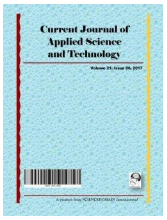

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A Review of the CMIP5 21st Century Climate Change Projection in the Niger Basin

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Author's contribution

The manuscript was written by the sole author. The study was designed, analyzed and interpreted by the author and duly acknowledged partners.

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ABSTRACT

Climate simulations in West Africa have been a challenge for climate models due to the complexity and the diversity of processes to be represented. No coherent trend for either decreasing or increasing precipitation emerges from the Coupled Model Intercomparison Project Phase 3 (CMIP3) Global Climate Model (GCM) products. The Coordinated Regional Downscaling Experiment (CORDEX) is a program sponsored by World Climate Research Program (WCRP) to develop an improved framework for generating regional-scale climate projections for impact assessments using recent CMIP5 GCM projections. This paper compares patterns of climate projections in the Niger basin with the most recent and improved CORDEX-CMIP5 climate projections. It presents a comparative evaluation of projected rainfall, temperature, and potential evapotranspiration (PET) trends in the Niger basin using 8 GCMs and two emission scenarios (RCP 4.5 and RCP 8.5) available within the CORDEX-Africa framework. Rainfall and temperature data from a set of 8 CMIP5 GCMs under the mild (RCP 4.5) and high (RCP 8.5) emission scenarios were analyzed. The GCMs were dynamically downscaled to about 50 km resolution with the RCM SMHI-RCA (Sveriges Meteorologiskaoch Hydrologiska Institute) within the CORDEX-Africa regional downscaling experiments. Potential evapotranspiration (PET) was computed from temperature based on the Hamon model. Spatio-temporal patterns of ensemble median of changes of the eight GCMs relative to the present-day reference period of 1970–1999 were evaluated in two future 30 years periods:

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the near term (2030–2059) and far-term (2070-2099). Results show that climate change will drive an increase in precipitation, temperature, and PET in the Niger basin. This analysis will enhance the deployment of suitable coping strategies to impending climate trends; especially for food and energy production schemes which are prerequisites to sustainable regional developments.

Keywords: Climate change; Niger basin; CMIP5; CORDEX; Africa.

1. INTRODUCTION

Climate change impacts are expected to exacerbate poverty in most developing countries, thereby creating new poverty pockets in countries with increasing inequality [1]. The West Africa hydrological system is changing due to change in climate, and becoming more evident with the recent droughts and floods which significantly impacted on the hydrological balance of the region [1–5]. The reported increases in the water column stratification in the regional lakes [1], resulted in the reduction of the area of Lake Chad prominently since 1970 [6]. Climate change have led to reduced discharge in West African rivers and increased soil moisture drought in the Sahel since 1970; nevertheless, a partial wet condition was experienced from 1990 [7,8].

The Niger River is home to over 100 million people and a vital asset for West Africa; a developing region unfortunately exposed to climate change and its attendant problems. According to Novonty and Stefan [9], the past 50 years witness a reduction in rainfall amount of 10 to 30% in the basin, which led to a deficit of 20 to 60% in the river discharge. A severe decrease in the river flow which was blamed on the 1970's droughts cases in the Niger basin have been reported by Lebel et al. [10].

As a consequent, the river dried up for several weeks in 1985 at the Malanville (Benin) gauging station, resulting from a one-year lag of lowest rainfall and runoff in 1984 [11]. An analysis of selected locations in the upper and middle Niger basin showed that projections by Global Climate Models (GCMs) and 20 AR4-models were not consistent regarding rainfall and runoff changes, making management of hydrological projects in the Niger basin difficult [12].

Several studies which include Sylla et al. [13], Mariotti et al. [14], Diallo et al. [15]; Oguntunde and Abiodun [16]; Laprise et al. [17]; Ibrahim et al. [18] and Panitz et al. [19] evaluated future patterns of climate change in the region. However, most of these studies used a single RCM and GCM projection. Multi-model ensembles of models, both of GCMs and RCMs, have been suggested to be a better predictor than individual climate models [20]. In line with the study of Diallo et al. [15], the present study ensembled the future climate prediction from eight (8) dynamically downscaled GCMs in order to obtain a better understanding of future climate trends in the Niger basin, and as a management support for polymakers in the mitigation and adaptation planning of climate change in the Niger basin region.

