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# Rainfall dynamics in the Sudano-Sahelian zone of Nigeria under RCP 8.5

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**Abstract.** The study analysed the historical (1961–1990) and projected rainfall variability for the rainy season expected in the near future (2021–2050) at selected locations within the Komadugu-Yobe and Sokoto-Rima River Basins in the Sudano-Sahelian zone of northern Nigeria. Three models were utilised, and analyses were based on Representative Concentration Pathway (RCP) 8.5. Projected changes in mean, level of variability and distribution of rainfall were analysed using the Relative Percentage Change Method and the Precipitation Concentration Index (PCI), while the performance of the models was evaluated using the Nash–Sutcliffe Efficiency (NSE) index. The results show that changes in mean rainfall will be predominantly negative, with a minimum and maximum level of change of -1.02 per cent at Nguru, and -70.4 per cent at Jos, based on the IPSL-CM5A and HadGEM2-ES models, respectively. The rainy season of the baseline period varied between low and moderate variability, while the near future ranges between low and high levels of variability. The validation indicates acceptable levels of performance, with most values ranging between 0.0 and 1.0. The PCI for the near future suggests that the rainy season will be mainly characterised by uniform and near-uniform rainfall distribution. Hence, the projected negative changes and high variability of rainfall at some locations call for the development of an Adaptive Benefit Mechanism that will minimise future natural resource conflicts.

**Key words:**
Semi-arid,
Climate Scenario Prediction,
Rainfall variability and distribution,
Sokoto-Rima,
Komadugu-YobeVegetation

## Introduction

Rainfall in Nigeria, just like other parts of West Africa and Africa at large, displays high levels of spatio-temporal variability. According to Sarr (2012), rainfall will be highly impacted by climate change, becoming more variable and less reliable. As the imprints of anthropogenic climate change become obvious, the changes are projected to cause an intensification of rainfall variability that will result in a higher frequency of floods or drought (Twisa et al. 2019). The current global warming and increased variability of rainfall in West Africa are likely to be amplified in the future, with greater regional variations and different degrees of confidence depending on the Global Climate Models (GCMs) used (Intergovernmental Panel on Climate Change (IPCC) 2013; Sylla et al. 2016).

Potential future changes in the driving factors of rainfall in West Africa, viz: the meridional excursion of the sun, regional tropospheric jets, land–ocean differential heating, as well as moisture transport and recycling, would alter the mean climate conditions of the region (Dezfuli and Ichoku 2017). This would lead to great implications for water resources, agriculture together with food security and other socio-economic activities. Alteration in the mean climate conditions could lead to increased vulnerability, as communities in Africa have a low level of resilience and limited adaptive capacity to withstand climate-related shocks and stresses. This is a result of pervasive poverty, high disease burden and political instability in some countries (Williams and Kniveton 2011).

To have an insight into possible or expected changes in future rainfall characteristics and patterns in West Africa, various studies have been conducted using both Global Climate Models (GCMs) and Regional Climate Models (RCMs) based on different emission scenarios (Diallo et al. 2012; Diallo et al. 2014; Sylla et al. 2015; Adeniyi 2016; Ekwezuo et al. 2017; Akinsanola et al. 2017; Akumaga and Tarhule 2018; Dosio et al. 2020; Ilori and Ajayi 2020; Sow et al. 2020). In Nigeria, however, only a limited number of studies have been conducted to project some of the expected changes in the time series of future rainfall characteristics under different emission scenarios or RCPs.

For instance, Abiodun et al. (2012) investigated the potential impacts of global warming on future climate and extreme events in Nigeria for two future periods under the B1 and A2 emission scenarios. The study suggested that the climate of the country will be wetter, with the highest increase of about 0.8 mm/day near the coast and the lowest increase of about 0.2 mm/day in the north-east under the B1 scenario. Under the A2 scenario, rainfall is projected to decrease in the north-east, while most parts of the country are expected to experience an increase.

In a study to investigate the expected future spatio-temporal changes of rainfall in Nigeria for three future periods under all RCPs (2.6, 4.5, 6.0 and 8.5), Shiru et al. (2019) revealed that the dry regions of the country, especially the north, will become wetter. The study also showed that rainfall increases will be highest for all future periods studied for arid and semi-arid regions, where rainfalls are usually very low. In addition, the study also showed that seasonal changes in rainfall will increase by 0–2 per cent in most parts of the north (especially the north-east), with some decrease in rainfall at a few locations in the north-west. The southern parts, which usually experience higher rainfall, are expected to witness a general decline, with the highest decrease expected to occur in the south-east.

Fasona et al. (2019) analysed the past and future climate of the Lagos coastal environment using the MRI-CGCM 2.3.2 model under the business-as-usual scenario. The study indicated that, while the long-term mean annual rainfall over the study area declined by about -1.75 mm per year for the historical period 1892 to 2015, the future rainfall for the period 2016 to 2079 will increase by about 0.6 mm per year.

Assessing the challenges posed to the water resources of the city of Lagos in the context of change climate for a projected period of 2010 to 2099, Shiru et al. (2019) utilised 17 GCMs to investigate the expected changes in rainfall and temperature under all Representative Concentration Pathways. The outcome of the study showed that there will be a decrease in rainfall in the future for all RCPs, with the highest decrease of 140 mm projected by the HadGEM2-ES model under RCP 2.6. The study also indicated that there will be some exceptions to the expected general decline in rainfall for a few years at the end of the 21st century based on the results obtained from CESM_CAM5, CSIRO and HadGEM2-ES models.

The report of the Third National Communication of the Federal Republic of Nigeria under the United Nations Framework Convention on Climate Change (UNFCC) (2020) indicated that, according to RCPs 4.5 and 8.5, rainfall all over the country for the periods 2041–2060 and 2061–2080 will exhibit varying levels of increases across all ecological zones.

Despite the works that have been done to investigate different aspects of expected future rainfall in Nigeria, some other aspects, such as future precipitation concentration or distribution, have received little attention. A lack of understanding and paucity of information on future rainfall variability and distribution could undermine development in the agricultural and water-resources sectors of a country. It could also affect the livelihood of poor farmers who practise rain-fed agriculture and the herders who rely on natural polder to nourish their animals. Any negative impact on the livelihoods of these farmers could result in socio-economic upheaval and deleterious natural and human consequences.

Given the variable, unpredictable and sometimes irregular nature of rainfall, it is of utmost importance to investigate the spatio-temporal variations of rainfall, so as to have a scientific and practical basis for the development and management of agriculture and water resources, especially in developing adaptive benefit mechanisms for the expected scenario. The outcomes of such investigations could also serve as a guide for making reliable predictions on expected changes in the future.

The aim of this study, therefore, was to investigate some important aspects of rainfall variability at two very important river basins in the Sudano-Sahelian zone of Nigeria (Komadugu-Yobe River Basin and Sokoto-Rima River Basin). The study examined the projected changes in mean rainfall for the rainy season and each month of the rainy season in the near future. It analysed the temporal variation of rainfall during the rainy season and each month of the rainy season during the baseline period and the near future at the two river basins. Lastly, it determined the concentration or distribution of rainfall during the rainy season of the baseline period and the near future at the two river basins.

