperature increased by less than 0.3^{0}c in the 2050s and 2080s.

Fig 7 Change in monthly, seasonal, and annual mean maximum temperature under RCP 2.6, 4.5 and 8.5

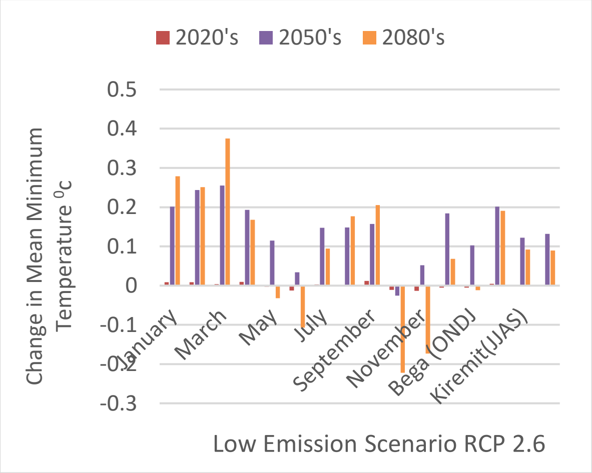


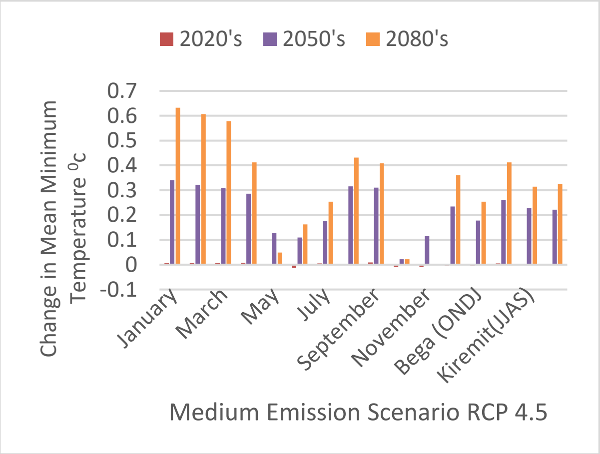


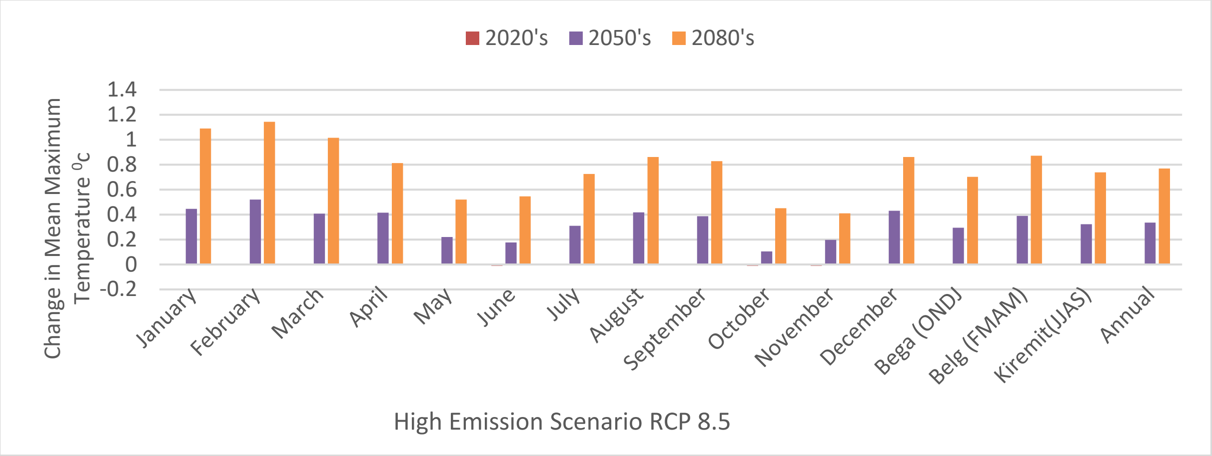
Minimum Temperature

In medium and high emission scenarios, the projected minimum temperature changes are expected in the 2050s and 2080s. In the RCP 4.5 emission scenario, the mean annual minimum temperature increases by 0.22 and 0.33^{0}c, and for the high emission scenario (RCP 8.5) 0.34, and 0.77^{0}c in the 2050s and 2080s, respectively. The monthly mean minimum temperature is projected to increase in the 2050s and 2080s under RCP 4.5 and RCP 8.5. The low emission scenario shows a decrease in mean minimum temperature in October, November, and June in the 2080s whereas the mean monthly minimum temperature is projected to increase in between 0.11 to 1.09^{0}C in the 2050s and 2080s in both medium and high emission scenarios.

Fig 9 Change in monthly, seasonal, and annual mean minimum temperature under RCP 2.6, 4.5 and 8.5