2. METHODOLOGY

2.1 Study Area

The Niger River Basin covers 2.27 million km^2 [21], at 4200 km in length, the basin is the third longest in Africa (Fig. 1). It is shared by ten countries (Algeria, Benin, Burkina Faso, Cameroon, Chad, Cote d'Ivoire, Guinea, Mali, Niger and Nigeria) with its source located close to the Fouta Djallon Mountains in the south of Guinea at an altitude about 800 m [16]. The Niger crosses areas with different climatic characteristics. A large part of the river basin is located in the Sahel, a semiarid area between the Sahara Desert and the Sudan savannas. Precipitation ranges from 250 to 750 mm/year in the Sahelian/desert zone to over 2,000 mm/year close to the river mouth in Nigeria with length of rainy season varying from 3 to 7 months [12]. The river flows northeast through the Upper Niger basin and enters the Inner Delta in Mali. It then flows southeastern through Niger, Benin, and Nigeria, where it connects the Atlantic Ocean at the Gulf of Guinea. Its main tributary, the Benue River, flows from highlands of Cameroon and joins the Niger at Lokoja, Nigeria, before reaching the Atlantic Ocean.

2.2 Data

Rainfall data from a set of 8 CMIP5 GCMs (Table 1) with two emission scenarios was used. The GCMs were dynamically downscaled to 0.44° x 0.44° (approximately 50km) resolution with the RCM SMHI-RCA (Sveriges Meteorologiskaoch Hydrologiska Institute) within the CORDEX-Africa regional downscaling experiments. The Coordinated Regional Downscaling Experiment (CORDEX) is a program sponsored by World Climate Research Program (WCRP) to develop an improved framework for generating regional-scale climate projections for impact assessment and adaptation studies worldwide within the IPCC AR5 timeline and beyond. Climate projection framework within CORDEX is based on the set of new global model simulations planned in support of the IPCC Fifth Assessment Report (referred to as CMIP5). This set of simulations includes a large number of experiments, ranging from new greenhouse-gas scenario simulations for the 21st century, decadal prediction experiments including the carbon cycle and experiments aimed at investigating individual feedback mechanisms [22]. These simulations are based on the reference concentration pathways (RCPs), that is, those prescribed greenhouse gas concentrations corresponding to different radiative forcing stabilization levels by the year 2100. Within CMIP5, the highest-priority global model simulations have been selected to be the RCP4.5 and RCP8.5, roughly corresponding to the IPCC SRES emission scenarios B1 and A1B, respectively [23]. The same scenarios are therefore also the highest priority CORDEX simulations [23]. Catchment boundary of the Niger basin was obtained from Hydrosheds [24].

Rainfall and temperature distribution in West Africa have been attributed with the back and forth movement of the Inter Tropical Convergence Zone (ITCZ) [25]. The movement of the ITCZ follows the position of maximum surface heating associated with meridional displacement of the overhead position of the sun, lower latitudes experience higher rainfall and lower temperature, whereas higher latitudes experience lower rainfall and higher temperatures. This has created a large rainfall gradient across latitudes which was to be considered in the study. The approach of James & Washington [26] for GCM/RCM regional data extraction was used to account for the latitudinal gradient. Basin rainfall and temperature series were calculated as the weighted average of all grid boxes by latitudes [27,28]. For extraction of rainfall, higher latitudes were given lower weights than the lower latitudes while the reverse was applied for temperature. Catchment potential evapotranspiration (PET) was computed from extracted temperature with the Hamon model [29,30]. This PET model was selected based on a recent finding that very simple evapotranspiration models relying on mean daily temperature are [29].

