



PROJECTED EXTREME RAINFALL INDICES IN GUINEA AND SUDANO-SAHELIAN ECOLOGICAL ZONES, NIGERIA

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ABSTRACT

Drought and Flood episodes are twin issues that are consequences of extreme rainfall events. The negative impact of extreme rainfall events makes understanding their behaviour under the future climate change necessary for regional planning. Hence, the objective of the study is to project extreme rainfall indices in Guinea and Sudano-Sahelian ecological zones, Nigeria. A set of four extreme rainfall indices namely: maximum 5-day rainfall (Rx5day), heavy rainfall days (R10mm), consecutive wet days (CWD) and consecutive dry days (CDD) were adopted. The data and computation were done using KNMI Climate Explorer. Projections were produced for the near-term 2019-2048, mid-term 2049-2078 and long-term 2079-2100 periods with reference to the 1959-1988 and 1989-2018 baselines. The multi-model ensemble mean of couple model intercomparison project 5 (CMIP5) under representative concentration pathways (RCPs) 2.6, 4.5, and 8.5 were used. Mann-Kendal statistical test was adopted to analyze the trends in extreme rainfall indices at the 0.05 significance level. Based on the results, it can be deduced that there is a significant positive trend in the whole Guinea and Sudano-Sahelian ecological zone as a region for maximum 5-day rainfall with respect to all the three RCPs. As for heavy rainfall, it reveals that there is no significant positive trend for RCP2.6 with respect to the three projected periods under consideration but significant positive trends with respect to 2049-2078 for RCP4.5 as well as RCP8.5 with respect to 2049-2078 and 2079-2100 periods. Increase in CDD, as well as a decrease in CWD, were both not significant at the 0.05 confidence level. Therefore, it is expected that this study will aid guidance to the understanding of the ongoing changes as well as possible changes in rainfall and rainfall-related extremes. It is also important for future planning of water resources management and agriculture in Guinea and Sudano-Sahelian ecological zones of Nigeria.

KEYWORDS: *Extreme rainfall indices, Guinea, Sudano-Sahelian, Ecological zones, Nigeria*

1 INTRODUCTION

Climate change is increasing the frequency and severity of extreme rainfall events with devastating consequences such as floods and droughts around the world (Guoyong *et al.*, 2016). Under the background of global warming, extreme events also changed in frequency and intensity, even more significantly than the mean climate. From a global perspective, the wet extremes are projected to become more severe in many land areas where the mean precipitation is projected to increase (Meehl *et al.*, 2007 cited in Li *et al.*, 2016). Extreme precipitation increases the snow storage and provides the condition for dangerous spring flood. According to Deniz *et al.* (2017), extreme precipitation in the winter and summer periods often causes catastrophic flood in some areas, which increases its risk on human livelihood, industrial and social infrastructures. This can critically affect water supply, wastewater, and stormwater drain facilities. Moreover, this effect acts stronger for ageing infrastructure. Drought and Flood episodes are twin issues that further aggravate the already tensed water resources management around the world. However, Zobel *et al.* (2018) submitted that not all flooding events are caused by extreme rainfall, but there is usually a strong link between the two. Mamadou *et al.* (2015) contend that these consequences are more severe in regions dominated by arid and semiarid climate such as West Africa. Africa as a whole is one of the most vulnerable continents due to its high exposure and low adaptive capacity. The negative impact of extreme rainfall events makes understanding their behaviour under future climate change necessary for regional planning (Herold *et*

al., 2017; Stella *et al.*, 2019). While Revadekar *et al.* (2011) posited that changes in the precipitation extreme events may require adaption and mitigation measures for proper water management. Abdullah (2015) stated that an investigation of climate change effects on extreme rainfall events can be roughly grouped into (1) studies on the existing effects of climate change based on the analysis of historical rainfall records, and (2) studies on future effects of climate change based on the analysis of future rainfall projections derived from climate models under greenhouse gas emission scenarios.