## Materials and methods

### Study area

This study is focused on six locations within the Komadugu-Yobe River basin (KYB) (represented by Jos, Kano, Bauchi, Potiskum, Maiduguri and Nguru meteorological stations) and four locations within the Sokoto-Rima River basin (SRB) (represented by Yelwa, Katsina, Sokoto and Gusau meteorological stations). These two river basins are located within the Sudano-Sahelian region of Nigeria (Fig. 1).

### Komadugu-Yobe River Basin

The Komadugu-Yobe River basin (Fig. 1) is a transboundary basin shared by Nigeria, the Niger Republic and parts of the Lake Chad basin. The KYB has its headwaters in the Jos Plateau and traverses five states in Nigeria (Kano, Jigawa, Bauchi, Yobe and Borno). It drains an area of 85,470 km2 within Nigeria before entering Lake Chad. The Yobe River sub-system is drained by many rivers, including the Kano, Hadejia and Jama'are / Bunga and Komadugu-Gana, which eventually come together to form the Yobe River system that later flows into Lake Chad (Oyebande 2001, 2008). The basin is predominantly located within the Sudano-Sahelian ecological zone, and the climate is characteristically semi-arid. The

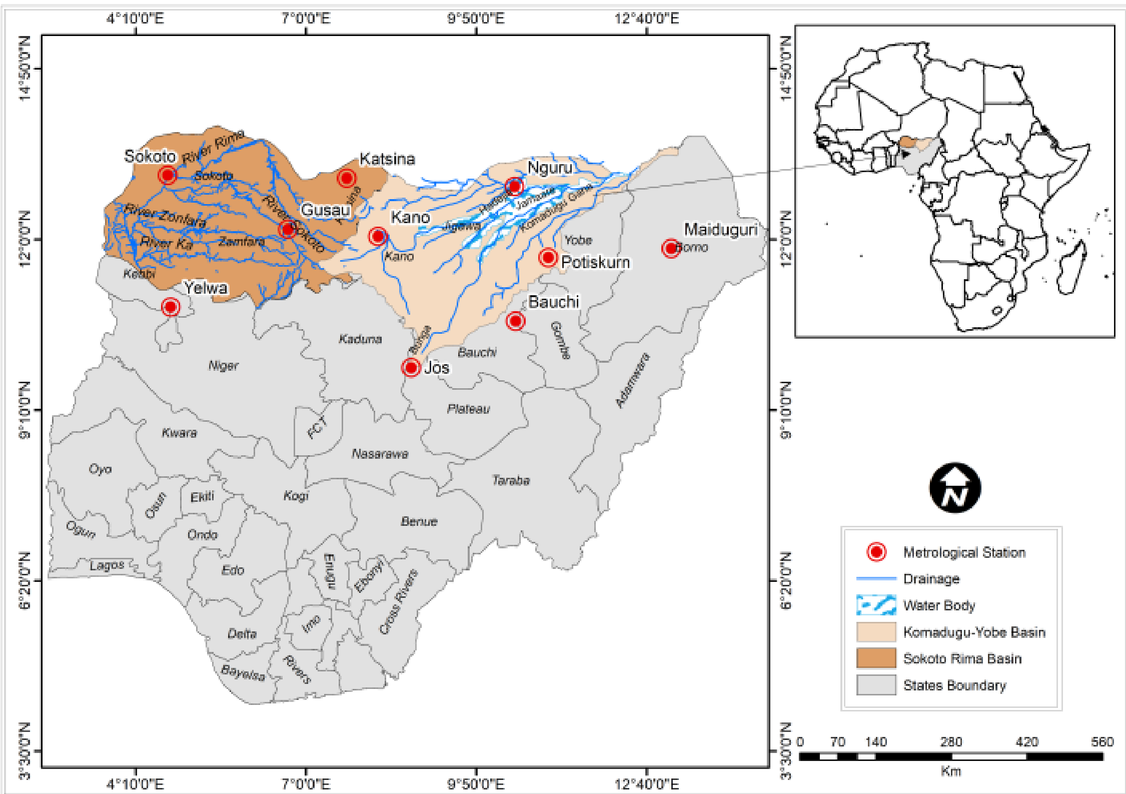

Fig. 1. Komadugu-Yobe and Sokoto-Rima River Basins

wet season usually begins in May and lasts until October (Adeyeri et al. 2019). Average rainfall in the basin varies from >1,000 mm in the upstream basement complex area to about 500 mm in the Hadejia-Nguru wetlands and less than 300 mm near Lake Chad (Oyebande 2008).

### Sokoto Rima River Basin

The Sokoto-Rima River basin (Fig. 1) is located in the semi-arid north-western part of Nigeria. It is situated within the Sudano-Sahelian ecological zone and covers an expanse of 131,000 km$^2$. The basin is bounded by the Niger Republic to the north and covers Sokoto, Kebbi, Zamfara and Katsina States in the east. It shares a boundary with the Benin Republic to the west and is bounded to the south-east by Niger state (Abdullahi 2014). The basin is largely drained by River Sokoto, which, along with its major tributaries the Ka, Zamfara and Rima, which originate from the Mashika and Dunnia highlands. At the source region in the eastern part of the basin, the river system is seasonal, while in the western parts it becomes perennial due to baseflow contribution from groundwater (Abdullahi 2014). Rainfall in the basin is highly seasonal, with the rainy season starting in May or June and lasting until September or early October, depending on the rainfall pattern for that year (Ezemonye and Chukwudi 2015). Information on the ten meteorological stations used for the study is provided in Table 1.

## Methods

The outputs of three coupled Model Inter-comparison Project Phase 5 (CMIP 5) projections of daily rainfall for the baseline period (1961 and 1990) and the near future (2021 to 2050) under RCP 8.5 were used for this study. RCP 8.5 represents a high pathway that reaches >8.5 W/m$^2$ by 2100 and continues rising for some time beyond 2100 (Riede et al. 2016). The three GCMs (Table 2) used for the study are available at http://cmip-pcmdi.llnl.gov/cmip5/. RCP 8.5 was used for the study because its underlying assumptions are similar to the prevailing conditions in Sub-Saharan Africa, where Nigeria is located (Ogunrinde et al. 2020). These assumptions are: high population growth, slow rate of economic development, and relatively slow tempo of technological change, coupled with increased greenhouse gas emission, moderate improvement rates of energy intensity and a dearth of good climate change policies (Riahi et al. 2011; Ogunrinde et al. 2020). HadGEM2-ES and IPSL-CM5A models were selected for use because they have been shown to simulate the observed climate of Nigeria well (Third National Communication of the Federal Republic of Nigeria under the UNFCC), while ICHEC- EC-EARTH was used because it is not a widely used model for climate change studies in Nigeria.