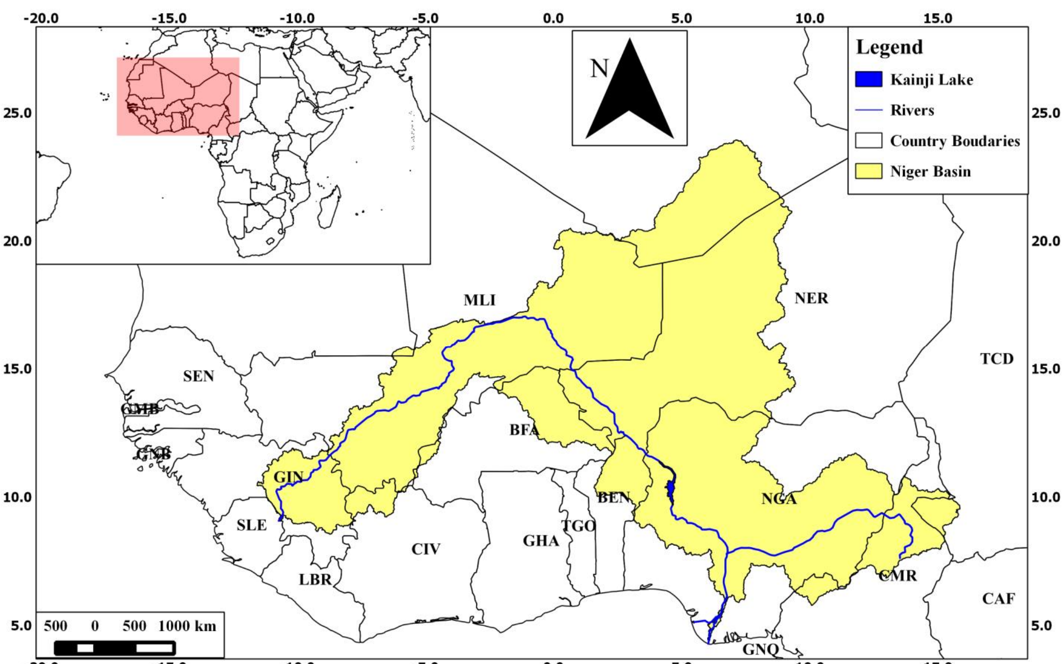

Fig. 1. The Niger Basin

Evaluation of CORDEX Africa climate models was done by Kim et al. [31] who reported that CORDEX Africa RCMs reasonably simulated basic climatological features of some climate variables. Mounkaila et al. [32] showed that CORDEX RCMs have remarkable skills in predicting the rainfall-onset dates in West Africa. Laprise et al. [17] also disclosed that CORDEX Africa regional model is able to add value compared to the simulations of the driving GCMs. Based on these findings, this study evaluated 21st century projected climate trends in the Niger basin with data obtained from CORDEX Africa RCM SMHI-RCA (Sveriges Meteorologiskaoch Hydrologiska Institute) forced by 8 GCMs under the mild (RCP 4.5) and high (RCP 8.5) emission scenarios.

2.3 Spatio-temporal Climate Trends

Ensembles of models, both of GCMs and RCMs, were reported as better predictor than individual models [20]. Spatial pattern of ensemble median of changes of eight GCMs relative to the present-day reference period of 1970–1999 were evaluated in two future 30 years periods: the near term (2030–2059) and far term (2070-2099). Annual and seasonal climate trends from 2010 to 2100 relative to 1970-1999 were presented in line graphs.

Trends were calculated as:

$$\left(\frac{x_{fut}^{i} - \overline{x_{hist}}}{\overline{x_{hist}}}\right) X\ 100$$

x_{fut}^{i} is the regional future (2010-2100) climate variable x of year i and $\overline{x_{hist}}$ is the historical (1970-1999) regional average of climate variable x.

3. RESULTS AND DISCUSSION

3.1 Rainfall

Fig. 2 showcase RCP 4.5 ensemble median projections in the Niger basin which revealed above 5% increase at the source and in the Sahelian parts of the basin. The Guinea regions around Nigeria are expected to experience about 5% decrease in rainfall towards the end of the century. Annual temporal trends (Fig. 3) shows that under the RCP 8.5 scenario the entire basin will experience rainfall above 20% increase in the most parts of the basin toward the end of the 21st century. Monthly trends of rainfall presented in Table 1 indicated that there will be increase in rainfall amount in the months of July, August and September, while the remaining months will witness decreases under the two time slices and scenarios. These increases in the July, August and September months is very important in the basin since they are above 60% (based on reported observation from 1997 -2010) of the annual rainfalls within these three months in line with the study of Sylla et al. [33] and Klutse et al. [34]. Sahelian region will experience greater increases in rainfall compared to other ecological zones due to the intensification of the hydrological cycle caused by increasing atmospheric temperatures [35]. The study also revealed that the greater the greenhouse gas emissions, the more the hydrological perturbation as shown in Figs. 2 and 3 for RCP 4.5 and RCP 8.5 emission scenarios.

