Received: 17 October 2023 | Revised: 25 December 2023 | Accepted: 5 January 2024 | Published online: 23 January 2024

RESEARCH ARTICLE

Green and Low-Carbon Economy
2024, Vol. 00(00) 1–12
DOI: 10.47852/bonviewGLCE42021893

BON VIEW PUBLISHING

Evaluation of CORDEX-Africa Model Data Reliability and Bias Correction for Climate Change Impact Assessment: Upper Tekeze River Basin, Tigray (Ethiopia)

Ghrmawit Haile Gebrehiwot[1,*], Kassahun Ture Bekitie[1], Fikru Abiko[2], Weldemariam Seifu[3] and Haftu Brhane Gebremichael[4]

[1]*Center for Environmental Sciences, Addis Ababa University, Ethiopia*

[2]*College of Natural and Computational Sciences, Wolkite University, Ethiopia*

[3]*College of Agriculture and Natural Resources, Salale University, Ethiopia*

[4]*College of Natural and Computational Sciences, Haramaya University, Ethiopia*

Abstract: Model simulation evaluation is crucial for selecting the best regional climate models, as their performance may vary across different locations or variables. This research aims to examine and correct potential biases in the Coordinated Regional Climate Downscaling Experiment (CORDEX) ensemble climate dataset over the period of 1987–2005 so as to establish trust in utilizing the CORDEX ensemble forecasts for climate change impact assessment focusing on the upper Tekeze River Basin (UTRB). The Pearson correlation coefficient is employed to assess the degree of correlation between CORDEX and observation data, and the applicability of the CORDEX ensemble data for the UTRB. The statistical analysis reveals a significant correlation between the monthly mean rainfall and temperature in the CORDEX-Africa ensemble simulation and the corresponding observation data for most of the 18 stations. The finding suggests that the CORDEX-Africa ensemble dataset holds promise for future climate projection in the UTRB. The statistical approaches of bias, root mean square error, and mean absolute error are employed to assess the adequacy of the CORDEX ensemble model in reproducing observed data. Various bias correction approaches are employed to enhance the accuracy of rainfall and temperature datasets, addressing discrepancies from over and under simulation. The reliability evaluation results indicate that the CORDEX-Africa ensemble precipitation and temperature dataset has undergone bias adjustment in order to accurately reproduce the observed gridded dataset for the same period. This adjustment was performed using various methodologies across the 18 stations. Following the bias modifications, the CORDEX ensemble's precipitation and temperature dataset exhibited a high degree of concordance with the grid observation dataset across all 18 observation stations, for the corresponding time. The approaches utilized in this work possess the potential for practical applicability in generating dependable climate data that may be employed in evaluating and forecasting the consequences of climate change using globally accessible data resources.

Keywords: CORDEX-Africa, climate data, climate projection, performance evaluation, bias refinement

1. Introduction

Global climate models (GCMs) serve as valuable tools in the examination of the climate system's reactions to various external influences, as well as in the formulation of climate projections and forecasts spanning time periods ranging from seasonal to decadal and beyond. At present, GCMs possess substantial credibility as computational instruments for simulating the potential response of the global climate system to an elevation in the atmospheric concentration of greenhouse gases [1–6]. Nevertheless, it is widely acknowledged that the spatial resolution of GCMs is generally considered insufficient for accurately assessing the specific impacts, hence requiring additional downscaling techniques.

Thus, the field of regional climate modeling has witnessed significant expansion over the past few decades, attracting a wide range of scholars and researchers from varied scientific backgrounds. Regional climate models (RCMs) have the capability to be executed throughout a broad spectrum of scales, encompassing hydrostatic to convection-resolving resolutions, hence facilitating diverse applications. RCMs are commonly favored for the purpose of analyzing the impacts of regional climate change, mostly due to their enhanced reliability and superior resolution [6]. Dynamic downscaling techniques are employed in order to generate localized, high-resolution information that effectively highlights the orographic effect in diverse and uneven geographical landscapes [3].

*Corresponding author: Ghrmawit Haile Gebrehiwot, Center for Environmental Sciences, Addis Ababa University, Ethiopia. Email: ghrmawit.haile@aau.edu.et

Nevertheless, the accuracy of RCMs may be compromised as a result of their reliance on GCM data [2, 7, 8, 9]. RCMs have a higher level of computational complexity and associated costs due to their smaller grid cell resolution, increased availability of surface data, and incorporation of additional processes. Hence, the development of RCMs is typically undertaken by research organizations possessing adequate computational capabilities and technical proficiency, thereby posing a problem for economically disadvantaged countries with constrained resources [10].

Climate models encompass a range of interpretations and simplifications, which may introduce biases in the simulated climate data when compared to the observed dataset. This is due to their inherent nature as approximations of the complex climate system [11]. According to Charles et al. [11], the RCMs exhibit some deficiencies, including the smoothing of terrain, inaccurate representation of site elevation, and an overestimation of the frequency of days with precipitation. Hence, it is recommended that prior to utilization in various research endeavors, the data generated by RCMs should undergo thorough evaluation and appropriate measures be taken to rectify any biases present [5, 7, 10, 12]. The reproducibility of historic (observed) conditions is a fundamental need for any downscaling method utilized in hydrological applications [13]. Hence, it is recommended to conduct a comprehensive assessment of the performance reliability and validation of RCM models using historical simulations of pertinent variables (e.g., temperature and rainfall) in comparison to corresponding observational data for the corresponding time frame [14].

Various techniques could be employed to evaluate the capacity or competence of RCMs to accurately reproduce climatic conditions at a specific location [2, 6]. Since no single technique or performance metric is superior, it is recommended to combine several techniques to provide a complete picture of model performance [2, 15]. Different studies recommend using a variety of metrics, such as but not limited to, root mean square error (RMSE) and mean absolute error (MAE), because each metric only projects one model error and highlights one error characteristic [16].

Given the significant reliance of Ethiopia's economy on rainfall-dependent sectors, including agriculture and hydroelectric, sectors highly affected by climate change impacts, the matter of water resources assumes particular urgency and warrants immediate attention. However, precise climate projections are required for impact assessment and the provision of relevant climate services, and this in turn requires reliable climatic data. In Ethiopia and across Africa, there is a dearth of high-quality observation datasets, both in terms of temporal and spatial resolution [2].

Therefore, to address this gap, it is suggested that impact assessment studies conducted within the country should utilize globally accessible climate data sources, such as the Coordinated Regional Climate Downscaling Experiment (CORDEX) climate dataset. This collection includes both individual models and multi-model ensembles, which can provide valuable insights for conducting comprehensive impact assessments.

Moreover, the comprehensive examination and documentation of the utilization of RCMs and GCMs to elucidate forthcoming climate variations in semi-arid Ethiopia have not received sufficient scholarly attention. Given this research gap, this study aims to conduct a climatological and statistical evaluation of the CORDEX-Africa RCMs ensemble in relation to the upper Tekeze River Basin (UTRB) of Tigray, Ethiopia. In Ethiopia, where weather stations are scarce and small in number, the lack of availability of such data is a significant underlying barrier that limits research such as assessments of the impact of climate change. However, merging station observations with globally accessible products like satellite proxies and model reanalysis data could greatly improve data availability [17].

The objective of this study is to assess how effectively the CORDEX-Africa RCMs ensemble simulates rainfall and air temperature over Northern Ethiopia, to be used for climate-impact studies at the local scale as well as regionally. Our key aim is to evaluate the ability of the CORDEX-Africa ensemble dataset to effectively capture and exhibit a satisfactory level of reproducibility with the observed mean monthly rainfall and temperature data for the UTRB during the period from 1987 to 2005. Additionally, any discrepancies identified through the comparison are subsequently addressed through bias adjustment. Various procedures are employed to achieve the objective of testing and refining, the output generated by the CORDEX-Africa multi-model ensemble.