Daily observational data for the baseline period (1961–1990) were obtained from the Nigerian Meteorological Agency (NIMET). These data are maintained following the World Meteorological

Table 1. Meteorological Stations within the KYB and SRB

| Station | WMO ID | Latitude (°N) | Longitude (°E) | Elevation (m) |
|---|---|---|---|---|
| Maiduguri | 65082 | 11.85 | 13.08 | 353.8 |
| Potiskum | 65073 | 11.70 | 11.03 | 414.8 |
| Katsina | 65028 | 13.02 | 7.68 | 517.6 |
| Kano | 65046 | 12.05 | 8.20 | 472.5 |
| Nguru | 65064 | 12.88 | 10.47 | 343.1 |
| Bauchi | 65055 | 10.28 | 9.82 | 609.7 |
| Jos | 65134 | 9.87 | 8.75 | 1290.0 |
| Sokoto | 65010 | 13.02 | 5.25 | 350.8 |
| Yelwa | 65001 | 10.88 | 4.75 | 244.0 |
| Gusau | 65015 | 12.17 | 6.70 | 463.9 |

Source: Adefisan and Abatan (2015)

Table 2. Information on GCMs used for the study

| Model | Institution | Resolution (Long x Lat) |
|---|---|---|
| HadGEM2-ES | Hadley Centre Global Environmental Model 2-Earth System United Kingdom Meteorological Office | 1.875° × 1.24° |
| IPSL-CM5A | Institut Pierre-Simon Laplace | 2.5° × 1.259° |
| ICHEC-EC-EARTH | Consortium of European Research Institution and Research | 1.12° × 1.12° |

Source: Adefisan and Abatan (2015)

Organisation (WMO) approved guidelines and quality control. The baseline period of 1961–1990 was selected following the WMO climatological normal baseline period (IPCC-TGICA, 2007). The daily data for both observational and projected rainfall were aggregated to monthly data.

## Assessment of changes in mean rainfall

The projected changes in mean rainfall were determined for the rainy reason (May–Oct) and each month of the rainy season. The changes from the baseline period were computed using the Relative Percentage Change Method, as shown in equation 1, which is expressed as:

$$\bar{P}_{change} = 100\,X \left(\frac{\bar{P}_{future} - \bar{P}_{baseline}}{\bar{P}_{bseline}}\right)$$

Where $\bar{P}_{future}$ and $\bar{P}_{baseline}$ represent mean for the future (2021–2050) and mean for the baseline period (1961–1990), respectively.

## Assessment of temporal variation of baseline and future rainfall

The level of variation of rainfall for the rainy season and each month of the rainy season for both the baseline and the projected future period was determined using the coefficient of variation expressed as:

$$CV = \frac{\sigma}{\bar{P}}\, X\, 100$$

Where $\bar{P}$ is the long-term mean rainfall (for the rainy season and each month of the rainy season, as applicable), and $\sigma$ is the standard deviation of rainfall (for the rainy season of each year and each month of the rainy season for each year, as applicable). The values for the coefficient of variation were classified based on Hare (1992) as follows:

CV < 20 = Less variable
20 < CV < 30 = Moderate variability
CV > 30 = High variability

## Validation of model performance

The performance of the selected models was evaluated using the Nash–Sutcliffe Efficiency index, which is expressed as:

$$NSE = 1 - \frac{\sum_{i=1}^{n} (Y_i^{Obs} - Y_i^{Prd})^2}{\sum_{i=1}^{n} (Y_i^{Obs} - Y_i^{Mean})^2}$$

Where $Y_i^{Obs}$ and $Y_i^{Prd}$ are the observed and predicted rainfall, respectively, $Y^{Mean}$ is mean predicted rainfall and n is the number of observations. The values of NSE vary between -∞ and 1, with NSE of 1 being the optimal value. Values in the range of 0.0 to 1.0 are considered to be acceptable levels of performance, while values of ≤0.0 suggest that the mean observation value is a better predictor than the predicted value, which indicates unacceptable performance (Moriasi et al. 2007).

### Concentration or distribution of rainfall

The concentration or distribution of rainfall during the rainy season of the baseline period and the projected future period was assessed using the Precipitation Concentration Index (PCI). The PCI as proposed by Oliver (1980) is an indicator of the temporal distribution of rainfall (de Luis 2011). The PCI was computed for the six months of the rainy season according to Equation 4 below as:

$$PCI_{rainy\ season} = \frac{\sum_{i=1}^{6} Pi^2}{(\sum_{i=1}^{6} Pi)^2} X\ 50$$

The number 50 in the equation represents the six months of the rainy season, which is 50 per cent of the months of the year. The values of the PCI according to their categorisation and interpretation are as shown in Table 3. A PCI value of 10 was interpreted as near-uniform concentration or near-low precipitation distribution.

## Results and discussion

### Changes in mean rainfall

The results obtained from the three GCMs used for this study indicate that the projected changes in mean rainfall for the rainy season at the two river basins for the near future will be negative (Figs 2 to 7). The only exception is the Nguru station in the KYB, which is projected to exhibit a positive change of 29.2 per cent based on the EcEarth model. This result is in line with previous studies (Akinsanola and Zhou 2018; Shiru et al. 2019) that have shown that both positive and negative localised changes may be experienced in future rainfalls in the region. Furthermore, the lowest or minimum level of change of -1.02 per cent is also projected to occur at Nguru based on the IPSL-CM5A model, while the highest level of change of -70.4 per cent is expected at Jos based on the HadGem2 model.

Projected changes in the mean rainfall for each month of the rainy season based on the EcEarth Model are as presented in Table 4. As shown in the table, the projected changes in the rainfall for May in the KYB are expected to vary between -48.5 per cent and 460.3 per cent, while the changes in the SRB are projected to be between -25.1 per cent and 171.8 per cent. For June, the projected changes in rainfall in the KYB are predominantly negative, except for Nguru, where a positive change of 81.7 per cent is expected. In the SRB, negative changes in the range of -29.7 per cent to -51.5 per cent are expected.

For July and August, negative changes are expected at all the locations in the two river basins. This is an indication that rainfall peak in the near future is likely to be less intense and more variable. Furthermore, the projected negative change expected for August seems to attest to the fact that rainfall for August in the Sudano-Sahelian zone has not made a full recovery (Nicolson 2005). This fact was made evident by Nicholson (2013), who shows about 55 per cent reduction in the mean for August rainfall between 1931 and 1960, and about 37 per cent reduction between 1968 and 1997.

For September, all the stations within the KYB are expected to exhibit negative changes, while, in the SRB, all the stations except Gusau are projected to exhibit negative changes. For October, all the stations at both river basins are projected to experience very high positive changes in rainfall. The high level of positive changes expected in the month of October is consistent with the results obtained for retreat period rainfall by Adeniyi (2016) for the rainfall regions of the Sahel.

