Recent Trends and Future Projection in Precipitation and Temperature Changes in Nigeria

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Abstract

Extreme precipitation and temperature events have profound impacts on lives and properties of Nigerians. This paper examined and adopted three statistical change point detection techniques to identify changes in precipitation and temperature trends at 5% significant level. The ensemble mean were correlated with the observation datasets and with little or no bias when evaluated. There were indications of far and near-future precipitation anomalies with change-point detection. Significant change in temperature is expected to occur for all zones under RCP4.5 and RCP8.5 for future period 2020–2099 with increase in mean annual temperature trend 0.026–0.38°C. Projected relative change in seasonal cycle of precipitation shows that winter months may witness increase in precipitation amounts under RCP4.5 but significant decrease in magnitude under RCP8.5 in near and far-future. The results of this study show and affirm that climate change intensity and its magnitude may likely intensify in Nigeria in the near and far future.

1. Introduction

Natural processes and most especially human-induced forces have been responsible for the modification of climate pattern in Africa and in particular Nigeria (IPCC 2007). This is as a result of increase in Green House Gases (GHGs) emission through bush burning, refuse burning, open grazing, automobile exhaust fumes and as well as burning of fossil fuel. All these human activities have climate feedback that induces extreme weather and climate events such as increase in air temperature above average of 1.5^{o}C (Akinsanola and Zhou 2018; Gbode et al. 2019, IPCC, 2013). It also impacts spatio-temporal pattern of rainfall and temperature (Sylla et al. 2016) and sea level rise (IPCC, 2013). It was also reported in the fifth assessment report of the Intergovernmental Panel on Climate Change that average air temperature over Africa could exceed the twentieth-century range of variability by 2047 and 2069 under Representative Concentration Pathways (RCPs) RCP8.5 and RCP4.5, respectively (IPCC, 2013, Niang et al. 2015). In the same vein, the risk of deadly heat stress is likely to increase over West Africa, while heat waves are likely to be more frequent and longer under the effects of global warming (Diedhiou et al. 2018; Sylla et al. 2018).

From the food security point of view, Food and Agriculture Organization (FAO, 2001) also reported that dependent crops on minimum temperature threshold have been reduced by 15–35% in Nigeria. In addition to variation in temperature and rainfall, Ravindran et al. (2000) and Sivakumar et al. (2012) further shows that wind speed, evapotranspiration, solar radiation and relative humidity play major roles in agriculture and other sectors. More so, Collins (2011) reported that in Africa and Nigeria in particular, temperature has been increasing at about 0.15°C per decade. It is important to point out that the extent of change in temperature, precipitation, and all other climatic variables are not spatially and temporally uniform across the world (IPCC 2014; Yue and Hashino 2003). The regional variation is as a result of the differences in surface albedo, types of land surfaces, evapotranspiration and Green House Gas (GHGs) emission rate among many other factors affects climate in many forms (Meissner et al. 2003; Synder *et al.* 2004). Scientific evidences have also shown that the duration and intensity of rainfall have increased in some parts of the country, producing large runoffs and flood in many places in Nigeria. Most climatic regions for instance have continued to experience precipitation anomaly p which is quite noticeable during extreme precipitation (Nicholson, 2013). It is not also surprising that different degree of drought occurs at different seasonal transition thereby prolong cessation of precipitation in many places. It is very necessary to assess climate projection under different RCPs to ascertain the nature and magnitude of precipitation and temperature change in Nigeria. This information helps the policymakers in choosing relevant action that could militate against socio-economic impacts of climate change in Nigeria. However, only very few studies had examined changes in climate variables with statistical change detection technique. For example, (Akinsanola and Ogunjobi 2015; Oguntunde et al. 2011; Fasona et al. 2011; Ati et al. 2002) used an observation dataset to observed chnages in climate variables while Emmauel *et al*. (2019) made use of one RCM under RCP4.5 and RCP8.5 with projection from 2020–2050 over West Africa. However, change detection and trend test are known as non-parametric tests which includes Pettit's test (Mauget 2003; Yu et al. 2006), Standard Normal Homogeneity (Gonzalez Rouco *et al*. 2001; Stepanek et al. 2009) test, Buishand's range test (Buishand 1982; Jaiswal and Lohani 2015) and Mann–Kendall trend test (Kendall 1975; Wang et al. 2005; Karmeshu 2012). These tests have capability to identify an abrupt change and gradual trend superimposed on a climate variables. These tests have been widely used to detect change point and examined the trend in series of hydro-climatic variables like temperature, rainfall, wind speed, humidity and sunshine hour (Salarijazi et al. 2012; Sivakumar et al. 2012; Jaiswal and Lohani 2015; Emmanuel et al. 2019). The Pettit's test, SNHT, Buishand's range test, and MK trend test were used and performed over the three homogeneous agro-climatic zones of Nigeria. However, this study aimed at evaluating the performance of different selected RCMs adopted from Co-Ordinated Regional Climate Downscaling Experiment (CORDEX; Giorgi et al. 2009) through ensemble mean and as well as to assess trends and change in precipitation and temperature over Nigeria from 1961 to 2099.

2. Data And Methodology

2.1 Study Area

Nigeria is geographically located between 4–14^{o}N and 3–1^{o}E (Fig. 1). The country covers an approximate area of about 923,770 km^2 and is bordered to the north by the Republic of Niger, to the South by the Atlantic Ocean, to the West by the Republic of Benin and to the east by Cameroon. The country is divided into three different climatic zones (Fig. 1); Guinea Coast (4–8^{o}N), Savannah (8–11^{o}N) and Sahel (11–14^{o}N) based on similarities in land-use/land-cover, climate and ecosystems (Iloeje, 1981; Omotosho and Abiodun, 2007; Abiodun *et al.*, 2013). These zones are strongly influenced by the West African monsoon which provides precipitation for agricultural practices and other sectors of the economy. The Guinea coast zone is located in the Southern part of the country (4–8^{o}N) and is characterized by a sub-humid climate with average annual rainfall ranging from 1,575mm to 2,533 mm (Oguntunde et al., 2011). The Savannah zone is a semi-arid region with average annual rainfall of about 897–1,535 mm. Reduction in rainfall in this zone is linked to the monsoon jump which is observed abrupt latitudinal shift of maximum precipitation from the Guinea coast into the Sahel region around June (Sultan and Janicot, 2000; Le Barbe et al., 2002; Lebel et al., 2003; Hagos and Cook, 2007).