To reduce the uncertainties related to individual CORDEX climate models, this study makes use of the CORDEX-Africa multi-model ensemble. This work uses the ensemble monthly average over the years 1987–2005. Better accuracy and performance are two advantages of ensemble techniques over single models, especially for complex topographies. The ensemble fits the observed data more closely than the individual RCMs, according to Mutayoba and Kashaigili [3]. A study by Demissie and Sime [18] suggests that model ensembles should be used to examine past research conducted in Ethiopia that used single RCMs to assess the effects of climate change. This study by Demissie and Sime [18] further suggests that earlier researches in Ethiopia that evaluated the effects of climate change using single model RCMs should be reevaluated using model ensembles.

In regard to this study, different researches have been reviewed. A study finding by Sultan [19] revealed that RCMs in Ethiopia have a significant bias at higher altitudes; however, they yield credible results in lower altitude locations. This study provides unambiguous evidence of this trait in the CORDEX-Africa dataset. Furthermore, the findings of this study are consistent with previous research conducted by The Intergovernmental Panel on Climate Change [15] that assessed the accuracy of the CORDEX RCMs in replicating rainfall patterns in East Africa between 1990 and 2008, as well as by Shongwe et al. [20] that evaluated the effectiveness of the CORDEX RCM in simulating precipitation in southern Africa. The results of these investigations indicate that the RCMs exhibited more accuracy in forecasting rainfall in one region during the research period compared to another location. This study reveals similar performance characteristics in model simulations, with some stations showing better results than others within the same study basin.

The findings derived from this study have the potential to serve as valuable data for evaluating the effects of climate change on several sectors, including water resources.

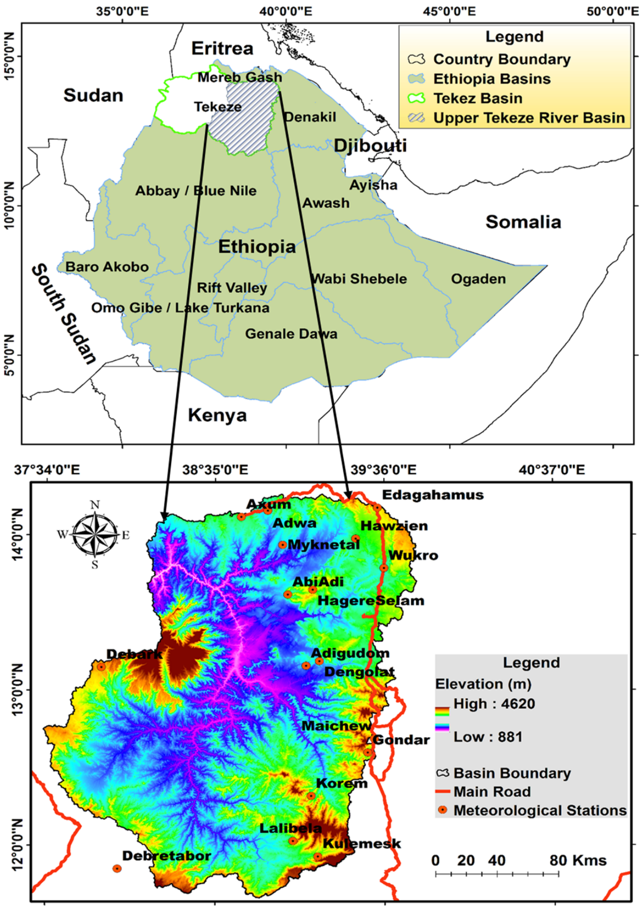
2. Material and Methods

2.1. Description of the study area

Tigray (Northern Ethiopia) is home to the UTRB, a sub-basin of the Blue Nile basin, located in the north-western area of the country, specifically between the geographical grid system of 12° 0'12.20" and 14° 45'42.29" N latitude, and 36° 32' 07.70" to 39° 46' 23.89" E longitude (Figure 1). The Tekeze River originates as a watershed characteristic in the southern part of the watershed, adjacent to the Ras Dashen Mountains. It proceeds in a northerly direction, subsequently changing course to the west, until it converges with the Atbara River in the northeastern portion of Sudan. The study site, the UTRB, encompasses a surface area of 45,694 square kilometers. The basin is geographically delimited to the north by Eritrea, to the east by the western escarpment of the Afar Depression, and to the west and south by the Semien Mountains. The UTRB has typical arid bio-geophysical characteristics [8]. The regions located to the east and north of the basin are characterized by a semiarid climate, while the southern region has a more humid environment.

The onset of the dry season commences in October and extends for duration of 4 months. The basin experiences a range of mean annual rainfall, with values ranging from approximately 400 mm in the northeast to over 1200 mm in the highlands of the southwest [21]. The mean annual temperature in the basin ranges from approximately 10 °C in elevated areas to over 28 °C in lower regions. The annual evapotranspiration varies from 2538 mm in the western region to 905 mm in the middle highlands, with an average of 1688 mm [22]. Approximately 66% of the annual rainfall takes place in the months of July and August. The primary land cover in the basin consists of agricultural land (>70%), grassland, forest land, shrub/bush land, barren land, built-up land, and water bodies [22, 23]. The basin is being degraded by deforestation, overgrazing, and farming due to the rough topography. The Tekeze hydropower dam, with a capacity of 300 MW, was constructed in the upper basin in 2009 and is located in the UTRB.

Figure 1
Location map and meteorological stations of the UTRB



2.2. Data sources and methods

2.2.1. Data

The gridded data for daily rainfall, maximum, and minimum temperature from 1987 to 2005 were obtained from the Ethiopian National Meteorology Agency. The data were taken from 18 observation sites, as shown in Figure 1. The observation sites are chosen with the aim of accurately representing the varied and challenging topography of the study region. The availability of high-quality data in Ethiopia is a significant obstacle to conducting scientific investigations, such as assessing the implications of climate change. In order to address this disparity, we utilized high-resolution (4 × 4 km) satellite and station data to supplement missing data and document temporal discrepancies in the observed data from the stations. The availability of high-resolution gridded data is of utmost importance for a region such as Ethiopia, where weather stations are scarce and widely scattered. The method integrates satellite-derived data that have been calibrated at a local level with station data from the national observation network, which has undergone quality control measures [24].

The CORDEX-Africa RCMs ensemble outputs utilized in this work are based on climate data from the CORDEX-Africa project's coordinated regional climate downscaling experiment, with a spatial resolution of longitude 0.44° and latitude 0.44° utilizing a rotated pole system coordinate [14]. The time resolution of the output from dynamically downscaled CORDEX scenarios is on a 6-hourly basis [2]. In this study, dataset from CORDEX archive file and data formats, as well as archive content is used. These models operate over an equatorial domain with a quasi-uniform resolution of approximately 50 km by 50 km [3]. For further description of CORDEX-Africa RCMs and their dynamics and physical parameterization, interested readers may refer to Nikulin et al. [25] for details. To reduce uncertainties related to individual CORDEX climate models, the ensemble average or multi-model average for the present (1987–2005) is adapted in this study. The output from CORDEX-RCMs is utilized to evaluate the extent to which the ensemble of CORDEX-RCMs can accurately reproduce observed monthly rainfall, as well as maximum and minimum temperatures, during the period spanning 1987–2005, taking into account the boundary conditions provided by the GCMs. The location and general information of the 18 observation stations are shown in Table 1 and Figure 1.