Table 3. Classification of Precipitation Concentration Index

| PCI Values | Interpretation |
|---|---|
| <10 | Uniform precipitation distribution / low precipitation concentration |
| 11–15 | Moderate precipitation distribution / moderation precipitation concentration |
| 16–20 | Irregular precipitation distribution / irregular precipitation concentration |
| >20 | Strong irregularity of distribution / high precipitation concentration |

Source: Adefisan and Abatan (2015)

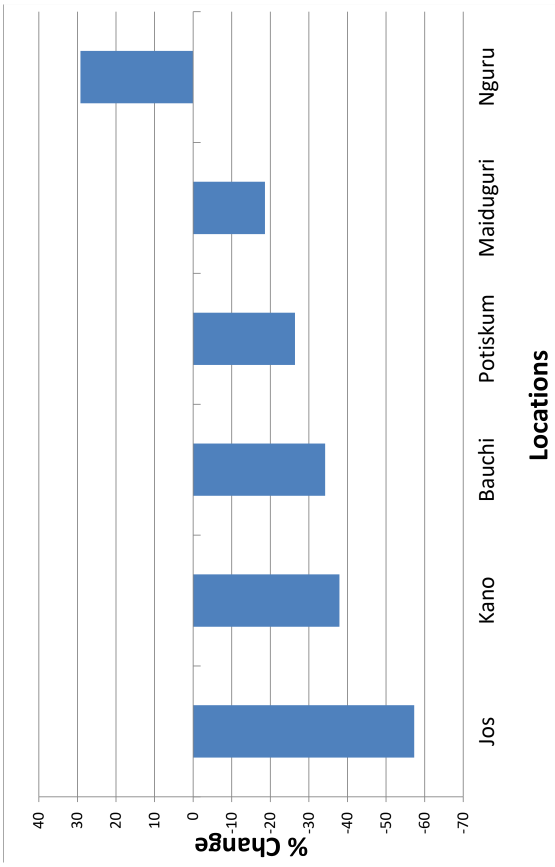


Fig. 2. Per cent change in projected mean rainfall for the rainy season for KYB based on EcEarth Model

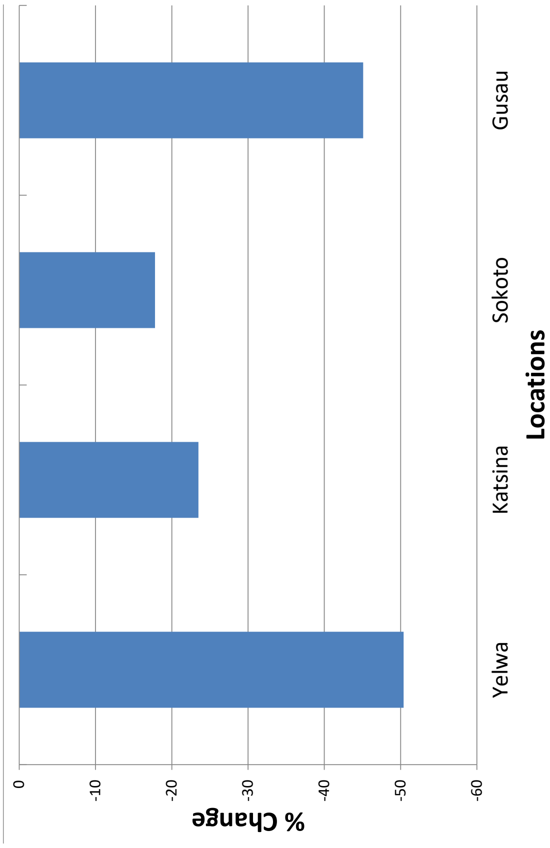


Fig. 3. Per cent change in projected mean rainfall for the rainy season for SRB based on EcEarth Model

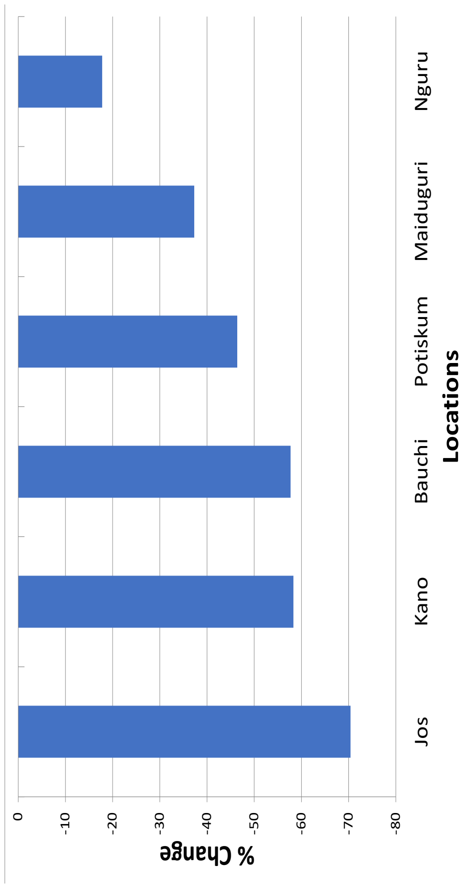


Fig. 4. Per cent change in projected mean rainfall for the rainy season for KYB based on HadGem2 Model

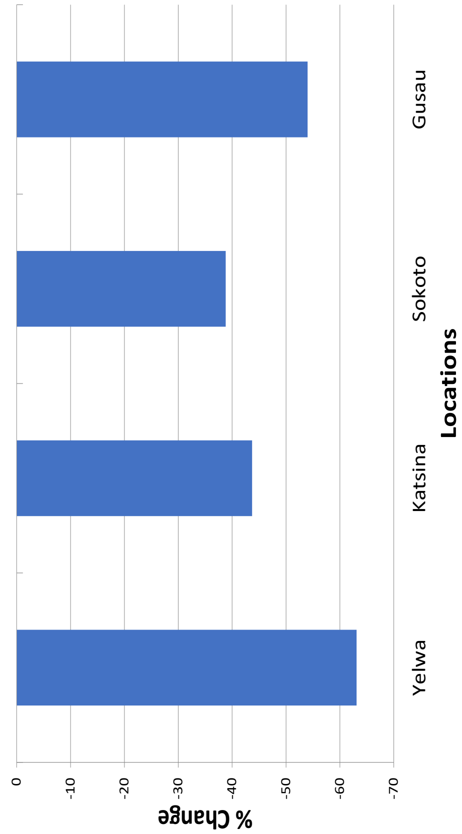


Fig. 5. Per cent change in projected mean rainfall for the rainy season for SRB based on HadGem2 Model

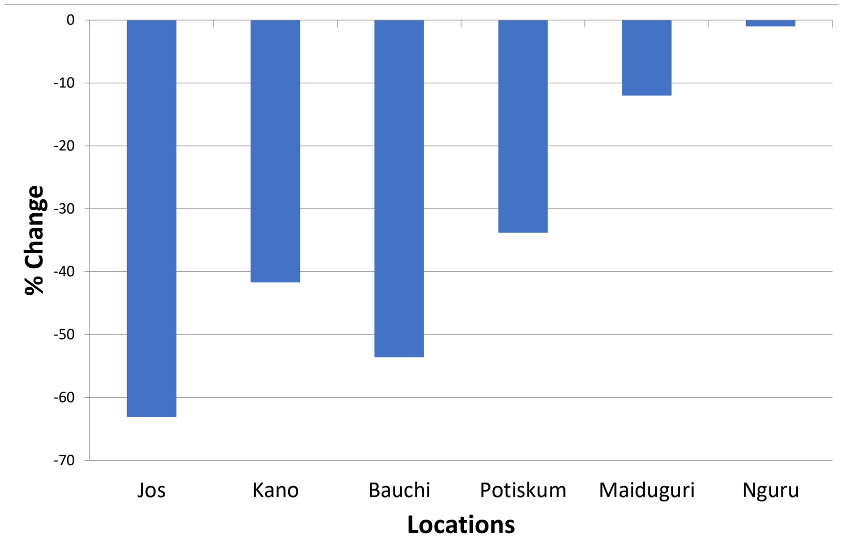


Fig. 6. Per cent change in projected mean rainfall for the rainy season for KYB based on IPSL-CM5A Model