2.2.Data

An ensemble mean of seven Regional Climate Models (RCMs) were computed. The selected RCMs were driven by different coupled Modeling Inter-comparison Project (CMIP5) Global Circulation Model in the CORDEX framework (Nikulin et al. 2018). The observations from the performance evaluation of the RCMs over Nigeria shows that the selected RCMs performed better in replicating the pattern and seasonal variation of temperature and precipitation (Nikulin et al. 2012; Gbobaniyi et al. 2014; Akinsanola et al. 2015; Ajayi and Ilori 2020). The datasets covered the period 1961 to 2000 for the historical framework and the time scale slice for near-future from 2020 to 2059 and far-future from 2060 to 2099. The selected RCMs dynamically downscaled seven GCM simulations at a horizontal resolution of 0.44° × 0.44° (Dieterich et al. 2013; Panitz et al. 2014). Also, the daily temperature and precipitation datasets from CORDEX were converted to monthly data format and were utilized over the three climatic zones of Nigeria. A statistical evaluation of all seven CORDEX dataset was performed based on ensemble mean with the gridded dataset of Climate Research Unit (CRU: Harris et al. 2014) version v4.03 to simulate seasonal cycle of temperature and precipitation, trend and change point detection. Table 1 highlight all the RCMs used and their driven GCMs.

2.4. Methodology

Performance evaluations of the ensemble mean were used with different parameters to ascertain how well the simulation data replicate the precipitation and temperature over the country Nigeria. The parameter observed includes Mean Bias Error (MBE), Mean Gross Error (MGE), correlation coefficient (*r*), and Nash-Sutcliffe Efficiency (NSE). Change point detection test was also performed using the Pettit's test, Standard Normal Homogeneity Test (SNHT), Buishand's range test over the three homogeneous climatic zones at 5% significant level while Mann-Kendall trend test was used to examine trend in temperature and precipitation spatially at 5% significant level over the agro-climatic zones of Nigeria. The standardized Rainfall Anomaly Index (SRAI) was also adopted to examine the degree of dryness and wetness of each year in the reference, near-future and far-future periods while Standardized Temperature Anomaly Index (STAI) was used to access the extent of warmth and cold relative to the near-future and far-future changes.

3. Results And Discussion

3.1 Evaluation of CORDEX ensemble dataset with Change Detection Test and Trend Analysis

Performance evaluation of the ensemble mean CORDEX datasets over the three agro-climatic zones of Nigeria was performed and summarized in Table 2&3. The simulation datasets covers the historical period 1961–2000 and the evaluation was performed with CRU observation datasets. The performance evaluation help us to have better understanding of the capability of ensemble mean of RCMs in replicating seasonal distribution of temperature and precipitation. The ensemble mean of the models captured temperature and precipitation very well over the three climatic zones when compared to CRU observation datasets. Nigeria was divided into three agro-climatic zones the Guinea coast, Savannah and Sahel. Evaluation of precipitation through Nash-Sutcliffe Efficiency (NSE) parameter shows very close estimated value for all the three agro-climatic zones with the least value of 0.84 in the Guinea coast and the highest value of 0.89 in the Sahel. The Mean Bias Error and Mean Gross Error shows the same precipitation trend with the highest estimated value of 23.9 and 31.73 in the Guinea coast respectively while the least values varies between Guinea coast and the Sahel region. The ensemble mean shows highest precipitation disparity in the Guinea coat when compared to observation. However, the correlation coefficient shows an overall significant value for the three agro-climatic zones but with the least value of 0.89 in the Guinea coast. Thus, ensemble mean of the seven selected simulated datasets performed relatively well in all the three regions when compared to observation. In the same vein, Table 3 presents statistical performance evaluation of ensemble mean temperature over the three agro-climatic zones of Nigeria. The NSE shows similar values for all the three zones with the least value of 0.79 in Savannah. The ensemble mean reproduced precipitation and temperature pattern over the three climatic zones but overestimates in some parts of the region. The reason for overestimation of the ensemble mean can be associated to different parameterization schemes used in the various RCMs that made up the ensemble mean (Afiesimama et al. 2006; Diallo et al. 2012).

However, change detection analysis was applied on the annual mean temperature and precipitation average over the Guinea Coast, Savannah, and the Sahel with historical datasets period of 1961 to 2000 at 5% significant level. Three statistical tests with null homogenous (H_0) hypothesis are presented in Tables 4&5 for rainfall and temperature. Figure 4, 5, and 6 represents the graphical form of ensemble-mean temperature with a change point over Nigeria. For identification of change point in rainfall and temperature the following three conditions have to be met which was earlier used and proven by Winingaard *et al.* (2003) and Jaiswal et al. (2015) for chamge point detection.

i. The first condition is when the change-point is homogeneous (HGN) or not occur. This is an indication that temperature and precipitation may be regarded as homogeneous when one or none of the test rejected the null (H_o) hypothesis at a significant level of 5%.

ii. The second condition is when the change-point occurs or heterogeneous (CPO).This is an indication that precipitation and temperature may have shifted or heterogeneous when two or the three tests reject the null (H_o) hypothesis at a significant level of 5%.
iii. The third condition is when the change point is Doubtful (DBF). This is an indication that the precipitation and temperature is regarded doubtful if at a significant level of 5%. It can also be affirmed if further evaluation of the three tests failed to agree on when the change point occurred.

However, Table 4 shows statistical test for Centre for Research (CRU) observation datasets and ensemble mean. The test revealed homogeneity nature of precipitation over Guinea Coast, Savannah and Sahel with a significant change point as both the Petite's, SNHT and Buishand's test agreed that precipitation over the three climatic zones are homogeneous except for ensemble mean which shows inhomogeneity change point for the climatic zones. Over the Guinea Coast, the change point occurred in 1984 while the Savannah and Sahel is 1983. Although, the precipitation in the Sahel is known to be homogeneous in nature but the three test were able to record the inhomogeneity of the precipitation for the change point in 1983 and 1984.

Likewise it is observed from the ensemble mean that there were no significant change point occurred in precipitation for all the three climatic zones except for the Buishand's test which shows significant change for the three climatic zones while precipitation in Sahel region also demonstrates homogeneous characteristic. The nature of the precipitation in the Savanna is doubtful as the three statistical tests could not agree on the change point. The reason for all these could be linked to Buishand's and Pettitt's test which are very sensitive to identify changes on the trends whereas SNHT is well known to locate change point at the beginning and end of a datasets as affirmed by (Winingaard et al. 2003; Jaiswal and Lohani 2015). The change point noticed from the CRU and ensemble mean agreed to have occurred in the early 1980s, a decade that is characterized with drought in Nigeria (Le Barbé *et al*. 2002; Lebel and Ali 2009; Nicholson 2013) A condition that resulted into significant low precipitation amount which has become a source of water stress in the region. The decade would likely been characterized with frequent sand storm and buildup of atmospheric dust (Ekpoh and Nsa 2011) which in turn might have contributed to precipitation anomaly (Adeniyi and Oladiran 2000) and as well weakened circulation of global monsoon (Pant 2003). These reflected in the change point observed over the rainfall over the three zones. Table 5 also presents change point detection in temperature over the three climatic zones of Nigeria. It shows a significant shift in the mean temperature which is in relation with the change point that occurred between 1976 and 1983 on different climatic zones with varying period but within the same decades of 1970 and 1980s. This was a period well known for prevailing droughts in the zone. The primary causes of the drought is associated with human activities that leads to increase in emission of Green House Gases (Charney et al. 1977; Sylla et al. 2016), The results of external forcing of GHGs due to change point in temperature could be responsible for global climate shift identified by Baines (2006).