2.2.2. Methods

CORDEX-Africa Ensemble Dataset Analysis and Performance Evaluation

The outputs of GCM and RCM models often exhibit bias, and it is advisable to apply corrections to the se outputs prior to their utilization in regional impact assessments [4, 7]. The capacity of the CORDEX models to accurately replicate past and present climate conditions and climate change aspects contributes to the establishment of trust in the reliability of their future climate prediction scenarios. An evaluation analysis is conducted to assess the performance of the model ensemble average for 1987–2005 climate dataset. This involves calculating the model and hybrid gridded monthly mean rainfall and maximum and minimum temperature dataset for the same period, using the monthly aggregated dataset for the 18 stations. The evaluation results indicate that the CORDEX ensemble dataset has undergone bias refinement. Various methodologies can be employed to assess the proficiency of RCMs in replicating climate patterns at a certain geographical point [6, 15]. According to Luhunga et al. [2], it is suggested that the integration of multiple methodologies is

Table 1
Meteorological stations of the upper Tekeze River Basin

Station	Latitude	Longitude	Elevation(m)
Adwa	14.16^0	38.90^0	1950
Axum	14.12^0	38.74^0	2200
Myknetal	13.94^0	38.99^0	1815
Korem	12.32^0	39.16^0	2450
Lalibela	12.03^0	39.05^0	2450
Maichew	12.69^0	39.54^0	2432
Edagahamus	14.18^0	39.56^0	2700
Hawzien	13.98^0	39.43^0	2255
HagereSelam	13.65^0	39.17^0	2630
AbiAdi	13.62^0	39.02^0	1850
Kulemesk	11.93^0	39.20^0	2360
Dengolat	13.19^0	39.21^0	1950
Adigudom	13.16^0	39.13^0	2100
Gondar	12.60^0	39.50^0	2316
Wukro	13.79^0	39.60^0	1995
Shire	11.10^0	38.28^0	1920
Debark	13.15^0	37.90^0	2850
Debretabor	11.85^0	38.00^0	2969

necessary in order to have a thorough understanding of model performance. This suggestion stems from the belief that no single technique or performance indicator is considered superior to others. In this study, the performance of the CORDEX ensemble simulation in reproducing the hybrid gridded data (rainfall and temperature) for the selected gauging stations over 1987–2005 is evaluated using four statistical measures recommended by World Meteorological Organization [26]. The Pearson correlation coefficient (r(Mod, Obs)), bias, RMSE, and MAE are applied in the model ensemble dataset performance evaluation listed in Table 2, Equations (1–4).

Before the CORDEX ensemble climate datasets reliability evaluation is carried out, the existence of an acceptable correlation between the observed and corresponding CORDEX dataset for the period 1987–2005 over the selected stations is checked by Pearson correlation using Equation (1), where observed mean monthly rainfall cycles over the full period (1987–2005) for the 18 stations are compared with the mean monthly rainfall data from the corresponding CORDEX ensemble average dataset for the same period. The Pearson correlation coefficient (r(Mod, Obs)) measures the strength of the linear relationship between CORDEX model simulations and observations and has the limits of 1 and –1. A Pearson correlation coefficient close to 1 indicates a better positive significant correlation between the model and observed data, and values far from 1 indicate lesser agreement between the two data [6]. The correlation does not fit a line through the data; it calculates the degree to which the two variables are related. The bias, calculated using Equation (2), is a measure of whether RCM ensemble overall under-estimates or over-estimates a particular climate variable. The positive bias value indicates over-simulation while a negative value indicates under-simulation of the RCM ensemble.

The RMSE, calculated using Equation (3), is a measure of the absolute error of climate model in simulating a particular climate variable [16]. RMSE is a quadratic scoring rule that also measures the average magnitude of the error. It is the square root of the average of the squared differences between simulation and actual observation [28]. RMSE is better interpreted and applied comparative rather than absolute. Therefore, there is no fixed threshold limit for RMSE. However, RMSE value, as low as possible, is always preferred [28]. MAE, Equation (4), is a statistical metric that measures errors between paired dataset expressing the same phenomenon (Table 2).

CORDEX Ensemble Average Precipitation Data Bias Adjustment Techniques

The model precipitation dataset is adjusted by calculating monthly adjustment factors for each selected observation station using the technique proposed by Equations (5) and (6) [29, 31]. For each CORDEX grid box, the daily precipitation dataset is modified by calculating 12 monthly adjustment factors for each month. Equation (7) was used to alter the simulated temperature dataset for the selected observation stations, specifically for the maximum and minimum temperatures [30]. According to Engen-Skaugen [30] and Mehrotra and Sharma [7], this bias-corrected approach can be utilized to rectify the projections of both the historical and future periods in the model ensembles output.

3. Results and Discussion

3.1. Result

3.1.1. CORDEX model ensemble simulation performance evaluation result

The evaluation of the model ensemble's ability to simulate rainfall, maximum temperature, and minimum temperature in the study area was conducted using Equations (2), (3), and (4). The model accurately replicated the rainfall, maximum, and minimum temperature with varying degrees of overestimation and underestimation. The connection between the monthly mean rainfall and temperature from the CORDEX ensemble simulation and the matching observation/point data is statistically significant at a 95% confidence level for the majority of the 18 sites. The strong similarity observed between the CORDEX simulation and the observation data suggests that the CORDEX dataset has the potential to be used for future climate projections in the study area, provided that proper bias correction measures are implemented. Nevertheless, relying solely on the correlation value may not be adequate to elucidate the model's proficiency in accurately replicating observations. Consequently, the model ensemble dataset is also evaluated for bias, RMSE, and MAE. The assessment findings for simulated precipitation and temperature (maximum and minimum) by the model ensemble are presented in Tables 3, 4, and 5, and Figures 2, 3, and 4, respectively. The results are deemed satisfactory, suggesting the possible applicability of the CORDEX ensemble dataset for the study area.

The evaluation of multi-model ensemble data for maximum and minimum temperature reveals minimal bias, low RMSE and MAE values, indicating a higher performance capability for most stations compared to the model-simulated rainfall, as demonstrated in Tables 4 and 5.

The tables presented, specifically Tables 3, 4, and 5, exhibit a significant and strong correlation between the two datasets, namely the CORDEX ensemble and gridded observation rainfall, maximum, and minimum temperature. The association is shown to be significant and robust across most stations. Most stations in the CORDEX ensemble show a slight bias, with some being over-simulated and others being under-simulated to different extents. The RMSE and

Table 2
List of equations used in CORDEX ensemble dataset (rainfall, maximum, and minimum temperature) evaluation and bias correction

Variable explanation	Equation		Reference
Person correlation, $r_{(Mod,Obs)}$	$r_{(Mod,Obs)} = \frac{\sum_{i=1}^{N}(\mathrm{Mod_i}-\mathrm{Mod_{mean}})(\mathrm{Obs_i}-\mathrm{Obs_{mean}})}{\sqrt{\sum_{i=1}^{N}(\mathrm{Obs_i}-\mathrm{Obs_{mean}})^2}\sqrt{\sum_{i=1}^{N}(\mathrm{Mod_i}-\mathrm{Mod_{mean}})^2}}$	(1)	[27]
Bias, model over or underestimation	$\mathrm{Bias} = \frac{1}{N}\sum_{i=1}^{N}(\mathrm{Mod_i} - \mathrm{Obs_i})$	(2)	[27]
RMSE – square root of the average of the squared differences between simulation and actual observation	$RMSE = \sqrt{\frac{1}{N}\left(\sum_{i=1}^{N}(\mathrm{Mod_i} - \mathrm{Obs_i}\right)\text{^}2}$	(3)	[16]
MAE – measure of mean absolute error	$MAE = \frac{1}{N}\sum_{i=1}^{N}\lvert \mathrm{Mod_i} - \mathrm{Obs_i}\rvert$	(4)	[28]
a_j – adjustment factor for month "*j*"	$\mathrm{aj} = \frac{\mathrm{Obs_j}}{\mathrm{Mod_j}}$	(5)	[29]
Y – bias-corrected model ensemble rainfall data	$Y = a_j X$	(6)	[29]
TBC(t) – bias corrected Model temperature data	$\mathrm{TBC(t)} = \overline{O_{REF}} + \frac{\sigma_{O,REF}}{\sigma_{T,REF}}\left(T_{RAW}(t) - \overline{T_{EF}}\right)$	(7)	[30]