Improved GCM agreements was shown in the CMIP5 projected rainfall patterns based on lower deviation across models which gives higher confidence (Fig. 3). Previously, there was no consistent trend in projected precipitation trends across the CMIP3 models in West Africa [36]. In agreement with study of Sillmann et al. [37] who reported reduced spread amongst CMIP5 models for several temperature indices compared to CMIP3 models, despite the larger number of models participating in CMIP5. There are management difficulties of the Niger Basin hydrological projects blamed mostly on the large disagreement in rainfall – run off projections [12]. The CMIP5 archive showcased greater potentials of reducing this challenge if adequately assessed. The archive will enhance effective climate change impacts assessments for several sectors such as water resources, agriculture, energy etc, and thereby improving human security.

3.2 Temperature and PET

For temperature (Fig. 4), a consistent but increasing trend with lower standard deviation across the GCMs was projected in the two scenarios. In the RCP 4.5 scenario, temperature will rise from about 0.05% to 0.1% from the beginning to the end of the century, while under RCP 8.5 the Niger basin will experience an increase of about 0.05% to 0.2% towards the end of the century. There will be about 2°C increase in monthly temperature at the near future under the two scenarios presented. While the far future will experience about 2-5°C monthly increase under the two scenarios. For PET (Fig. 4), a consistent increasing trend with high confidence level is also projected in the two scenarios. In the RCP4.5 scenario PET will rise from about 10% to 20% from the beginning to the end of the century while under RCP8.5 the Niger basin will experience about 10% to 40% increase in PET from beginning to the end of the century. Monthly PET will follow similar patterns as the annual trend. Increases in air temperature could further increase the vulnerability of agriculture through a yield resulting from heat stress, although large discrepancies exist in yield predictions as a result of climate change in the region and the sign of change is uncertain [38]. Furthermore, a rise in PET more than precipitation will aggravate the challenges of increased soil moisture drought which is domiciled in the region [1].