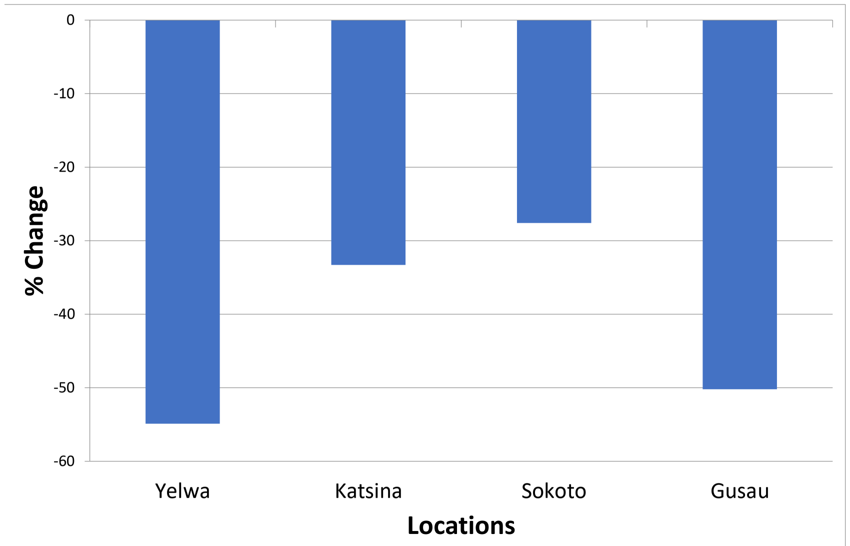


Fig. 7. Per cent change in projected mean rainfall for the rainy season for SRB based on IPSL-CM5A Model

Table 4. Projected changes in mean monthly rainfall for the HadGem2 model

| | | Months | | | | | |
|---|---|---|---|---|---|---|---|
| Basin | Station | May | Jun | Jul | Aug | Sep | Oct |
| KYB | Jos | -65.9 | -71.4 | -78.7 | -79 | -73.3 | 60.7 |
| KYB | Kano | -11.3 | -52 | -69.0 | -80.3 | -56.5 | 302.3 |
| KYB | Bauchi | -33.3 | -56.9 | -69.1 | -75.2 | -57.9 | 115.5 |
| KYB | Potiskum | 51.4 | -29.4 | -63.9 | -72.8 | -50.6 | 218 |
| KYB | Maiduguri | 122.4 | -22.6 | -57.6 | -69.6 | -41.8 | 475.3 |
| KYB | Nguru | 250.7 | 24.3 | -45.5 | -67.0 | -16.1 | 687.4 |
| SRB | Yelwa | -44.5 | -64.9 | -69.0 | -76.4 | -71.1 | 33.1 |
| SRB | Katsina | 102.9 | -32.3 | -64.1 | -74.4 | -45 | 485.5 |
| SRB | Sokoto | 86.7 | -41.0 | -57.4 | -68.0 | -44.6 | 267.2 |
| SRB | Gusau | -15.7 | -46.5 | -65.2 | -75.1 | -64.9 | 151.8 |

Based on the results from the HadGem2 model for the month of May (Table 5), negative changes are projected for Jos, Kano and Bauchi and positive changes for Potiskum, Maiduguri and Nguru in the KYB. In the SRB, negative changes are expected at Yelwa and Gusau, while positive changes are expected at Katsina and Sokoto. For June, all locations in the KYB, except Nguru will experience negative changes. In the same vein, all the locations in the SRB are also expected to experience negative changes. For July, August and September, the locations in both river basins are expected to exhibit negative changes, while all the locations are to experience positive changes in October.

For the IPSL-CM5A (Table 6), in the month of May, most of the locations in the KYB are projected to experience positive changes within the range of 43.4 per cent to 193.1 per cent. In the SRB, Sokoto and Katsina are projected to experience positive changes, while Yelwa and Gusau are projected to experience negative changes of -29.5 and -4.2 per cent, respectively. For the month of June, in the KYB, all but Maiduguri and Nguru will experience negative changes, just like all the stations in the SRB will also experience negative changes. For July and August, both river basins are projected to experience negative changes, while Nguru will be the only location to experience a positive change in the month of September. For October, all the locations in both river basins are projected to experience positive changes.

It is noted that Jos, which is a major headwater region of many rivers in northern Nigeria, is projected to experience a high magnitude of negative changes by the three models, with the exception of October. This situation has the potential to negatively impact water availability by reducing surface runoff and river discharge. In the SRB, a similar pattern is exhibited at Yelwa, which is located upstream of the Kainji Reservoir. Negative changes in rainfall at Yelwa may likely contribute to a reduction of inflow into the country's largest hydropower reservoir, reducing its ability to maintain its maximum pool elevation.

Table 5. Projected changes in mean monthly rainfall for the IPSL-CM5A model

| | | Months | | | | | |
|---|---|---|---|---|---|---|---|
| **Basin** | **Station** | **May** | **Jun** | **Jul** | **Aug** | **Sep** | **Oct** |
| KYB | Jos | -54.7 | -57 | -77.9 | -76.0 | -64.0 | 85.2 |
| KYB | Kano | 43.4 | -39.5 | -58.1 | -68.2 | -35.9 | 356.9 |
| KYB | Bauchi | -16.9 | -43.1 | -74.4 | -77.0 | -50.6 | 153.3 |
| KYB | Potiskum | 168.9 | -7.5 | -60.5 | -69.9 | -25.8 | 319.8 |
| KYB | Maiduguri | 140.8 | 12.2 | -32.4 | -59.9 | -12.2 | 739.7 |
| KYB | Nguru | 193.1 | 48.6 | -35.4 | -59.6 | 22.7 | 965.5 |
| SRB | Yelwa | -29.5 | -43.4 | -61.5 | -76.7 | -66.2 | 45.1 |
| SRB | Katsina | 103.5 | -8.5 | -56.6 | -71.1 | -27.2 | 549.3 |
| SRB | Sokoto | 82.4 | -21.5 | -55.9 | -62.9 | -23.5 | 365.4 |
| SRB | Gusau | -4.2 | -40.4 | -4.2 | -75.9 | -57.6 | 162.8 |