Where:

$\mathrm{Mod_i}$ and $\mathrm{Mod_j}$ are model simulated value, $\mathrm{Obs_i}$ and $\mathrm{Obs_j}$ are observed value, and *N* refers to the simulated and observed pairs and is the total number of such pairs for the analysis period, 1987–2005 (i.e., 19 years)

X is the model ensemble simulation precipitation data, *Y* is the adjusted model ensemble data, and "a_j" is the adjustment factor for month "*j*"

TBC(t) is the bias-corrected model ensemble temperature data; T_{Raw} is the model ensemble raw data; T_{REF} is the observation data, $\sigma_{T,\ REF}$ is the standard deviation in the reference period of the daily model ensemble values, and $\sigma_{O,\ REF}$ is the standard deviation of observations values; the bar over the variables denotes the average over the period of 1987–2005.

Table 3
CORDEX model ensemble performance evaluation result, rainfall

Station	$r_{(mod, obs)}$	Bias	RMSE	MAE
Adwa	0.99	−0.22	5.98	1.16
Axum	0.96	−0.55	3.58	0.57
Mykntal	0.99	0.03	4.19	0.71
Korem	0.94	7.23	52.44	7.23
Lalibela	0.99	6.86	50.43	6.86
Maichew	0.94	7.21	54.31	7.22
Edagahamus	0.71	11.80	73.55	11.80
Hawzien	0.82	12.17	73.63	12.17
Hagereselam	0.97	0.02	5.67	0.99
Abiadi	0.98	−0.91	7.32	1.07
Kulmesk	0.96	0.17	5.28	0.86
Dengolat	0.98	−0.24	3.11	0.54
Adigudem	0.98	−0.25	3.65	0.59
Gonder	0.98	4.23	33.19	4.41
Wukro	0.78	6.10	39.07	6.10
Shire	0.98	−0.17	7.37	1.17
Debark	0.90	−3.53	24.17	3.53
Debretabor	0.90	−2.73	16.42	2.73

Table 4
Model ensemble performance evaluation result for maximum temperature

Station	$r_{(mod, obs)}$	Bias	RMSE	MAE
Adwa	0.99	−0.22	5.98	1.16
Axum	0.96	−0.55	3.58	0.57
Mykntal	0.99	0.03	4.19	0.71
Korem	0.94	7.23	52.44	7.23
Lalibela	0.99	6.86	50.43	6.86
Maichew	0.94	7.21	54.31	7.22
Edagahamus	0.71	11.80	73.55	11.80
Hawzien	0.82	12.17	73.63	12.17
Hagereselam	0.97	0.02	5.67	0.99
Abiadi	0.98	−0.91	7.32	1.07
Kulmesk	0.96	0.17	5.28	0.86
Dengolat	0.98	−0.24	3.11	0.54
Adigudem	0.98	−0.25	3.65	0.59
Gonder	0.98	4.23	33.19	4.41
Wukro	0.78	6.10	39.07	6.10
Shire	0.98	−0.17	7.37	1.17
Debark	0.90	−3.53	24.17	3.53
Debretabor	0.90	−2.73	16.42	2.73

MAE values are rather small compared to the monthly mean values of measured rainfall, maximum temperature, and minimum temperature at most sites.

3.1.2. CORDEX-Africa multi-model ensemble simulation data adjustment (bias correction) results

The model evaluation findings indicated varying levels of overestimation and underestimation of the climate data for the research area. This discrepancy arises from the varying levels of bias included in the CORDEX ensemble dataset. The evaluation results were used to bias correct the ensemble data for rainfall and maximum and lowest temperature. This was done by applying

Table 5
CORDEX model ensemble performance evaluation result, minimum temperature

Station	$r_{(mod, obs)}$	Bias	RMSE	MAE
Adwa	0.948	0.028	1.072	0.045
Axum	0.918	0.075	1.591	0.075
Mykntal	0.937	0.060	1.292	0.060
Korem	0.852	−0.003	1.117	0.046
Lalibela	0.271	−0.083	2.459	0.118
Maichew	0.959	0.070	1.515	0.070
Edagahamus	0.879	−0.045	1.592	0.071
Hawzien	0.802	−0.0003	1.619	0.073
Hagereselam	0.857	0.043	1.315	0.057
Abiadi	0.618	−0.047	1.801	0.090
Kulmesk	0.497	−0.206	4.308	0.206
Dengolat	0.697	−0.018	1.476	0.064
Adigudem	0.657	−0.038	1.676	0.078
Gonder	0.886	0.143	2.818	0.143
Wukro	0.771	−0.014	1.892	0.084
Shire	0.773	0.054	1.587	0.071
Debark	0.800	0.281	5.432	0.281
Debretabor	0.937	0.130	2.540	0.130

Equations (5), (6), and (7), respectively. The monthly bias adjustment factors, a_j, in the model ensemble simulated daily rainfall data bias correction, are determined using Equation (5). The monthly bias adjustment factors (a_j) for precipitation are calculated for each CORDEX grid box and matched with the 18 observation stations, as shown in Table 6.

3.2. Discussion

An assessment was conducted on the accuracy of the raw CORDEX ensemble climate dataset, specifically regarding rainfall and temperature, during the time frame of 1987–2005. This evaluation utilized high-resolution, continuous gridded data with a resolution of 4 × 4 km, which integrated satellite and station data. The assessment focused on the 18 observation stations located in the UTRB region. The analysis revealed a strong association at a 95% confidence level for both rainfall and temperature across the majority of the 18 stations. This is supported by the findings in Tables 3, 4, and 5. The model's performance exhibited variability among different stations within the study basin. The model demonstrates good performance, with minimal bias, in the majority of the selected observation stations (Debretabore, Dengolat, Hagereselam, Mykntal, Maichew, Adwa, Axum, Korem, and Gonder). The unprocessed CORDEX RCMs ensemble accurately replicated the observed rainfall seasonality pattern, albeit with varying levels of over and underestimation. The model exhibits excellent performance in accurately representing the actual rainfall data, especially for certain observation stations. This is especially accurate in replicating the observation for the primary rainy season (June, July, August, and September) (Figure 5). The performance results for both rainfall and temperature over all 18 observation stations are provided in the attached extra file.

In regard to reproducing the observation temperatures, the model performs well in several observation stations (Axum, Adwa, Mykntal, Hagereselam, Abiadi, Kulmesk, Dengolat, and Adigudem). However, the performance is poor in other stations, with significant under and overestimation (Debark, Kulmesk Lalibela, Hawzien, Wukro, Abiadi, Shire) (Figure 6).