Table 8 presents Mann–Kendall trend test at 5% significant level performed over the three climatic zones of Nigeria for precipitation and temperature. CRU datasets precipitation trend analysis over Guinea Coast and the Sahel indicated a significant decrease in total annual precipitation at 5% significant level and a non-significant decreasing trend over the Savannah. An insignificant decrease in rainfall trend from the ensemble-mean was observed over the three climatic zones of Nigeria which shows a critical point in precipitation variability. This is also noted by Nicholson (2013) and Emmanuel et al. (2019). However ensemble mean and CRU temperature shows a significant increase in temperature trend at a significant level of 5% with a Sen.'s slope 0.0078 to be the lowest in the Guinea Coast and 0.0255 to be the highest in the Sahel region under RCP4.5 while there is a significant trend 0.057 and 0.063 under RCP8.5 over the three climatic zones of Nigeria. High frequency in precipitation and temperature variabilities have been linked to global warming due to human activities such as burning of fossil fuel which plays a major role in decreasing and increasing trend of rainfall over Nigeria (IPCC 2013; Sylla et al. 2016). These results are also similar to the findings of Nelson *et al*. (2010), N'Tcha M'Po *et al*. (2017) and Lawin *et al.* (2018) but with a projected increase in annual mean temperature between 0.59 °C and 1.30 °C. This further confirms that West Africaregion includong Nigeria will continue to be warmer than before.

Tables 9 and 10 shows a similar result for trend test at 5% significant level performed over the three climatic zones of Nigeria with respect to precipitation and temperature variability for the near and far future cases. It was deduced that precipitation in the near future replicates the same pattern with the reference period with insignificant change in precipitation trend but with decrease precipitation trend in the Sahel and with improvement in the Savannah for both CRU and ensemble mean datasets. The precipitation was more pronounced in the ensemble mean than the CRU datasets. There are also possibilities of increase in air temperature in the near future with the highest in the Sahel and Savannah. Far future for both CRU and ensemble mean shows insignificant change in precipitation and temperature in both RCP4.5 and RCP8.5 scenario. All these could be linked to the present variability in climate variables and changes in climatic trends while there could be limitation of global warming bellow 1.5 in far future.

Table 4 Results of temperature change point detection from the three tests for the historical period (1961–2000) at 5% significant level

3.2 Near-Future Rainfall and Temperature Pattern in Nigeria

3.2.1 Change Detection and Trend Analysis

Table 6 presents the results of change-point detection performed using SNHT, Pettitt's, and Buishand's test for the ensemble mean of precipitation and air temperature and as well as for Mann–Kendall test under RCP4.5 and RCP8.5 for the near-future (2020–2059). The change-point detection (HGN) is observed for both RCP4.5 and 8.5. HGN is an indication that no change occur in the precipitation time serie for all the three climatic zones as observed in Table 6. However, for the temperature series under RCP4.5, a change point expected to occur over the Guinea Coast and the Sahel by the year 2038 and 2036 and this may be as a result of the projected increase in the annual mean of temperature within the range of 0.56–0.91 °C in the near future as observed in Table 6. There is posibility of positive shift in the mean annual temperature which is likely to take place in Guinea coast and Savannah climatic zones by the year 2044 within the range of 1.26°C and 1.16°C in the near-future under RCP8.5 emission scenario. Table 7 presents far future point change detection for both precipitation and temperature respectivelly. Precipitation time series remain homogenous in all the three climatic zones and in both RCP4.5 &8.5 while the temperature shows a drastic increase in temperature and changes for the year 2081with temperature of 27.91^{o} C to 31.84 ^{o} C in Guinea coast and Sahel respectively and with difference of 1.15-1.58^{o}C in RCP 8.5 scenario.

Figure 2 presents projected temperature anomaly with sgnificant values of change detection in five years interval and with decadal scale variation. In addition Fig. 2a shows a projected increase in temperature meas\ value 25.87^{o}C before and 26.48 after change detection occurs for Pettitt's test on five years interval. Similarly Fig. 6b shows the mean temperature values before change detection is 25.87 and 26.43 after change detection occurred for the SNHT test. In the same vein, Buishand's test shows a similar change detection values in the same years interval. In all, the tests performed showed a similar change detection values for the near future projected years. Figure 3 shows annual mean rainfall trend analysis result over Nigeria from 2020–2059. The near-future precipitation trends under RCP4.5 indicate that there are indication of significant precipitation trends nearly in all three climatic zones of Nigeria excepts for the Guinea coast where there are insignificant trends of precipitation and this is due to homogeneity of precipitation pattern in the region but for the projected precipitation under RCP8.5 there are indication of more insignificant precipitation trends seen especially in the Savannah and Sahel region of the country. This means there is likely more drought events in the near future in the Savannah and Sahel region of Nigeria in relation to (IPCC, 2013) hypothesis that some regions will become warmer in sub-Sahara Africa. More so, far-future precipitation trends under RCP4.5 shows more than 40% of significant precipitation trends in the Savannah and Sahel while others under RCP 8.5 show a greater percentage of insignificant precipitation trends across all the three climatic zones. The stipple on the plot also indicates grid points with a statistically significant trend at 95% confidence interval.

However, mean temperature under RCP4.5 shows very significant trends in the Savannah and Sahel region of Nigeria than the Guinea coast region with an annual average temperature change 0.034^{o}C but less varying degree in the Coastal region while the mean temperature under RCP8.5 shows higher significant change from Coastal area to the Sahel with varying degree 0.038^{o}C in the Sahel region. This means that mean temperature will still be under the base line of 1.5^{o}C under RCP4.5 in the near future and it is likely to exceed the target of 1.5^{o}C in far future under RCP8.5 scenario.