Table 6. Projected changes in mean monthly rainfall for the IPSL-CM5A model

| | | Months | | | | | |
|---|---|---|---|---|---|---|---|
| **Basin** | **Station** | **May** | **Jun** | **Jul** | **Aug** | **Sep** | **Oct** |
| KYB | Jos | -54.7 | -57.0 | -77.9 | -76.0 | -64.0 | 85.2 |
| KYB | Kano | 43.4 | -39.5 | -58.1 | -68.2 | -35.9 | 356.9 |
| KYB | Bauchi | -16.9 | -43.1 | -74.4 | -77.0 | -50.6 | 153.3 |
| KYB | Potiskum | 168.9 | -7.5 | -60.5 | -69.9 | -25.8 | 319.8 |
| KYB | Maiduguri | 140.8 | 12.2 | -32.4 | -59.9 | -12.2 | 739.7 |
| KYB | Nguru | 193.1 | 48.6 | -35.4 | -59.6 | 22.7 | 965.5 |
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| SRB | Sokoto | 82.4 | -21.5 | -55.9 | -62.9 | -23.5 | 365.4 |
| SRB | Gusau | -4.2 | -40.4 | -4.2 | -75.9 | -57.6 | 162.8 |

## Temporal variation of baseline and future rainfall

The variability of rainfall in the study area, just like in other parts of the Sudano-Sahelian region of West Africa, is influenced by several factors. These includes fluctuations in high-altitude jet-stream circulation, which is made up of the African Easterly Jet (AEJ), the Tropical Easterly Jet (TEJ), the African Westerly Jet (AWJ), Low-Level Jets, the West African Westerly Jet (WAWJ), the Nocturnal Low-Level Jets (NLLJ), the Saharan Heat Low (SHL), and the Saharan Air Layer (SAL) that is responsible for the spatio-temporal variability of rainfall in the region, as well as seasonal regime changes (Nkiaka et al. 2017).

At the study locations, the rainy season of the baseline period varied between low and moderate variability. In the KYB, (Table 7), the coefficient of variability ranged between 11.6 per cent at the Jos station and 28.1 per cent at the Nguru station, while the values varied between 12.6 per cent at Gusau and 24.6 per cent at Katsina in the SRB.

For the projected near future, the EcEarth Model indicated that rainfall during the rainy season in the KYB will mostly be less variable (Table 8), with values ranging from 17.7 per cent to 19.8 per cent, except at Maiduguri, where rainfall is projected to be moderately variable, with a coefficient of variation of 20.9 per cent. In the SRB, the rainy season is expected to exhibit low variability ranging from 17.5 per cent to 18.3 per cent, except for Gusau, which is expected to be characterised by moderate variability, with a coefficient of variation of 20.5 per cent.

The HadGem2 model (Table 9) suggests that the rainy season in the KYB will exhibit a combination of low, moderate and high levels of variability in the near future. Low variabilities of 16 per cent, 17.7 per cent and 19.6 per cent are expected at Potiskum, Maiduguri and Bauchi, respectively, while moderate variabilities of 20.8 per cent and 23.5 per cent are expected at Jos and Nguru, and a high level of variability of 31 per cent at Kano. In the SRB, the rainy season is expected to be principally moderately variable, with the coefficient of variation ranging from 20.4 per cent to 22 per cent, while the rainy season at Katsina is expected to be less variable, with a coefficient of variation of 17.3 per cent.

For the IPSL-CM5A model (Table 10), the rainy season at most of the stations in the KYB (67 per cent of the stations) is expected to be moderately variable, with a coefficient of variation in the range of 20.3 per cent to 23.8 per cent, except for Nguru and Potiskum, where low variability is expected. In the SRB, rainfall at all the stations is expected to be moderately variable, with values in the range of 22.4 per cent to 24.9 per cent. These results are within the range of values for semi-arid regions of West Africa. According to Nicholson, (2018), the coefficient of variation for semi-arid regions of West Africa varies from 20 per cent in the southern parts, to between 75 per cent and 100 per cent in the northern parts.

Based on these results, it can be inferred that, in spite of the generally negative changes of mean rainfall projected for the rainy season, the wet season is expected in the near future to experience a moderate to high level of rainfall reliability. This implies that the near future will be favourable for rain-fed agriculture and water resources in general. At Kano, however, the high level of variability is an indication of low rainfall reliability and a vulnerability to drought conditions.

The individual months of the rainy season for the baseline period showed that May in both river basins was highly variable (Table 11), ranging from 34.5 per cent to 170.2 per cent in the KYB, and between 48.5 per cent and 90.1 per cent in the SRB. A high level of rainfall variability is not uncommon at the

Table 7. Variability of rainfall during the rainy season for the baseline period

| | KYB | | | | | | SRB | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Jos | Kano | Bauchi | Potiskum | Maiduguri | Nguru | Yelwa | Katsina | Sokoto | Gusau |
| CV (%) | 11.6 | 22.5 | 15.5 | 25.8 | 25.1 | 28.1 | 16.1 | 24.6 | 23.6 | 12.6 |

Table 8. Variability of rainfall during the rainy season of the near future based on EcEarth model

| | KYB | | | | | | SRB | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Jos | Kano | Bauchi | Potiskum | Maiduguri | Nguru | Yelwa | Katsina | Sokoto | Gusau |
| CV (%) | 18.0 | 19.0 | 19.8 | 17.7 | 20.2 | 18.7 | 17.5 | 18.0 | 18.3 | 20.7 |

Table 9. Variability of rainfall during the rainy season of the near future based on HadGem2 model

| | KYB | | | | | | SRB | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Jos** | **Kano** | **Bauchi** | **Potiskum** | **Maiduguri** | **Nguru** | **Yelwa** | **Katsina** | **Sokoto** | **Gusau** |
| CV (%) | 20.8 | 56.5 | 19.6 | 16.0 | 17.7 | 23.5 | 22.0 | 17.3 | 20.9 | 20.4 |

Table 10. Variability of rainfall during the rainy season of the near future based on IPSL-CM5A model

| | KYB | | | | | | SRB | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Jos** | **Kano** | **Bauchi** | **Potiskum** | **Maiduguri** | **Nguru** | **Yelwa** | **Katsina** | **Sokoto** | **Gusau** |
| CV (%) | 23.8 | 22.1 | 22.4 | 19.9 | 20.3 | 14.3 | 24.9 | 22.4 | 24.3 | 23.7 |

onset of the rainy season. According to Odumodu (1983), rainfall variability is usually higher at the onset and cessation of the rainy season than it is during the middle of the season. High variability and the low level of reliability associated with the onset of the rainy season leads to uncertainty and disruption of the scheduling of farm operations (Bello 1996).

The month of June was also highly variable, except in Jos, which was categorised as moderately variable, with a coefficient of variation value of 20.7 per cent. The months of July and August were moderately variable at Bauchi, Gusau and Jos, while rainfall was highly variable at other locations. The months of September and October were highly variable except at Yelwa, where the rainfall for September was moderately variable, with a coefficient of variation of 29 per cent.

For the individual months of the rainy season for the near future, the EcEarth model (Table 12) indicates that the individual months of the rainy season will be mainly characterised by high variability, except for Bauchi, Maiduguri and Potiskum (in the KYB), where the month of October is expected to be moderately variable. The HaGem2 and the IPSL-CM5A models (Tables 13 and 14) suggest that each month of the rainy season in the two river basins will be highly variable. These results imply that, despite the predominantly low to moderate variability of rainfall being projected for the rainy season, rainfall in the individual months that make up the rainy season will be most highly variable.