Figure 2
UTRB model raw/biased and observation rainfall

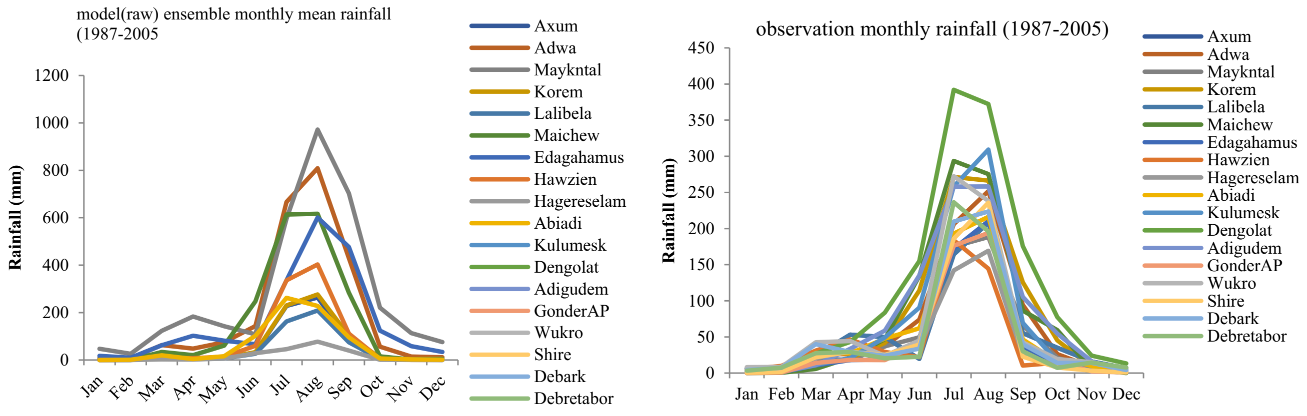


Figure 3
UTRB model raw/biased and observation, maximum temperature

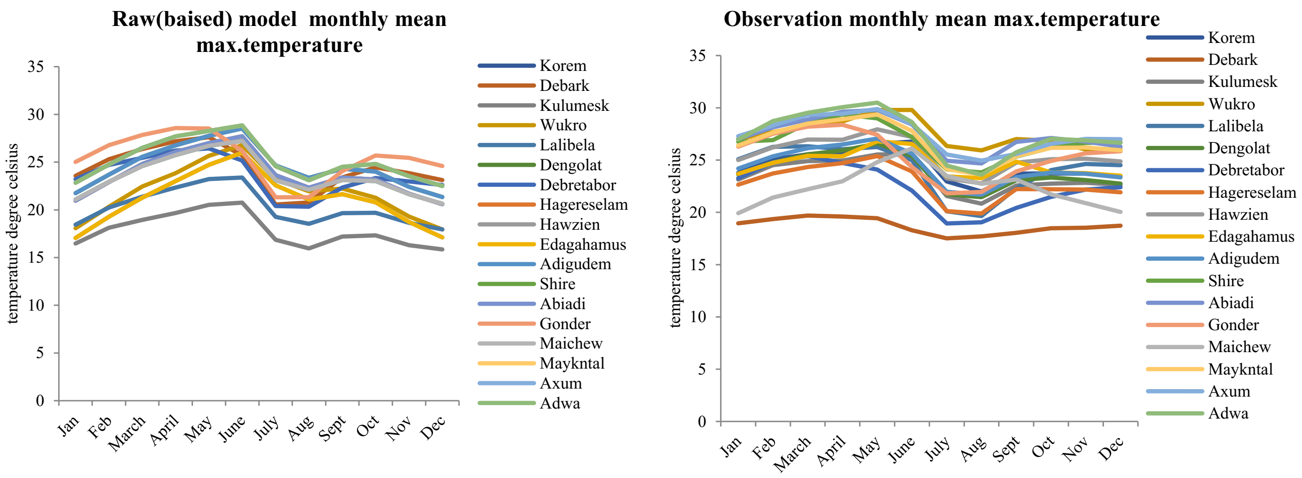


Figure 4
UTRB model ensemble raw/biased and observation data, minimum temperature

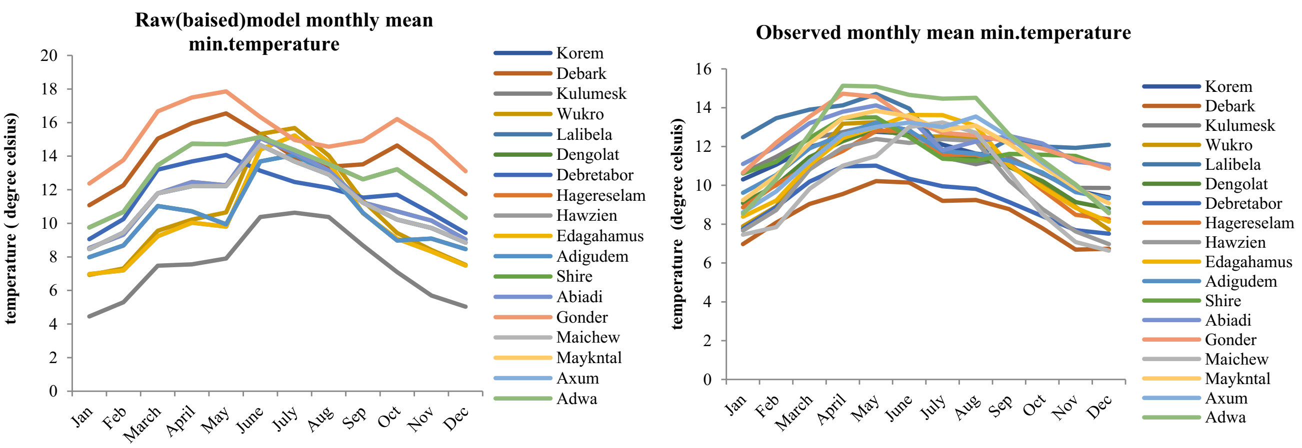


Table 6
Model ensemble simulated rainfall daily data monthly bias adjustment factors (a_j)

		Model ensemble simulated rainfall data monthly bias adjustment factors (a_j)											
Station	GridBoxNo	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Adwa	114226	17.32	7.75	3.86	4.33	3.76	2.01	1.02	1.02	1.10	2.31	1.59	3.83
Axum	114226	12.31	3.51	2.93	4.79	4.04	1.94	1.02	0.91	0.69	2.72	2.21	1.82
Mykntal	114226	11.40	33.53	3.17	2.90	4.28	1.45	0.87	0.83	0.82	1.85	1.07	6.93
Korem	115222	0.57	0.87	0.57	0.49	0.34	0.20	0.33	0.29	0.10	0.17	0.66	0.52
Lalibela	115222	0.86	0.81	0.55	0.74	0.39	0.27	0.40	0.31	0.11	0.22	0.66	0.53
Maichew	116223	0.34	0.32	0.32	0.4	0.52	0.17	0.39	0.27	0.11	0.25	0.29	0.39
Edagahamus	116226	0.07	0.44	0.32	0.43	0.37	0.26	0.31	0.18	0.02	0.05	0.08	0.08
Hawzien	116226	0.00	0.07	0.12	0.15	0.20	0.27	0.26	0.18	0.03	0.04	0.05	0.03
Hagereselam	115225	0.61	2.10	2.43	4.73	5.74	1.64	0.92	0.88	0.52	1.06	1.50	0.24
Abiadi	115225	0.16	1.22	1.11	3.95	5.94	2.36	1.23	1.27	0.81	1.24	0.58	0.19
Kulmesk	112221	14.37	3.05	1.29	5.40	5.47	1.50	1.49	1.74	1.72	6.01	8.39	14.86
Dengolat	115224	0.00	3.94	1.96	3.91	3.21	1.52	1.20	1.07	0.56	1.58	0.79	0.23
Adigudem	115224	0.73	4.79	1.46	3.92	3.10	1.56	1.20	1.15	0.48	1.36	0.95	0.69
Gonder	111223	0.00	2.70	0.17	0.72	0.93	0.51	0.48	0.45	0.30	1.87	1.16	0.07
Wukro	116225	0.02	0.13	0.27	0.26	0.31	0.47	0.59	0.37	0.04	0.05	0.04	0.03
Shire	113226	4.14	27.59	1.36	2.72	3.61	1.74	0.90	0.75	1.07	5.45	2.99	9.54
Debark	112224	5.66	1.70	0.38	1.64	1.88	0.55	0.40	0.38	0.41	2.61	2.66	1.05
Debretabor	115221	0.31	0.36	0.24	0.25	0.18	0.08	0.22	0.19	0.06	0.06	0.28	0.30

The findings of this investigation are consistent with previous research conducted by The Intergovernmental Panel on Climate Change [15], which assessed the accuracy of the CORDEX RCMs in replicating rainfall patterns in East Africa from 1990 to 2008. Additionally, the study conducted by Shongwe et al. [20] evaluated the performance of the CORDEX RCM in simulating precipitation in southern Africa. The results of these investigations indicate that the RCMs exhibited more accuracy in forecasting rainfall in one region during the research period compared to another location. This investigation reveals a consistent pattern of model performance, where the simulation of the model is superior for certain stations compared to others within the same study basin (Figures 6, 7, and 8). Based on this investigation, the discrepancy in model predictions for temperature data is quite minor compared to the precipitation dataset, indicating that the models perform better in simulating temperature.