3.3. Standardized Precipitation and Temperature Anomaly Index near-future under RCP4.5 and RCP8.5

Figure 5 and table 11 shows an average number of years of precipitation based on different degree of wetness and dryness in the near-future. The relative change in decadal rainfall in Guinea coast under RCP4.5 in Fig. 5a projects moderately wet and dry years in the first decade 2020–2030 and as well as moderate wet years with no significant dry years in the second decades 2030–2040. There are projected extreme wet and dry years in 2040–2050 and mild dry years in 2050–2060 decade. In Savannah however, 2030–2040 decades projects moderately wet years while the last two decades 2040 – 260 projects mild and severe dry years. The Sahel region projects decadal moderately wet years with extreme dry years in 2020–2060. However, Standardized Rainfall Anomaly Index (SRAI) under RCP8.5 for the near-future projects moderate decadal dry years 2030 – 250 in the Guinea coast and with extreme wet years in the first and last decade 2050–2060. In the same vein, there are projected dry years for two decades 2030–2050 in the Savannah (Fig. 5b) with moderate and with severe drought in the year 2020–2030 and 2050–2060. The decadal precipitation pattern in the Sahel region are similar to the Savannah except the high intensity of dryness in the year 2030–2050 with moderate precipitation in the first and the middle of last decade. In all, there are projected dry years in the near future with high degree of decadal precipitation variation across the three climatic zones of Nigeria. Figure 6a and table 12 shows extreme dry years and Standardized Rainfall Anomaly Index (SRAI) in the first decades 2060–2070 and as well as 2090–2100. Also from mild to moderate dry years in the second and third decade 2070–2090 with moderately wet years from 2070–2100. Extreme wet years are projected toward the end of the third decade 2080–2090 and as well as severe dry years in the first decade of 2060–2070 in the Savannah under RCP 4.5 for the far future (Fig. 6c). However, Sahel in Fig. 6e also shows similar trends of precipitation anomaly with extreme wet years toward the end of the third decade 2080–22090. For precipitation anomaly index under RCP8.5 was projected in Guinea coast with extreme wet years in the last decade 2090–2100 (Fig. 6b) and as well as moderate dry years in the middle of 2080–2090 and 2090–2100. Figure 6d shows Savannah precipitation anomaly index with extreme wet year in the fourth decade 2090–2100 and with moderate dry years in the third decade 2080–2090 while Fig. 6f shows precipitation anomaly index for Sahel under RCP8.5 with extreme wet years in the first decade of 2060–2070 and also with moderate wet years from 2080–2100 and also with moderate dry years in the third decade 2080–2090. In all, precipitation anomaly index shows more dry decades with few extreme years of precipitation in the near future and as well as with extreme wet years in the far future in all the three agro-climatic zones of Nigeria. The reasons for this is linked to continuous burning of fossil fuel and cutting of trees as an important factors in bio-geophysical feedback mechanism which have been suspected together with a shift in global climate system (Farmer and Wigley 1985; Charney et al. 1977; Baines 2006) to be responsible for the projected anomalies in rainfall and temperature.

Figure 7 shows projection of higher temperature values when compare to historical period under RCP4.5 and RCP8.5. Also, the rate of increase in temperature relative to historical mean was noticed to be higher under RCP8.5 when compared to lower emission scenarios (RCP4.5). Since the warmer atmosphere can hold larger moisture, the projected increase in precipitation relative to the historical mean over the Guinea Coast and Savannah may be associated with the expected increase in temperature (Lenderink and Meijgaard 2010)

4. Summary And Conclusion

We used ensemble mean of seven RCMs driven by GCMs obtained from the archive of CORDEX in this study over the historical (1961–2000) and projected (2020–2099) periods over three climatic regions of Nigeria. The projected period was further divided into near-future (2020–2059) and far-future (2060–2099) as most of the RCMs agreed that warming level above 1.5°C would have been achieved by the year 2060. Change-point detection and trend analysis method were performed using a non-parametric statistical test which includes Standard normal homogeneity test, Buishand’s range test, and Pettitt’s test have been used to detect change point while the Mann–Kendall test was also used to examine precipitation trends and temperature changes at the annual scale. An assessment through performance evaluation was carried out on the ensemble mean while comparing its results to that of CRU datasets for the historical period with a view to observing change point in seasonal cycle of precipitation and temperature changes. The projected change in seasonal cycle of precipitation and temperature variability relative to historical mean was also investigated to examine near and far-future precipitation and temperature deviates from the historical period and the difference changes observed are summarized as follows:

- The ensemble mean reproduced the observed seasonal variation and precipitation pattern and temperature variability when compared to CRU datasets over the three agro-climatic zones of Nigeria. There were little differences in the magnitude of precipitation and temperature and zonal variations in precipitation amount and temperature values.
- Precipitation is expected to be homogeneous in the near-future over the three climatic zones of Nigeria under RCP4.5 while Savannah region will likely be heterogeneous under RCP8.5 with a shift in precipitation amount 105.18 mm by 2044.
- Projected change in seasonal cycle of rainfall relative to the historical period for the near-future shows the winter months will have more precipitation amount under RCP4.5 while the temperature will likely increase in all the months under both pathways with more warming under RCP8.5.
- Annual precipitation anomaly relative to historical long-term mean projects Guinea Coast and Savannah to have increased rainfall amount under RCP4.5. The rainfall in the Sahel will be reduced under the two emission scenarios as temperature expected to increase than the historical period under RCP4.5 and RCP8.5.

- A significant change point in temperature over the three climatic zones is also expected by the year 2040–2050 under RCP8.5 with an average increase 0.17–0.30 °C in the temperature mean.

5. Declarations

We declare that the manuscript is the original idea of the authors and that it has not been published elsewhere

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All authors have participated in (a) conception and design, or analysis and interpretation of the data; (b) drafting the article or revising it critically for important intellectual content; and (c) approval of the final version and this manuscript has not been submitted to, nor is under review at, another journal or other publishing venue.

Availability of data and material

The datasets used for this work will be made available on request

Code availability

There was no special software used or applied except the ones adopted for the data analysis

Consent to participate

I have read and I understand the provided information regarding the publishing guideline. I understand that submitting manuscripts has to follow prescribed format.

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Author's Contribution

All listed authors participated in all phases of the manuscripts development

1. Conception of ideas of the work Akinyoola J. Adekola
2. Data collection Imoukhoude O. Bimpe
3. Data Analysis Akinyoola J. Adekola
4. Drafting the article Akinyoola J. Adekola
5. Critical revision of the article Olorubtade A. Johnson
6. Final approval of the work to the publish Oloruntade A. Johnson

Ethic's approval

All procedures performed in this work involving human participants were in accordance with the ethical standards of the institutional and national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Consent for publication

I, the lead author give my consent for the publication of recent trends and future projection in precipitation and temperature changes in Nigeria to be published in theoretical and applied climatology journal Article.

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7. Tables

Table 1
List of seven Regional Climate Models employed in the study

S/N	INSTITUTE	GCMs	Downscaling RCMs
1	Norwegian Climate Centre (Norway)	NCC-NorESM1-M	HIRHAM5
2	NOAA Geophysical Fluid Dynamics Laboratory, USA	NOAA-GFDL-GFDL-ESM2G	REMO
3	National Institute for Environmental Studies, And Japan Agency For Marine-Earth Science and Technology (MIROC), Japan	MIROC-MIROC5	RCA4
4	Consortium of European Research Institution and Researchers	ICHEC-EC-EARTH	RACMO
5	Max Planck Institute for Meteorology (Germany)	MPI-M-MPI-ESM-LR	CCLM4
6	Canadian Centre For Climate Modeling and Analysis (Canada)	CCCma-CanESM2	CRCM5
7	Institute Pierre-Simon Laplace, France	IPSL-IPSL-CM5A-MR	RCA4

Table 2
Results of the statistical evaluation between the observation and ensemble mean precipitation over the three agro-climatic zones of Nigeria