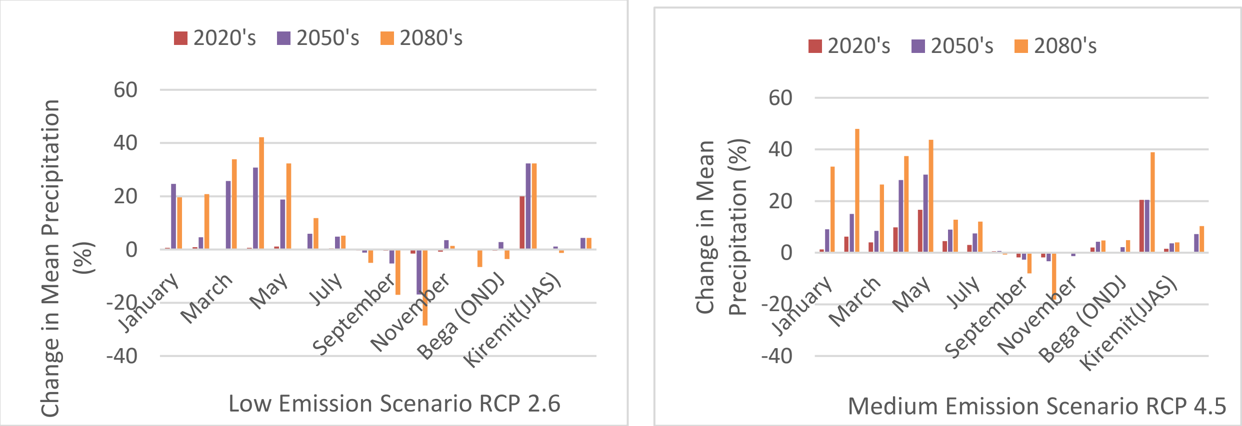


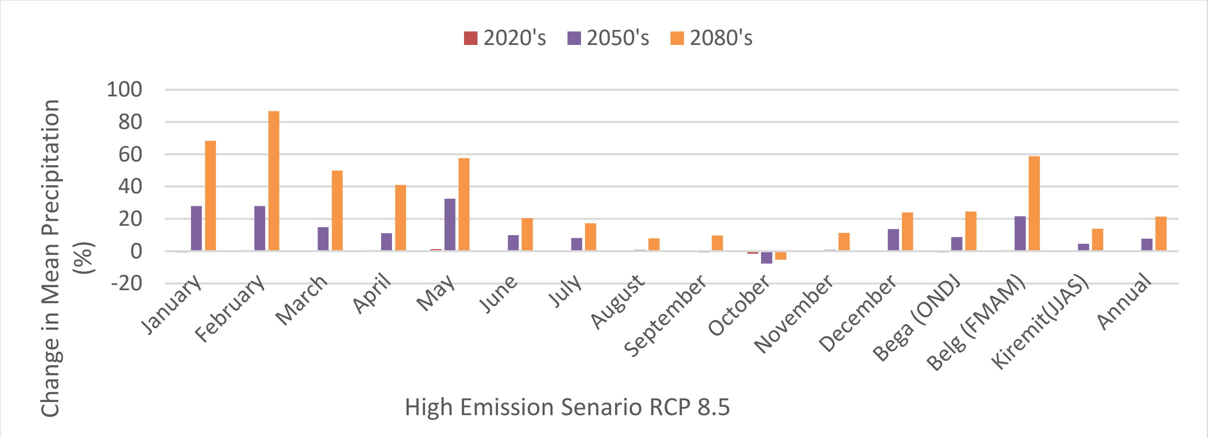


Precipitation

The percentage change of mean annual precipitation indicates an increasing trend, and it will be higher in medium and high emission scenarios for the 2080s. The highest mean annual precipitation change is indicated under medium and high emission scenarios, increasing by 10.2% and 21.5% in the 2080s, respectively. A rainfall projection for Bega (October–January) shows an increase in the 2050s and a decrease in the 2020s and 2080s in RCP 2.6 emission scenarios. In the medium emission (RCP 4.5) and high emission scenario (RCP 8.5) rainfall in the Bega is expected to increase in the 2050s and 2080s while decreasing in the 2020s for the high emission scenario. Belg's (February–May) projection shows an increasing trend in all emission scenarios (RCP 2.6, 4.5, and 8.5) for the 2020s, 2050s, and 2080s. The highest precipitation is expected to increase in Belg by about 58% in the 2080s under the RCP 8.5 emission scenario. The mean monthly rainfall of Belg (February–May) shows an increasing trend in all months in the low, medium, and high emission scenarios in the 2020s, 2050s, and 2080s. The Kiremt (June–September) season is projected to decrease in the 2080s by 1.4%, increasing in the 2050s by 1.1% in the low emission scenario, whereas in the RCP 4.5 emission scenario, the Kiremit season is expected to increase by 1.6, 3.6, and 4% in the 2020s, 2050s, and 2080s, respectively. In the high-emission scenario, the Kiremit season is expected to increase in the 2050s and 2080s by 4.6 and 13.9%, respectively.

Fig 8 Change in monthly, seasonal, and annual mean minimum temperature under RCP 2.6, 4.5, and 8.5





The mean monthly change in the Kiremit season shows a decreasing trend in June, August, and September in the 2020s, August in the 2050s, and August and September in the 2080s in the low-emission scenarios. In RCP 4.5, the monthly mean rainfall decreases in September in the 2020s, 2050s, and 2080s while the projection shows a decrease in August in the 2080s. The high emission scenario also shows a decrease in August and September in the 2020s and the month of September also shows a decrease in the 2050s.