The variability of rainfall in the study region is primarily linked to the seasonal movement of the inter-tropical convergence zone and the intricate terrain [32]. The UTRB's topography, which is very varied and unpredictable, plays a crucial role in influencing the rainfall patterns within the study basin. Hence, the variation in model performance across different stations and locales within the study basin can be attributed to the influence of topographic heterogeneity on the model's skill. In RCMs, Charles et al. [11] found that the topography is smoothed, the location's elevation is inaccurately depicted, and there is an overestimation of days with precipitation. Hence, the spatial resolution of the CORDEX model, which is around 50 × 50 km, would be inadequate for accurately representing local conditions in areas with diverse and irregular topographies, like the study area. This may be associated with the limitations of the CORDEX models in accurately replicating orographic rainfall in diverse terrains (Figure 9).

The evaluation of the model ensemble showed strong performance in accurately representing the seasonal patterns of the observed rainfall data, especially during the primary rainy period (JJAS) in the research region. Similarly, the assessment of the model ensemble's performance reveals its effectiveness in reproducing the temperature of the study basin, but with varying

Figure 5
Model performance in simulating rainfall

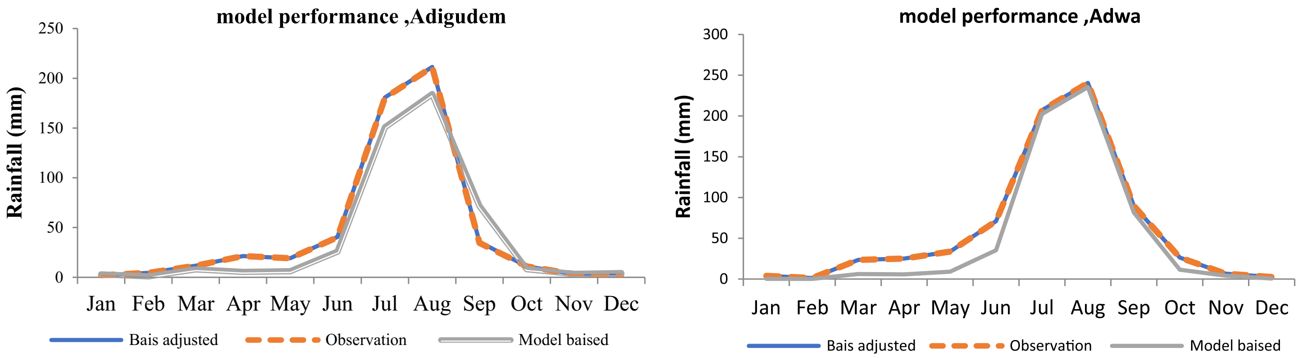


Figure 6
Model good and bad performance in simulating maximum temperature

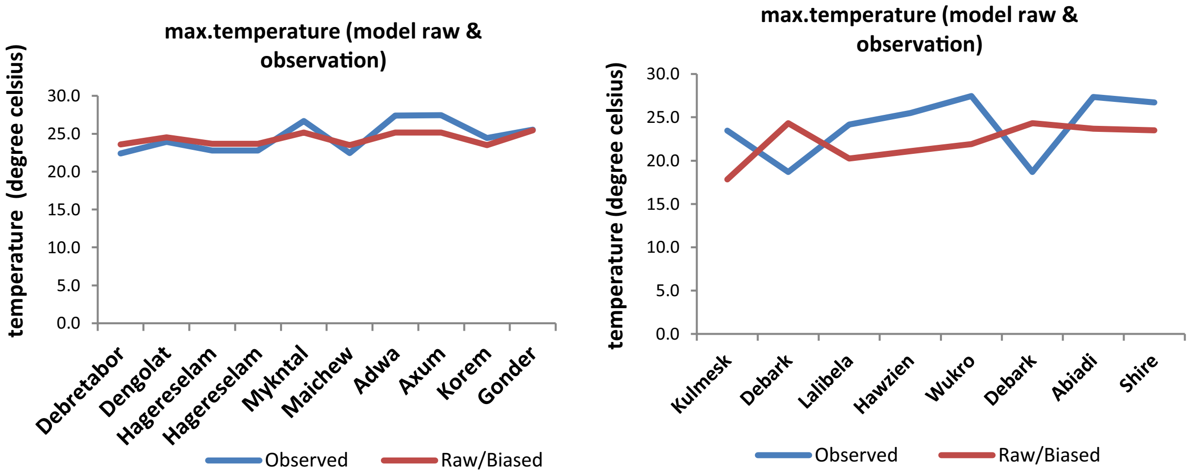
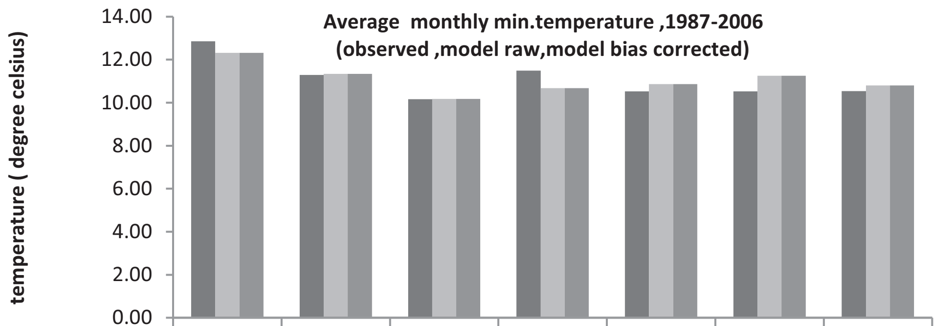
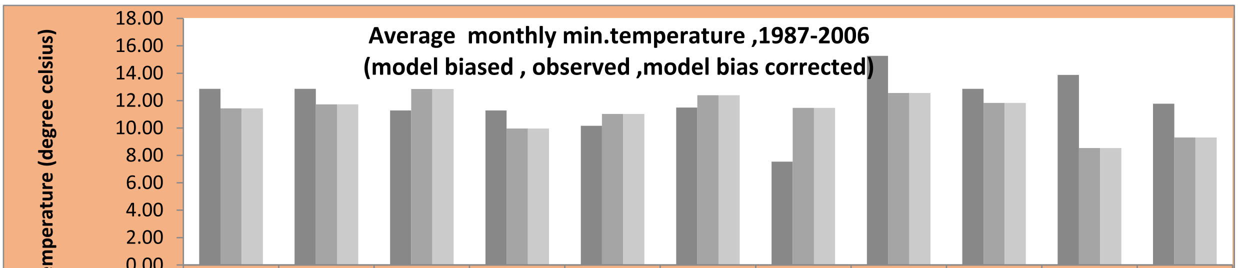


Figure 7
Model performance in simulating minimum temperature (good performance)