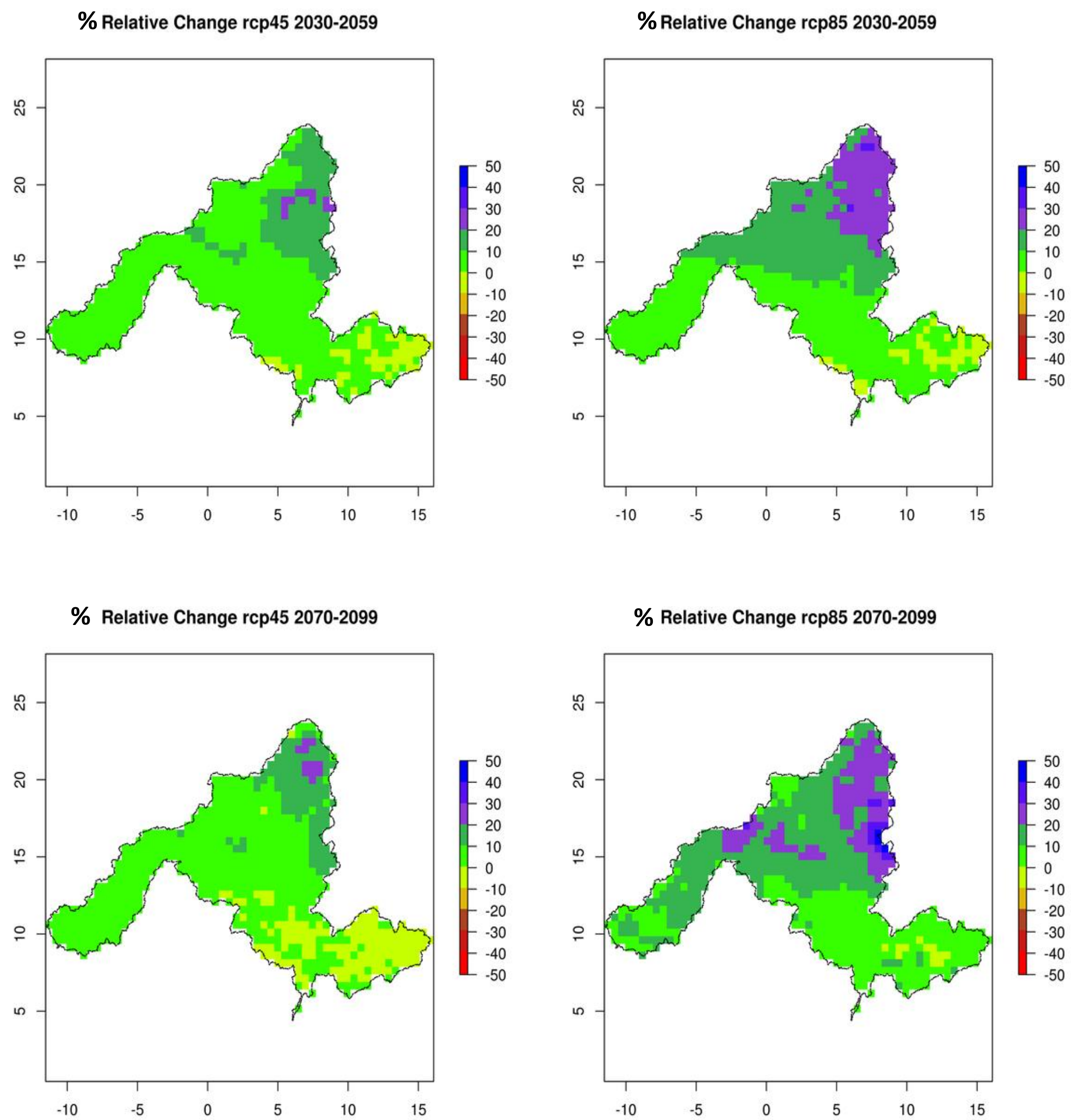

Fig. 2. RCP 4.5 and RCP 8.5 ensemble median precipitation trends at near and far term relative to 1970-1999 in the Niger Basin; using 8 GCM-RCM combinations

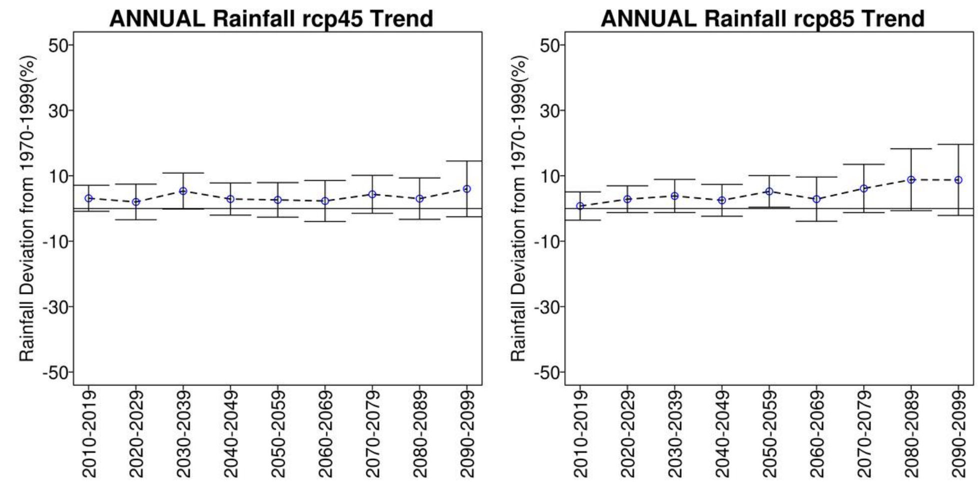

Fig. 3. RCP 4.5 and RCP 8.5 ensemble median 21st century interannual rainfall trends relative to 1970-1999 in the Niger Basin; error bars depicts mean plus and minus standard deviation respectively, calculated from annual values of all 8 models