CLIMATIC ZONE	NSE	MBE	MGE	r
GUINEA COAST	0.84	23.9	31.73	0.89
SAVANNAH	0.85	14.04	24.14	0.93
SAHEL	0.89	11.67	26.25	0.95

Table 3
Results of the statistical evaluation between the observation and ensemble mean temperature over the three agro-climatic zones of Nigeria

CLIMATIC ZONE	NSE	MBE	MGE	r
GUINEA COAST	0.84	12.57	16.09	0.92
SAVANNAH	0.79	14.86	13.25	0.89
SAHEL	0.80	-14.01	15.37	0.88

Table 4
Precipitation change point detection from the three tests for the historical period (1961–2000) at 5% significant levelChange detection over Nigeria with reference period (1961–2000)

Climatic Zone	Datasets	Pettitt's Test			SNHT			Buishand's Test			Final Results	
		Statistics	Change	Year of Change	Statistics	Change	Year of Change	Statistics	Change	Year of Change	Nature	Year of Change
CRU	GUINEA COAST	227	yes	1984	16.581	yes	1984	11.321	yes	1984	Shift	1984
	SAVANNAH	223	yes	1983	16.211	yes	1983	10.998	no	nill	Shift	1983
	SAHEL	251	yes	1984	19.517	yes	1983	12.203	yes	1983	HGN	1983
ENSEMBLE MEAN	GUINEA COAST	119	no	nill	8.554	yes	1983	8.441	yes	1983	Shift	1983
	SAVANNAH	93	no	nill	7.1	yes	1983	8.391	yes	1987	DBF	-
	SAHEL	81	no	nill	1.913	no	nill	7.021	yes	1984	HGN	-

Table 5
Temperature change point detection from the three tests for the historical period (1961–2000) at 5% significant level

Climatic Zone	Datasets	Pettitt's Test			SNHT			Buishand's Test			Final Results	
		Statistics	Change	Year of Change	Statistics	Change	Year of Change	Statistics	Change	Year of Change	Nature	Year of Change
CRU	GUINEA COAST	205	yes	1982	10.55	yes	1982	10.031	yes	1982	Shift	1982
	SAVANNAH	297	yes	1979	16.119	yes	1979	12.158	yes	1979	Shift	1979
	SAHEL	241	yes	1978	16	yes	1978	12.122	yes	1978	Shift	1978
ENSEMBLE MEAN	GUINEA COAST	358	yes	1983	22.238	yes	1983	12.782	yes	1983	Shift	1983
	SAVANNAH	337	yes	1976	20.687	yes	1976	12.354	yes	1976	Shift	1976
	SAHEL	322	yes	1976	21.301	yes	1976	12.011	yes	1976	Shift	1976

Table 6
NEAR- FUTURE (2020–2059) mu1 and mu2 depicts the mean before and after change point has occurred

		PRECIPITATION					**TEMPERATURE**				
Scenario	CLIMATIC ZONE	Nature of the series	Year of change	mu1	mu2	diff	Nature of the series	Year of change	mu1	mu2	diff
RCP4.5	GUINEA COAST	HGN	-	1871.3	-		CPO	2038	25.87	26.43	0.56
	SAVANNAH	HGN	-	1196.82	-		DBF	2036	26.11	26.80	0.69
	SAHEL	HGN	-	624.44	-		CPO	2037	27.21	28.12	0.91
RCP8.5	GUINEA COAST	HGN	-	1878.67	-		CPO	2044	28.61	29.87	1.26
	SAVANNAH	HGN	-	1187.11	-	-	CPO	2044	29.76	30.92	1.16
	SAHEL	HGN	-	613.19	-		CPO	2043	30.02	31.41	1.39

Table 7
FAR-FUTURE (2060–2099) mu1 and mu2 depicts the mean before and after change point has occurred

Scenario	CLIMATIC ZONE	PRECIPITATION					TEMPERATURE				
		Nature of the series	Year of shift	mu1	mu2	diff	Nature of the series	Year of shift	mu1	mu2	diff
RCP4.5	GUINEA COAST	HGN	-	1878.67	-	-	CPO	2077	26.89	27.11	0.22
	SAVANNAH	HGN	-	1187.1	-	-	CPO	2077	26.91	27.51	0.60
	SAHEL	HGN	-	613.18	-	-	CPO	2076	28.01	29.32	1.31
RCP8.5	GUINEA COAST	HGN	-	1630.63		-	CPO	2081	27.97	29.12	1.15
	SAVANNAH	HGN	-	1261.89	-	-	CPO	2081	29.20	30.51	1.31
	SAHEL	HGN	-	403.77	-	-	CPO	2081	31.84	33.42	1.58

Table 8

Trend analysis over the three climatic zones reference period

Scenario	CLIMATIC ZONE	PRECIPITATION		TEMPERATURE	
		P-Value	Sen's Slope	P-Value	Sen's Slope
CRU	GUINEA COAST	0.0390	-3.306	0.0368	0.0078
	SAVANNAH	0.1459	-2.195	0.0005	0.0164
	SAHEL	0.0290	-3.387	0.0001	0.0255
ENSEMBLE MEAN	GUINEA COAST	0.5084	-0.434	0.0001	0.0260
	SAVANNAH	0.7607	-0.241	0.0015	0.0205
	SAHEL	0.8870	-0.154	0.0001	0.0243

Table 9

Trend analysis over the three climatic zones for near-future

Scenario	CLIMATIC ZONE	PRECIPITATION		TEMPERATURE	
		P-value	Sen's Slope	P-value	Sen's Slope
RCP4.5	GUINEA COAST	0.6025	-0.824	0.0011	0.022
	SAVANNAH	0.5012	0.689	0.0001	0.029
	SAHEL	0.7142	0.266	0.0026	0.035
RCP8.5	GUINEA COAST	0.5010	2.502	0.0019	0.062
	SAVANNAH	0.1575	1.977	0.0013	0.068
	SAHEL	0.2736	0.814	0.0003	0.071

Table 10

Trend analysis over the three climatic zones for far-future

Scenario	CLIMATIC ZONE	RAINFALL		TEMPERATURE	
		P-Value	Sen's Slope	P-Value	Sen's Slope
RCP4.5	GUINEA COAST	0.7438	-0.068	0.0001	0.009
	SAVANNAH	0.9797	0.924	0.0013	0.011
	SAHEL	0.6639	0.215	0.0009	0.014
RCP8.5	GUINEA COAST	0.3848	-1.841	0.0022	0.079
	SAVANNAH	0.8675	-2.118	0.0069	0.084
	SAHEL	0.2154	-2.941	0.0092	0.094

Table 11
Number of years based on different degree of wetness and dryness in the near-future using McKee et al. (1993) method of classification