## Model performance / validation

The validation results (Table 15) show that most of the values were within the acceptable range, indicating acceptable levels of performance by the models. The only exceptions were the performances of EcEarth and HadGem2 in predicting the rainfall at Nguru, with an NSE value of -0.07 for both models, and the performance of HadGem2 at Katsina, with an NSE value of -0.04. Cumulatively, IPSL-CM5A performed best in rainfall prediction, with all ten stations having values within the acceptable range. EcEarth model has nine stations within the acceptable range, while HadGem2 model had eight.

Table 11. Variability of rainfall for each month of the rainy season for the baseline period

| | KYB | | | | | | SRB | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Jos** | **Kano** | **Bauchi** | **Potiskum** | **Maiduguri** | **Nguru** | **Yelwa** | **Katsina** | **Sokoto** | **Gusau** |
| | CV (%) | | | | | | CV (%) | | | |
| May | 34.5 | 68.8 | 43.4 | 84.8 | 81.9 | 170.2 | 48.5 | 90.1 | 72.4 | 52.2 |
| Jun | 20.7 | 57.9 | 32.3 | 63.7 | 50.0 | 87.1 | 33.7 | 50.4 | 55.7 | 35.0 |
| Jul | 22.2 | 41.6 | 30.0 | 40.4 | 36.5 | 48.3 | 37.9 | 43.7 | 38.2 | 28.8 |
| Aug | 21.6 | 39.2 | 26.8 | 44.0 | 44.3 | 38.1 | 32.7 | 34.9 | 33.3 | 26.2 |
| Sep | 34.2 | 48.0 | 41.5 | 43.2 | 51.9 | 58.7 | 29.0 | 40.4 | 42.8 | 36.7 |
| Oct | 89.9 | 157.5 | 73.5 | 129.3 | 185.6 | 227.2 | 88.3 | 192.6 | 168.4 | 134.9 |

Table 12. Variability of rainfall for each month of the rainy season for the near future based on EcEarth model

| | KYB | | | | | | SRB | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Jos** | **Kano** | **Bauchi** | **Potiskum** | **Maiduguri** | **Nguru** | **Yelwa** | **Katsina** | **Sokoto** | **Gusau** |
| | CV (%) | | | | | | CV (%) | | | |
| May | 44.0 | 55.4 | 47.6 | 47.9 | 53.4 | 45.4 | 55.1 | 38.3 | 45.2 | 42.9 |
| Jun | 33.7 | 56.2 | 45.5 | 41.3 | 47.7 | 36.4 | 50.1 | 53.2 | 44.0 | 45.3 |
| Jul | 41.3 | 59.9 | 51.9 | 39.5 | 40.0 | 44.0 | 45.8 | 43.2 | 39.7 | 54.0 |
| Aug | 52.1 | 56.1 | 52.1 | 47.8 | 62.4 | 58.1 | 48.8 | 54.8 | 43.8 | 53.6 |
| Sep | 43.6 | 34.3 | 49.3 | 42.9 | 46.5 | 35.6 | 40.7 | 41.1 | 43.0 | 41.1 |
| Oct | 38.3 | 31.6 | 28.8 | 30.0 | 26.1 | 30.8 | 37.7 | 31.5 | 45.6 | 40.6 |

Table 13. Variability of rainfall for each month of the rainy season for the near future based on HadGem2 model

| | KYB | | | | | | SRB | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Jos** | **Kano** | **Bauchi** | **Potiskum** | **Maiduguri** | **Nguru** | **Yelwa** | **Katsina** | **Sokoto** | **Gusau** |
| | CV (%) | | | | | | CV (%) | | | |
| May | 58.6 | 56.5 | 50.8 | 44.9 | 53.8 | 47.4 | 63.1 | 47.8 | 55.7 | 58.5 |
| Jun | 51.0 | 72.8 | 50.0 | 40.8 | 48.0 | 71.8 | 54.4 | 70.9 | 47.2 | 59.2 |
| Jul | 48.1 | 43.6 | 43.3 | 33.7 | 34.7 | 47.7 | 49.7 | 40.6 | 39.0 | 42.9 |
| Aug | 44.5 | 56.6 | 40.5 | 49.2 | 48.7 | 41.2 | 53.3 | 44.7 | 48.2 | 50.0 |
| Sep | 40.1 | 48.5 | 36.5 | 35.2 | 38.2 | 32.1 | 42.6 | 46.8 | 44.9 | 47.0 |
| Oct | 48.0 | 56.1 | 37.4 | 42.3 | 35.6 | 42.4 | 44.8 | 47.0 | 49.8 | 44.0 |

Table 14. Variability of rainfall for each month of the rainy season for the near future based on IPSL-CM5A model

| | KYB | | | | | | SRB | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Jos** | **Kano** | **Bauchi** | **Potiskum** | **Maiduguri** | **Nguru** | **Yelwa** | **Katsina** | **Sokoto** | **Gusau** |
| | CV (%) | | | | | | CV (%) | | | |
| May | 50.2 | 61.1 | 46.9 | 44.5 | 42.6 | 46.7 | 51.0 | 51.0 | 59.6 | 56.8 |
| Jun | 48.4 | 41.6 | 48.6 | 41.3 | 39.4 | 41.2 | 53.2 | 47.2 | 53.7 | 49.7 |
| Jul | 43.8 | 47.3 | 66.1 | 52.5 | 47.8 | 49.3 | 51.8 | 43.5 | 45.5 | 44.2 |
| Aug | 66.5 | 62.8 | 55.8 | 58.4 | 48.4 | 38.4 | 60.5 | 45.7 | 59.0 | 68.9 |
| Sep | 47.6 | 42.9 | 41.8 | 41.8 | 49.2 | 39.8 | 55.6 | 55.7 | 44.9 | 47.9 |
| Oct | 37.1 | 32.2 | 46.9 | 46.9 | 34.8 | 36.0 | 36.7 | 34.8 | 34.5 | 37.2 |

Table 15. Values of Nash–Sutcliffe Efficiency Index for the three models

| **Months**<br>**Basin** | **Station** | **EcEarth** | **HadGem2** | **IPSL-CM5A** |
|---|---|---|---|---|
| KYB | Jos | 0.96 | 0.28 | 0.93 |
| KYB | Kano | 0.87 | 0.28 | 0.87 |
| KYB | Bauchi | 0.94 | 0.23 | 0.92 |
| KYB | Potiskum | 0.87 | 0.17 | 0.66 |
| KYB | Maiduguri | 0.65 | 0.09 | 0.53 |
| KYB | Nguru | -0.07 | -0.07 | 0.45 |
| SRB | Yelwa | 0.94 | 0.40 | 0.87 |
| SRB | Katsina | 0.79 | -0.04 | 0.66 |
| SRB | Sokoto | 0.87 | 0.07 | 0.44 |
| SRB | Gusau | 0.96 | 0.25 | 0.60 |