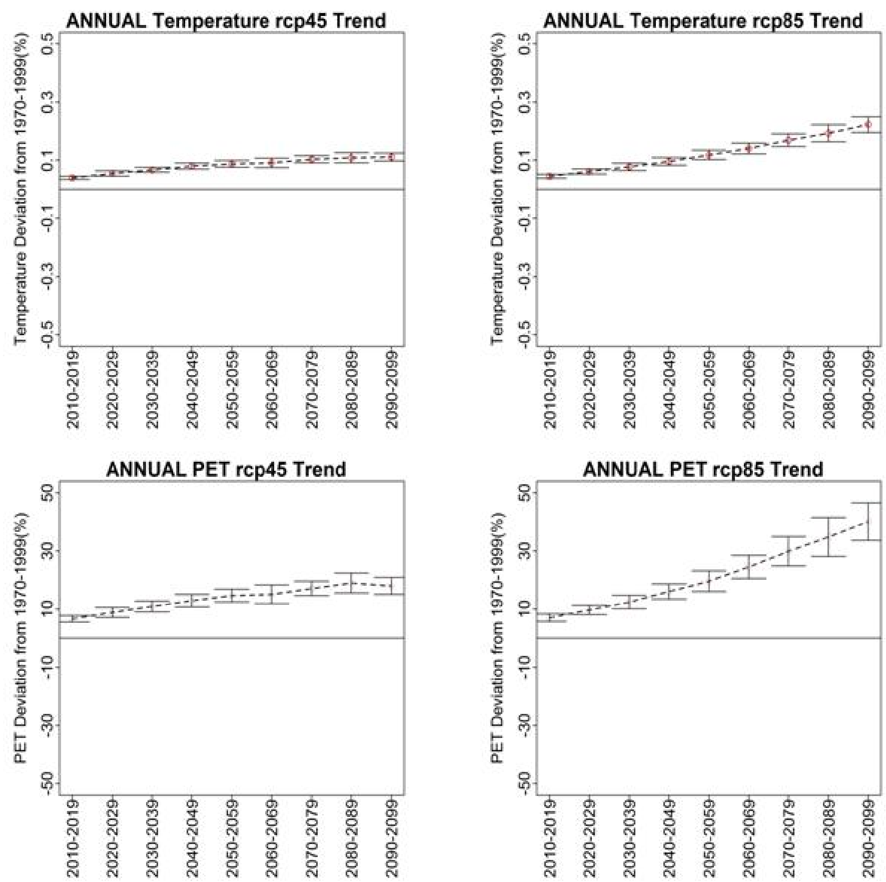

Fig. 4. RCP 4.5 and RCP 8.5 ensemble median 21st century interannual temperature and PET trends relative to 1970-1999 in the Niger Basin; error bars depict mean plus and minus standard deviation respectively, calculated from annual values of all 8 models

Table 1. Monthly trends of climate projections at the Near Future (NF) and Far Future (FF) relative to 1970-1999

Months	RCP4.5						RCP8.5					
	RAIN (%)		TEMP (°C)		PET (%)		RAIN (%)		TEMP (°C)		PET (%)	
	NF	FF	NF	FF	NF	FF	NF	FF	NF	FF	NF	FF
Jan	-25.60	-28.30	1.77	2.43	11.46	16.17	-34.91	-50.78	2.15	4.37	14.26	31.33
Feb	-7.95	-10.12	1.69	2.30	10.93	15.21	-21.26	-20.23	2.13	4.37	13.95	31.26
Mar	-7.21	-9.19	1.84	2.60	12.02	17.60	-12.60	-12.60	2.37	4.73	16.03	34.45
Apr	-3.83	-4.95	2.02	2.64	13.43	17.90	-3.87	-6.51	2.39	4.93	16.10	36.10
May	-0.60	-9.22	1.97	2.81	13.04	19.18	-3.59	0.76	2.53	5.02	17.09	36.86
Jun	-4.15	-8.18	2.01	3.02	13.31	20.71	0.02	-1.37	2.51	5.14	16.97	37.93
Jul	4.66	7.56	1.92	2.78	12.71	18.99	5.89	11.04	2.38	4.92	16.03	36.04
Aug	2.45	6.19	1.92	2.68	12.76	18.28	4.70	8.73	2.36	4.84	15.86	35.33
Sep	4.54	8.71	2.02	2.76	13.41	18.79	6.20	15.54	2.46	4.89	16.62	35.77
Oct	-8.58	-10.15	2.10	2.85	14.00	19.42	-5.60	-2.61	2.61	5.20	17.72	38.39
Nov	-8.04	-12.80	1.97	2.78	13.05	19.00	-16.23	-13.91	2.52	4.94	17.04	36.35
Dec	1.30	-10.62	1.90	2.56	12.51	17.37	-5.50	-13.25	2.46	4.70	16.66	34.12

4. CONCLUSIONS

The Niger basin has been battling with climatic challenges which are not well captured in projections and observations. The present study evaluated the CMIP5 rainfall and temperature projections with 8 GCM-RCM combinations. In the near future, climate change will drive increases in precipitation, temperature, and PET in the Niger basin. The Sahelian region will experience more considerable increase in rainfall compared to other ecological zones. Improved GCM agreements in the CMIP5 projected precipitation patterns shows higher confidence in the CMIP5 projections in the Niger basin. Further research should endeavor to use the CMIP5 climate projections for climate change impacts studies on agriculture, hydropower and water resources management in the Niger basin.

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COMPETING INTERESTS

Author has declared that no competing interests exist.

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