		RCP4.5			**RCP8.5**		
SRAI VALUES	CLASSIFICATION	GUINEA COAST	SAVANNAH	SAHEL	GUINEA COAST	SAVANNAH	SAHEL
> 2.00	Extremely wet	2	1	2	1	1	1
1.50 to 1.99	Severely wet	2	3	2	2	1	3
1.00 to 1.49	Moderately wet	2	5	2	5	6	2
0.50 to 0.99	Slightly wet	6	3	6	4	5	7
-0.49 to 0.49	Near normal	16	13	15	15	10	13
-0.99 to -0.50	Mildly dry	7	6	6	8	8	6
-1.49 to -1.00	Moderately dry	4	5	5	2	3	6
-1.99 to -1.50	Severely dry	0	4	2	2	6	2
< -2.00	Extremely dry	1	0	0	1	0	0

Table 12
Number of years based on different degree of wetness and dryness in the far-future using McKee et al. (1993) method of classification

		RCP4.5			**RCP8.5**		
SRAI VALUES	CLASSIFICATION	GUINEA COAST	SAVANNAH	SAHEL	GUINEA COAST	SAVANNAH	SAHEL
> 2.00	Extremely wet	0	1	1	2	1	1
1.50 to 1.99	Severely wet	2	0	0	1	1	3
1.00 to 1.49	Moderately wet	5	6	6	4	6	1
0.50 to 0.99	Slightly wet	6	6	9	5	1	4
-0.49 to 0.49	Near normal	15	13	8	14	17	13
-0.99 to -0.50	Mildly dry	7	7	9	7	7	9
-1.49 to -1.00	Moderately dry	2	4	5	4	5	8
-1.99 to -1.50	Severely dry	2	3	1	3	2	1
< -2.00	Extremely dry	1	0	1	0	0	0

Figures

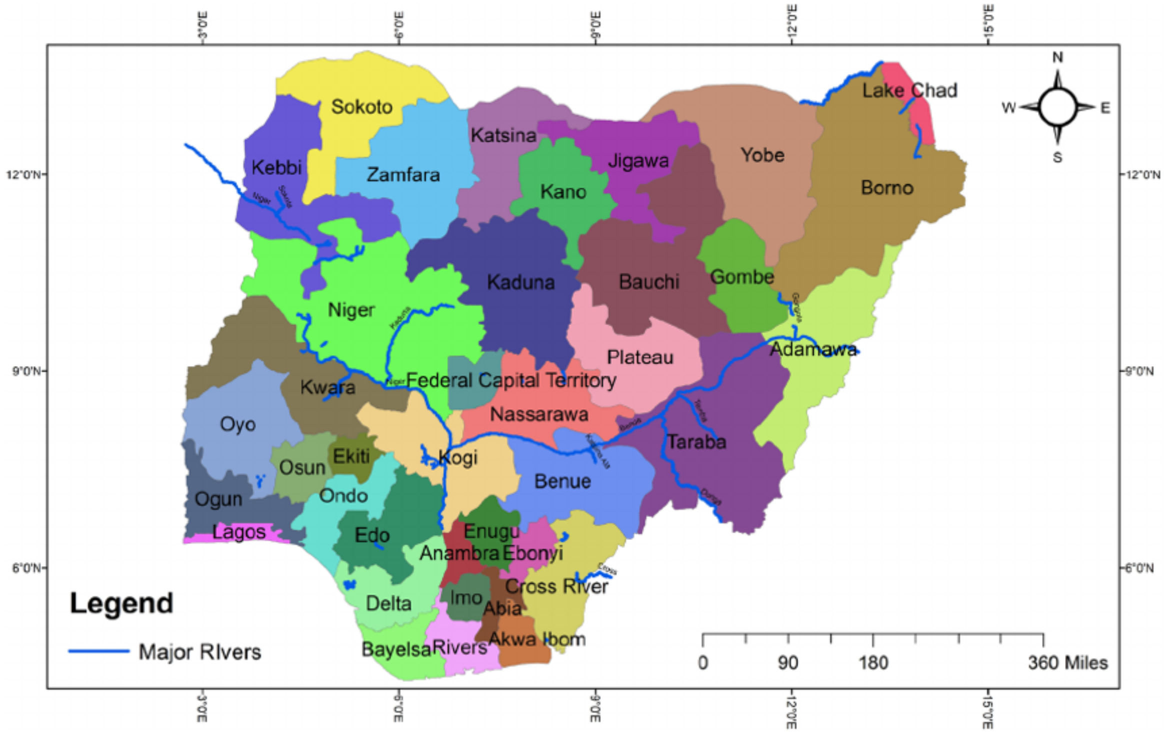

Figure 1

Geographical location of stations in Nigeria, source (Akinyoola et al., 2018)

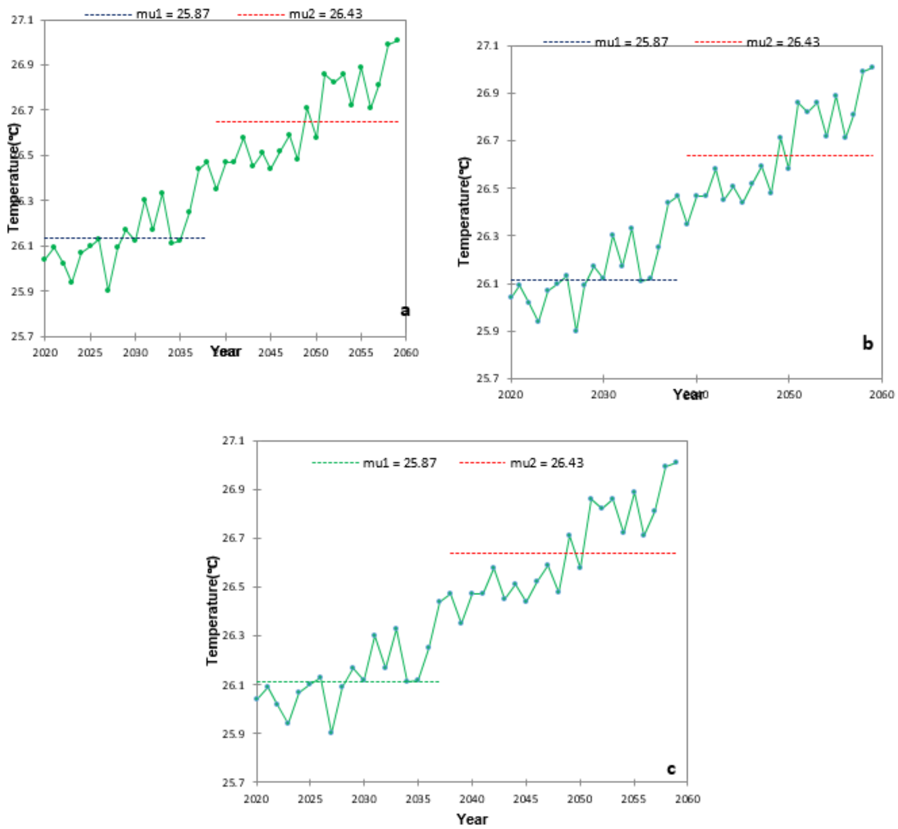

Figure 2

Graphical illustration of detection of change point in the annual mean series of temperature average over the Guinea Coast as shown by (a) Pettitt's test, (b) SNHT, and (c) Buishand's test where mu1 and mu2 depicts the mean before and after change point has occurred in temperature series, respectively.