Table 16. Number of years of different PCI classes for the baseline period

| PCI Classes | KYB | | | | | | | SRB | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Jos | Kano | Bauchi | Potiskum | Maiduguri | Nguru | Yelwa | Katsina | Sokoto | Gusau |
| NURD | 17 | 1 | 4 | - | 1 | 1 | 7 | - | 3 | 2 |
| URB | 1 | - | - | 1 | - | - | 4 | - | 4 | 1 |
| MRD | 12 | 23 | 26 | 23 | 21 | 15 | - | 22 | - | 27 |
| IRD | - | 6 | - | 6 | 7 | 10 | 19 | 7 | 23 | - |
| SIRD | - | - | - | - | 1 | 4 | - | 1 | - | - |

*NURD means Near Uniform Rainfall Distribution, URD means Uniform Rainfall Distribution, MRD means Moderate Rainfall Distribution, IRD means Irregular Rainfall Distribution and SIRD means Strongly Irregular Rainfall Distribution

## Concentration or distribution of rainfall

The analyses of rainfall concentration or distribution for the rainy season of the baseline period (Table 16) reveals that rainfall was predominantly moderately distributed at the two river basins. In the KYB, moderate rainfall concentration varied from 12 years at Jos to 26 years at Bauchi. In the SRB, moderate rainfall distribution varied from 22 years at Katsina to 27 years at Gusau. At Bauchi, Kano and Maiduguri in the KYB, and at Katsina in the SRB, none of the years experienced a uniform distribution of rainfall during the rainy season, while at Jos, 17 years were categorised as having experienced near-uniform concentration.

Irregular distribution of rainfall varied between six years and ten years in the KYB. In the SRB, irregular distribution of rainfall varied between seven and 23 years, while the rainy season of one year at Katsina was categorised as strongly irregular. It is observed that the years whose rainy season was categorised to have experienced irregular and strongly irregular rainfall distribution coincided with the years when the Sudano-Sahelian Zone of Nigeria and West Africa at large experienced drought episodes of varying severity (Ayode 1977; Adefolalu 1986).

For the near future (Tables 17 to 19), the rainy season is projected to be mostly characterised by uniform and near-uniform precipitation

Table 17. Number of years of different PCI classes for the near future based on EcEarth model

| PCI Classes | KYB | | | | | | | SRB | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Jos | Kano | Bauchi | Potiskum | Maiduguri | Nguru | Yelwa | Katsina | Sokoto | Gusau |
| NURD | 12 | 13 | 10 | 12 | 13 | 9 | 11 | 10 | 14 | 10 |
| URB | 14 | 9 | 13 | 14 | 12 | 18 | 13 | 14 | 12 | 15 |
| MRD | 4 | 8 | 7 | 4 | 5 | 3 | 6 | 6 | 4 | 5 |
| IRD | - | - | - | - | - | - | - | - | - | - |
| SIRD | - | - | - | - | - | - | - | - | - | - |

*NURD means Near Uniform Rainfall Distribution, URD means Uniform Rainfall Distribution, MRD means Moderate Rainfall Distribution, IRD means Irregular Rainfall Distribution and SIRD means Strongly Irregular Rainfall Distribution

Table 18. Number of years of different PCI classes for the near future based on HadGem2 model

| PCI Classes | KYB | | | | | | | SRB | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Jos | Kano | Bauchi | Potiskum | Maiduguri | Nguru | Yelwa | Katsina | Sokoto | Gusau |
| NURD | 11 | 15 | 10 | 12 | 3 | 10 | 13 | 9 | 13 | 7 |
| URB | 11 | 10 | 15 | 14 | 20 | 15 | 8 | 13 | 12 | 13 |
| MRD | 8 | 5 | 5 | 4 | 7 | 5 | 9 | 8 | 5 | 10 |
| IRD | - | - | - | - | - | - | - | - | - | - |
| SIRD | - | - | - | - | - | - | - | - | - | - |

*NURD means Near Uniform Rainfall Distribution, URD means Uniform Rainfall Distribution, MRD means Moderate Rainfall Distribution, IRD means Irregular Rainfall Distribution and SIRD means Strongly Irregular Rainfall Distribution

Table 19. Number of years of different PCI classes for the near future based on IPSL-CM5A model

| PCI Classes | KYB | | | | | | | SRB | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Jos | Kano | Bauchi | Potiskum | Maiduguri | Nguru | Yelwa | Katsina | Sokoto | Gusau |
| NURD | 13 | 12 | 10 | 5 | 12 | 12 | 12 | 8 | 16 | 11 |
| URB | 10 | 9 | 10 | 23 | 11 | 10 | 11 | 15 | 10 | 12 |
| MRD | 7 | 9 | 10 | 2 | 7 | 8 | 7 | 7 | 4 | 7 |
| IRD | - | - | - | - | - | - | - | - | - | - |
| SIRD | - | - | - | - | - | - | - | - | - | - |

*NURD means Near Uniform Rainfall Distribution, URD means Uniform Rainfall Distribution, MRD means Moderate Rainfall Distribution, IRD means Irregular Rainfall Distribution and SIRD means Strongly Irregular Rainfall Distribution

concentration or distribution based on the three models. This result is in line with the findings of Quenum et al. (2021) that rainfall during the rainy season will be uniformly distributed in the savanna regions of West Africa within the global warming context. Furthermore, the PCI analyses and categorisation indicated that none of the stations in the two river basins will experience irregular or strongly irregular distribution of rainfall during the rainy season. The uniform distribution of rainfall suggests that rainfall during the rainy seasons of the near future will be well distributed and less erratic, thereby enabling farmers to cultivate their crops at the appropriate time of the year. In addition, the uniform precipitation concentration also suggests that there will be less dependence on supplemental irrigation for crops planted during the season. Juxtaposing the results of the three models reveals some complex spatio-temporal patterns, with successive uniform precipitation concentration observed at different times across space for the wet season in the near-future (2021–2050) scenario (EcEarth Model, Nguru; HadGem2 Model, Kano; and IPSL_CM5A, Potiskum). Therefore, changes in PCI seem to be complex and appear to be related to synoptic and local factors affecting precipitation trends (de Louis et al. 2011).

## Conclusion

In order to understand the past and future variability of rainfall over the KYB and SRB, date from the observed stations' for the baseline period of 1961–1990 and the three GCMs were used.

The results showed predominantly negative changes in mean monthly and seasonal rainfall and a near future of mostly high rainfall variability. The results also suggested that the two river basins will be characterised by mainly near-uniform and uniform rainfall distribution.

Based on the projected negative changes and high rainfall variability, there is a need to evolve effective coping strategies in line with Adaptive Benefits Mechanisms to mitigate some of the associated consequences. For example, high variability, especially during the onset of the rainy season, may require farmers to stagger their crop-planting dates. Furthermore, insights into the future variability of rainfall at the study areas can serve as a useful tool for the River Basin Development Authorities and other relevant stakeholders in averting future social and political conflicts brought about by farmer–herder clashes and in the prevention of economic losses, especially in the agriculture sector.

## Disclosure statement

No potential conflict of interest was reported by the author.

## Author contributions

Study design: OA; data collection: OA, SO; statistical analysis: OA, SO; result interpretation: OA, SO; manuscript preparation: OA, SO; literature review: OA.

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