CONCLUSION

Using the outputs of CanESM2, developed by the Canadian Center for Climate Modeling, the upper Awash basin's future climate projection has been carried out which is too coarse for basin-level research. As a result, the outputs have been downscaled to station level using a statistical downscaling model (SDSM). Three RCPs, which cover a wide range of scenarios, are used to project future precipitation and temperature, and these results are compared to the base period of 1983–2016. The model's predictors were screened and selected based on the R^2 and p-values. During the validation period, the study found a good correlation between the modeled data and observed values. For all RCPs, future temperatures will be higher than in the baseline period. The change is expected to be greatest after 2020. Up to 2020, the climate will not significantly change. The predictions, however, are higher for 2050 and 2080. The worst-case scenarios for 2080 result in changes to the mean maximum temperature of 1.57^0C. Likewise, in 2080, the average minimum temperature rises by 0.77^0C. The upper Awash basin's future precipitation will significantly increase. The annual average precipitation will increase by 21.5% by 2080 in the worst-case scenario. Precipitation changes vary seasonally. The total precipitation increases by 2080 by 38.8 percent (RCP4.5) and by 58.8 percent (RCP8.5) in the Belg season. Moreover, the upper basin will be vulnerable to drought and flooding due to the anticipated increase in temperature and precipitation brought on by global climate change. Therefore, to create better adaptation mechanisms, it advised that decision-makers should incorporate the findings of this research.

Acknowledgments

The authors gratefully thank the secondary data provider, the Ethiopian National Meteorology Service Agency (NMSA) for providing meteorological data.

Data availability

The data that support the findings of this study are openly available, except observed data collected from Ethiopian National Meteorology Service Agency. The authors have no authority to openly distribute the observed data.

Declarations

The authors declare no conflict of interest.

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