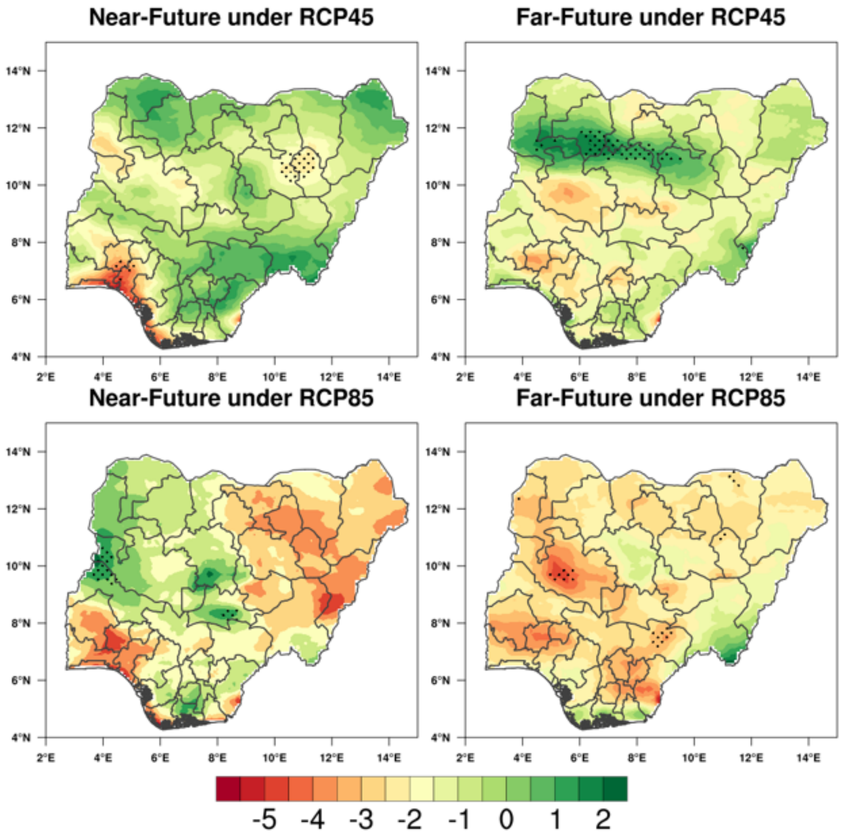

Figure 3

Annual mean precipitation trend analysis result over Nigeria for near and far-future . Stipples on the plot represent grid points with a statistically significant trend at a 95% confidence interval.

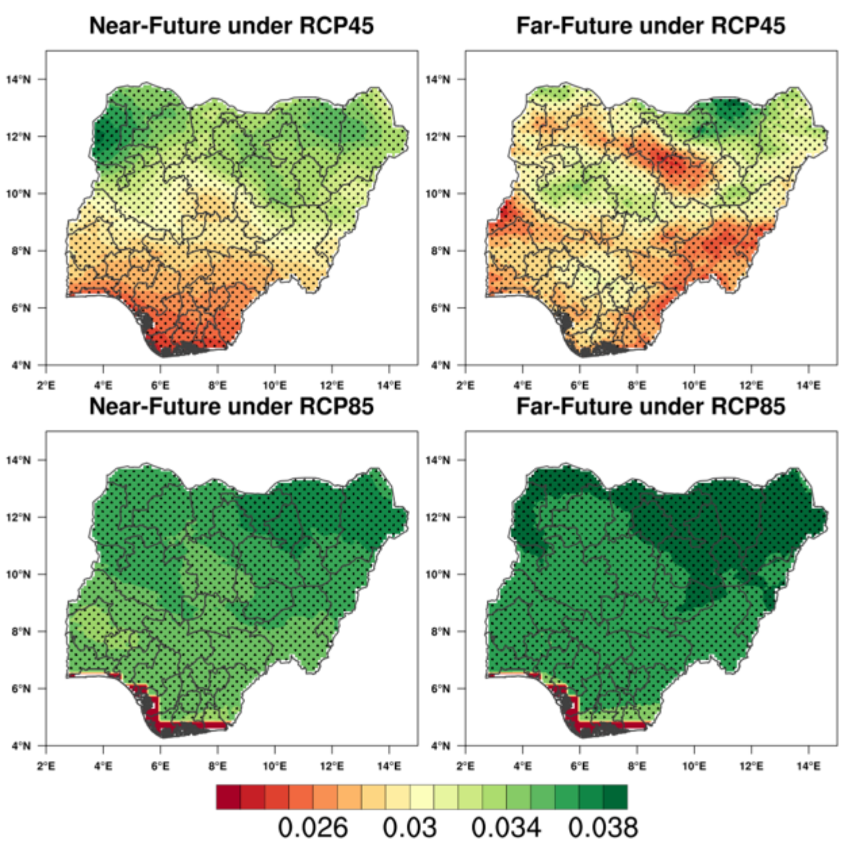

Figure 4

Mean annual temperature trend analysis result over Nigeria for near and far future. Stipples on the plot represent grid points with a statistically significant trend at a 95% confidence interval