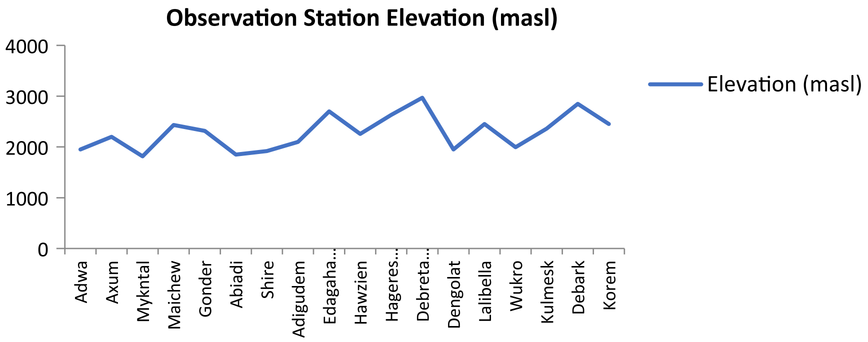
	Adwa	Korem	Hawzien	Hageresel am	Dengolat	Adigudem	Wukro
Biased	12.86	11.29	10.17	11.49	10.53	10.53	10.54
Observed	12.32	11.34	10.17	10.67	10.86	11.25	10.80
Corrected	12.32	11.34	10.17	10.67	10.86	11.25	10.80

Figure 8
Model performance in simulating minimum temperature (poor performance)



	Axum	Mykntal	Lalibela	Maichew	Edagaha mus	Abiadi	Kulmesk	Gonder	Shire	Debark	Debretab or
Biased	12.86	12.86	11.29	11.29	10.17	11.49	7.55	15.27	12.86	13.88	11.77
Observed	11.44	11.73	12.85	9.96	11.03	12.39	11.47	12.56	11.83	8.54	9.31
Corrected	11.44	11.73	12.85	9.96	11.03	12.39	11.47	12.56	11.83	8.54	9.31

Figure 9
Observation stations' elevation (masl)



levels of overestimation and underestimation. Consequently, in order for the model ensembles dataset to be effectively utilized in various impact assessment studies, it is necessary to perform bias correction or calibration against the observation data.

The discrepancy between the observed and simulated precipitation and temperature datasets for the period from 1987 to 2005 in the study basin is rectified by the implementation of bias correction. The bias-corrected and modified historic CORDEX ensembles accurately aligned with the gridded observation dataset for the same period across all selected stations, in terms of mean monthly precipitation and temperature. The average monthly rainfall, highest and lowest temperature values obtained from the daily data of the three datasets (raw model ensemble simulation, bias adjusted model ensemble simulation, and gridded observation), is graphed for all 18 selected stations (supplementary materials).

The application of climate projections is widely recognized as crucial for effective preparedness and adaptation to climate change in the future. The results of this study show important progress in illustrating the possible use of bias-corrected CORDEX-Africa climate data in Ethiopia and the surrounding region. The application of the bias-corrected CORDEX climate data has the potential to be used in several environmental contexts, as well as in evaluating the effects of climate change and devising adaptation methods. Establishing confidence in the reliability of the CORDEX-Africa model to accurately reproduce future climate projection scenarios has the potential to improve climate change adaptation and planning activities in Ethiopia and the surrounding region.

4. Conclusion

This work aims to assess and modify the historical precipitation and temperature CORDEX ensemble dataset in order to build a reliable basis for utilizing the CORDEX future projections across the UTRB. The assessment was conducted for a total of 18 observation stations located within 11 CORDEX grid boxes (18 observation stations). The CORDEX RCMs multi-model ensemble simulation successfully captured and replicated the characteristics and distribution of high-resolution observed gridded monthly mean rainfall and temperature (maximum and minimum) at all selected stations after bias adjustment. The approaches used to evaluate and adjust the performance of the model ensemble dataset for the UTRB CORDEX climate data can be practically utilized to provide credible climate data in other similar scenarios. The methodologies employed in this article serve to augment and refine the comprehension of the historical, current, and future climate and climate change within a specific study region. The data that have been corrected for bias can be utilized for various investigations and analyses related to the impacts of climate change. The work could also offer a practical example of utilizing globally accessible climate datasets, such as the CORDEX climate dataset, especially in areas where there is a lack of trustworthy long-term observed data for the study area. We intend to evaluate the effects of climate change on the UTRB after confirming the dependability of the CORDEX ensemble climate.

Under future research, the findings of this study could be included into different investigations, such as the use of crop models, to evaluate the effect of climate change on Ethiopia's rain-fed crop output under current and future climatic circumstances. This holds important significance as the agricultural sector, albeit facing challenges arising from climate change and variability, supports around 80% of the workforce and makes a substantial contribution to the nation's gross production.

Acknowledgement

The authors greatly appreciate the National Meteorology Agency of Ethiopia for providing the gridded data for the 18 observation stations in the UTRB.

Funding

This study was partially funded by Addis Ababa University for data collection only.

Ethical Statement

This study does not contain any studies with human or animal subjects performed by any of the authors.

Conflicts of Interest

The authors declare that they have no conflicts of interest to this work.

Data Availability Statement

The data used to have the findings of this study are submitted as an additional file.

Author Contribution Statement

Ghrmawit Haile Gebrehiwot: Conceptualization, Methodology, Formal analysis, Investigation, Data Curation, Writing - Original Draft, Writing - Review & Editing, Visualization, Project administration. **Kassahun Ture Bekitie**: Supervision, Funding acquisition. **Fikru Abiko**: Validation, Formal analysis, Writing - Review & Editing.

Weldemariam Seifu: Writing - Review & Editing. **Haftu Brhane Gebremichael**: Writing - Review & Editing.

References

[1] Endris, H. S., Lennard, C., Hewitson, B., Dosio, A., Nikulin, G., & Panitz, H. J. (2016). Teleconnection responses in multi-GCM driven CORDEX RCMs over Eastern Africa. *Climate Dynamics*, *46*, 2821–2846. https://doi.org/10.1007/s00382-015-2734-7

[2] Luhunga, P., Botai, J., & Kahimba, F. (2016). Evaluation of the performance of CORDEX regional climate models in simulating present climate conditions of Tanzania. *Journal of Southern Hemisphere Earth Systems Science*, *66*(1), 32–54. https://doi.org/10.22499/3.6601.005

[3] Mutayoba, E., & Kashaigili, J. J. (2017). Evaluation for the performance of the CORDEX regional climate models in simulating rainfall characteristics over Mbarali River catchment in the Rufiji Basin, Tanzania. *Journal of Geoscience and Environment Protection*, *5*, 139–151. https://doi.org/10.4236/gep.2017.54011

[4] Teutschbein, C., & Seibert, J. (2013). Is bias correction of regional climate model (RCM) simulations possible for non-stationary conditions? *Hydrology and Earth System Sciences*, *17*(12), 5061–5077. https://doi.org/10.5194/hess-17-5061-2013

[5] Van de Velde, J., de Baets, B., Demuzere, M., & Verhoest, N. E. (2020). Comparison of occurrence-bias-adjusting methods for hydrological impact modelling. *Hydrology and Earth System Sciences Discussions, 2020*, 1–35. https://doi.org/10.5194/hess-2020-83

[6] Worku, G., Teferi, E., Bantider, A., Dile, Y. T., & Taye, M. T. (2018). Evaluation of regional climate models performance in simulating rainfall climatology of Jemma sub-basin, Upper Blue Nile Basin, Ethiopia. *Dynamics of Atmospheres and Oceans*, *83*, 53–63. https://doi.org/10.1016/j.dynatmoce.2018.06.002

[7] Mehrotra, R., & Sharma, A. (2015). Correcting for systematic biases in multiple raw GCM variables across a range of timescales. *Journal of Hydrology*, *520*, 214–223. https://doi.org/10.1016/j.jhydrol.2014.11.037

[8] Tesfaye, S., Taye, G., Birhane, E., & van der Zee, S. E. (2019). Observed and model simulated twenty-first century hydro-climatic change of Northern Ethiopia. *Journal of Hydrology: Regional Studies*, *22*, 100595. https://doi.org/10.1016/j.ejrh.2019.100595

[9] Trzaska, S., & Schnarr, E. (2014). *A review of downscaling methods for climate change projections*. Retrieved from: http://www.ciesin.org/documents/Downscaling_CLEARED_000.pdf

[10] Fang, G. H., Yang, J., Chen, Y. N., & Zammit, C. (2015). Comparing bias correction methods in downscaling meteorological variables for a hydrologic impact study in an arid area in China. *Hydrology and Earth System Sciences*, *19*(6), 2547–2559. https://doi.org/10.5194/hess-19-2547-2015

[11] Charles, S. P., Bari, M. A., Kitsios, A., & Bates, B. C. (2007). Effect of GCM bias on downscaled precipitation and runoff projections for the Serpentine catchment, Western Australia. *International Journal of Climatology*, *27*(12), 1673–1690. https://doi.org/10.1002/joc.1508

[12] Gudmundsson, L., Bremnes, J. B., Haugen, J. E., & Engen-Skaugen, T. (2012). Technical note: Downscaling RCM precipitation to the station scale using statistical transformations–A comparison of methods. *Hydrology and Earth System Sciences*, *16*(9), 3383–3390. https://doi.org/10.5194/hess-16-3383-2012

[13] Wood, A. W., Leung, L. R., Sridhar, V., & Lettenmaier, D. P. (2004). Hydrologic implications of dynamical and statistical approaches to downscaling climate model outputs. *Climatic Change*, *62*(1), 189–216. https://doi.org/10.1023/B:CLIM.0000013685.99609.9e

[14] Mavume, A. F., Banze, B. E., Macie, O. A., & Queface, A. J. (2021). Analysis of climate change projections for Mozambique under the representative concentration pathways. *Atmosphere*, *12*(5), 588. https://doi.org/10.3390/atmos12050588

[15] The Intergovernmental Panel on Climate Change. (2013). *Evaluation of climate models -9*. Retrieved from: https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter09_FINAL.pdf

[16] Chai, T., & Draxler, R. R. (2014). Root mean square error (RMSE) or mean absolute error (MAE)?–Arguments against avoiding RMSE in the literature. *Geoscientific Model Development*, *7*(3), 1247–1250. https://doi.org/10.5194/gmd-7-1247-2014

[17] Dinku, T., Asefa, K., Hilemariam, K., Grimes, D., & Connor, S. (2011). Improving availability, access and use of climate information. *WMO Bulletin*, *60*(2), 80–86.

[18] Demissie, T. A., & Sime, C. H. (2021). Assessment of the performance of CORDEX regional climate models in simulating rainfall and air temperature over southwest Ethiopia. *Heliyon*, *7*(8), E07791. https://doi.org/10.1016/j.heliyon.2021.e07791

[19] Sultan, B. (2015). Peer review report 1 On "Calibration and bias correction of climate projections for crop modelling: An idealised case study over Europe". *Agricultural and Forest Meteorology*, *201*, 469. https://doi.org/10.1016/j.agrformet.2015.07.056

[20] Shongwe, M. E., Lennard, C., Liebmann, B., Kalognomou, E. A., Ntsangwane, L., & Pinto, I. (2015). An evaluation of CORDEX regional climate models in simulating precipitation over Southern Africa. *Atmospheric Science Letters*, *16*(3), 199–207. https://doi.org/10.1002/asl2.538

[21] Gebremicael, T. G., Mohamed, Y. A., Zaag, P. V., & Hagos, E. Y. (2017). Temporal and spatial changes of rainfall and streamflow in the Upper Tekezē–Atbara river basin, Ethiopia. *Hydrology and Earth System Sciences*, *21*(4), 2127–2142. https://doi.org/10.5194/hess-21-2127-2017

[22] Gebremicael, T. G., Mohamed, Y. A., van der Zaag, P., & Hagos, E. Y. (2018). Quantifying longitudinal land use change from land degradation to rehabilitation in the headwaters of Tekeze-Atbara Basin, Ethiopia. *Science of the Total Environment*, *622–623*, 1581–1589. https://doi.org/10.1016/j.scitotenv.2017.10.034

[23] Tefera, W. D. (2003). *Integrating geo-information for the management of River Basins in the Ethiopian part of the Nile Basin*. Retrieved from: https://webapps.itc.utwente.nl/librarywww/papers_2003/msc/nrm/tefera.pdf

[24] Dinku, T., Funk, C., Peterson, P., Maidment, R., Tadesse, T., Gadain, H., & Ceccato, P. (2018). Validation of the CHIRPS satellite rainfall estimates over eastern Africa. *Quarterly Journal of the Royal Meteorological Society*, *144*, 292–312. https://doi.org/10.1002/qj.3244

[25] Nikulin, G., Jones, C., Giorgi, F., Asrar, G., Büchner, M., Cerezo-Mota, R., . . . , & Sushama, L. (2012). Precipitation climatology in an ensemble of CORDEX-Africa regional climate simulations. *Journal of Climate*, *25*(18), 6057–6078. https://doi.org/10.1175/JCLI-D-11-00375.1

[26] World Meteorological Organization. (2000). *Guidelines on performance assessment of public weather services*. Retrieved from: https://library.wmo.int/idurl/4/44889

[27] Worku, G., Teferi, E., Bantider, A., & Dile, Y. T. (2020). Statistical bias correction of regional climate model simulations for climate change projection in the Jemma sub-basin, upper Blue Nile Basin of Ethiopia. *Theoretical and Applied Climatology*, *139*(3), 1569–1588. https://doi.org/10.1007/s00704-019-03053-x

[28] Cheng, K. S., Lien, Y. T., Wu, Y. C., & Su, Y. F. (2017). On the criteria of model performance evaluation for real-time flood forecasting. *Stochastic Environmental Research and Risk Assessment*, *31*(5), 1123–1146. https://doi.org/10.1007/s00477-016-1322-7

[29] Zhai, R., Zhang, C., Li, W., Zhang, X., & Li, X. (2020). Evaluation of driving forces of land use and land cover change in New England area by a mixed method. *ISPRS International Journal of Geo-Information*, *9*(6), 350. https://doi.org/10.3390/ijgi9060350

[30] Engen-Skaugen, T. (2007). Refinement of dynamically downscaled precipitation and temperature scenarios. *Climatic Change*, *84*(3), 365–382. https://doi.org/10.1007/s10584-007-9251-6

[31] Ahrens, B., & Dobler, A. (2015). Regional climate projections. In N. Sharma & W. A. Flügel (Eds.), *Applied geoinformatics for sustainable integrated land and water resources management (ILWRM) in the Brahmaputra River basin* (pp. 11–15). India: Springer India. https://doi.org/10.1007/978-81-322-1967-5_4

[32] Hafez, Y. (2012). Variability of intertropical convergence zone (ITCZ) and extreme weather events. In I. Yucel (Ed.), *Atmospheric model applications*. UK: IntechOpen. https://doi.org/10.5772/33809

How to Cite: Gebrehiwot, G. H., Bekitie, K. T., Abiko, F., Seifu, W., & Gebremichael, H. B. (2024). Evaluation of CORDEX-Africa Model Data Reliability and Bias Correction for Climate Change Impact Assessment: Upper Tekeze River Basin, Tigray (Ethiopia). *Green and Low-Carbon Economy*. https://doi.org/10.47852/bonviewGLCE42021893