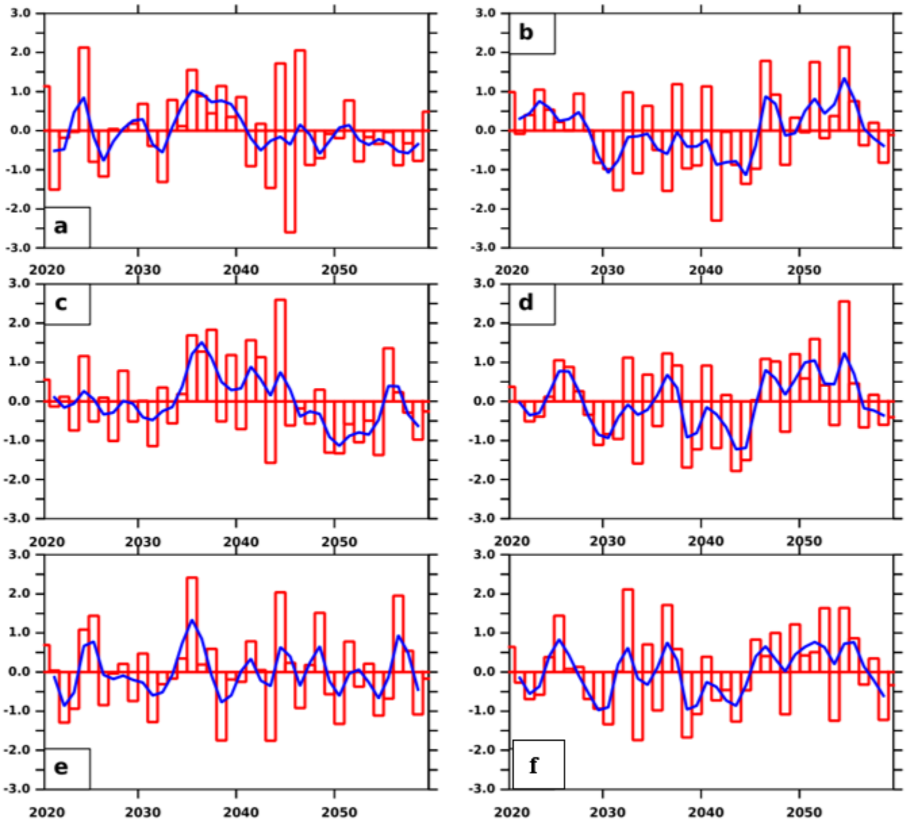

Figure 5

Standardized Rainfall Anomaly Index (SRAI) for the near-future under RCP4.5 (left panels) and RCP8.5 (right panels) over the Guinea Coast (a,b), Savannah (c,d) and Sahel (e,f) relative to the reference period (1961-2000) mean. Blue curve on each plot depicts non-linear trend of two years moving average

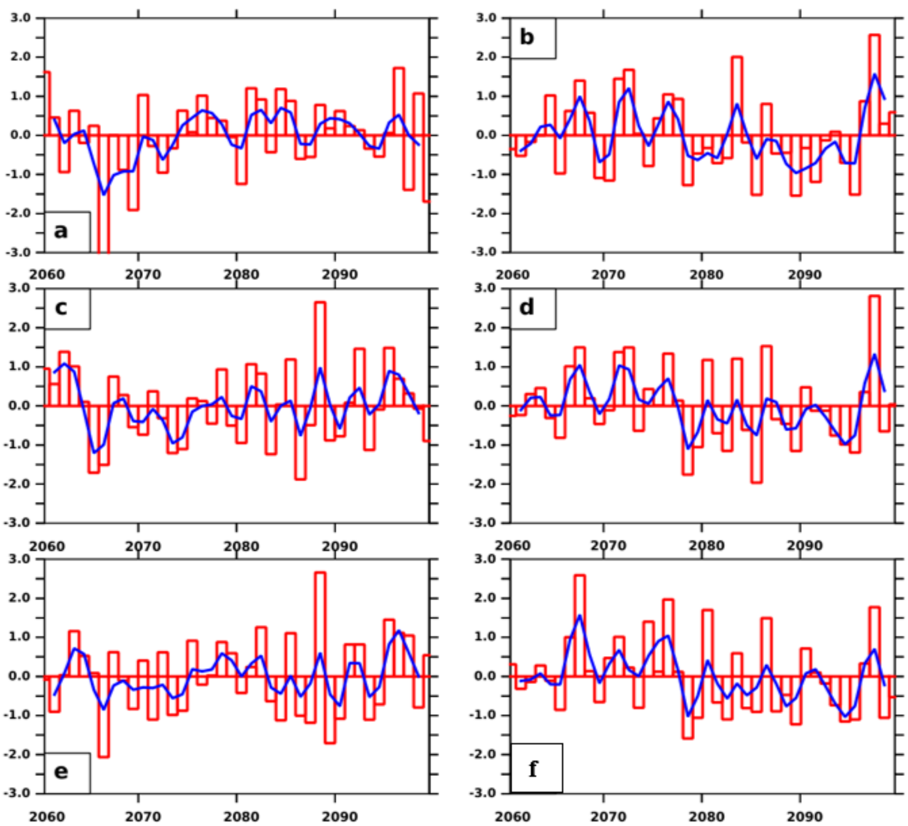

Figure 6

Standardized Rainfall Anomaly Index (SRAI) for the far-future under RCP4.5 (left panels) and RCP8.5 (right panels) over the Guinea Coast (a,b), Savannah (c,d) and Sahel (e,f) relative to the reference period (1961-2000) mean. Blue curve on each plot depicts non-linear trend of two years moving average

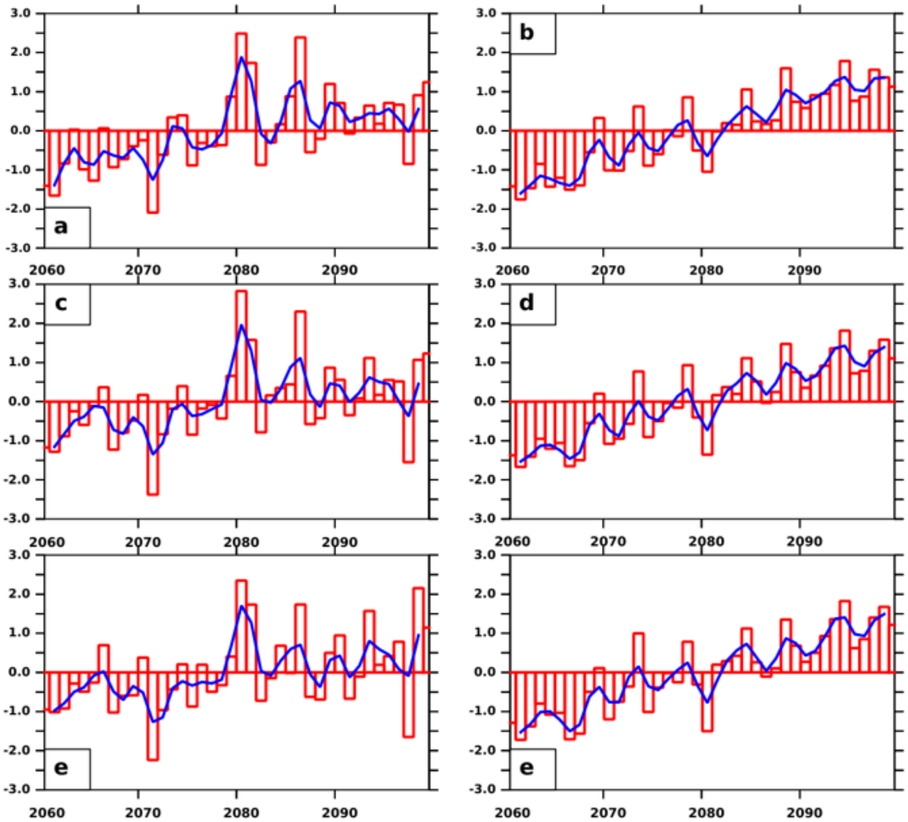

Figure 7

Standardized Temperature Anomaly Index (STAI) for the far-future under RCP4.5 (left panels) and RCP8.5 (right panels) over the Guinea Coast (a,b), Savannah (c,d) and Sahel (e,f) relative to the reference period (1961-2000) mean. Blue curve on each plot depicts non-linear trend of two years moving average