According to Arthur and Christopher (2017) examples in the literature demonstrated the extent to which extreme precipitation has increased from both regional and global perspectives point to increases in atmospheric water vapor. This is consistent with increasing average temperature and increases in the frequency of local convective storm events as physical reasons for these changes. Increase in maximum atmospheric water vapor due to temperature rise is a principal factor for increasing the intensity of individual precipitation events (Kunkel *et al.*, 2013 cited in Akio and Hirokazu, 2016). However, in some regions, linkages to certain atmospheric circulation patterns have been posed as influencing changes in precipitation extremes. Given the populated coastal areas and the importance of agriculture to the economy, the Southeast Asia region is considered to be especially susceptible to the effects of climate change, including from flooding, tropical cyclones, heat waves and sea-level rise (Pengpeng *et al.*, 2017). IPCC (2014) report highlights potential impacts to health, biodiversity,

food security, and aggravation of existing social, economic and political tensions (Coffel *et al.*, 2019). That recurrent major flooding has occurred over the last century, with flooding typically reaching its peak towards the end of southwest Thailand. Similarly, water resources have been threatened by the persistent impact of climate change. This is noticeable from the occurrence of drought to the continuous decrease in the quality and quantity of water due to reduced river flows and reservoir storage, lowering of water tables, drying up of aquifers and wetlands (Esther *et al.*, 2012). Lake Chad, for example, has shrunk from its initial 25,000km² in the 1960s to 1350km² in 2005 (Yunana *et al.*, 2017). Streams in these zones which hitherto were perennial have now become seasonal so that water can only be found in them during the wet seasons with little or no water in dry seasons.

Nigeria in general and Guinea and Sudano-Sahelian ecological zones to be specific have its own share of the extreme rainfall phenomena. Climate projection in Niger Delta area of Nigeria demonstrated that the coastal communities will be more vulnerable to the effects of climate change, leading to an increase in frequency and intensity of flood (Agumagu, 2015). Guinea and Sudano-Sahelian ecological zones of Nigeria covered about 79% of the entire landmass of Nigeria. It is inhabited by over 50% of the country's 167 million people (Ojoye *et al.* 2016) sparsely distributed across 79% of the country's total landmass. It is home to over two-thirds of Nigeria's 250 ethnic groups (Yunana *et al.*, 2017). Historical climate records indicate that this region has experienced significant increases

in rainfall related extremes since the late 20th to the beginning of the 21st century (Abdussalam, 2015; Ojoye *et al.*, 2016). The archive of Royal Netherland Meteorological Institute known as KNMI Climate Explorer (<https://climexp.knmi.nl>) is an emerging source of global climatology data. Many climate change studies have been undertaken using data from this source (Arthur *et al.*, 2016; Nurmohamed and Donk 2017; Jacquelyn *et al.*, 2018 and Mitchell *et al.*, 2019). In addition, the data also include extreme rainfall indices. It comprises of observed and simulated evapotranspiration, temperature, rainfall and extreme rainfall indices data. The observed data are that of Climate Research Unit (CRU TS 4.2) and the simulated data are that of couple model intercomparison project 5 (CMIP5) under the representative concentration pathways (RCPs) 2.6, 4.5, and 8.5 all found in the KNMI database. Hence, the objective of this study is to project extreme rainfall indices in Guinea and Sudano-Sahelian ecological zones, Nigeria. However, this study used a set of four extreme rainfall indices namely: maximum 5-day rainfall (Rx5day), heavy rainfall days (R10mm), consecutive wet days (CWD) and consecutive dry days (CDD).

2 MATERIALS AND METHODS

The study area lies between Longitudes 3°E to 15°E of the Greenwich meridian and Latitudes 8°N to 14°N of the equator (Table 1). The area covers Guinea and Sudano-Sahelian ecological zones of Nigeria. It is bordered to the north by the Niger Republic, to the east by the Republic of Cameroun, to the south by the tropical rainforest and to the west by the Benin Republic. The two

predominant air masses that influence the weather and climate of these zones are Tropical Continental (CT) air mass and Tropical Maritime air mass (mT) (Abdulkadir *et al.*, 2015). The former is dry and dusty which originates from the Sahara Desert, while the latter is dense and moist which originates from the Atlantic Ocean. The rainfall distribution shows a mean of 1120 mm but attains 1500 mm around the plateau area. The temperature shows a mean annual of 24°C to 30°C.

General Circulation Models (GCMs) is a mathematical description of the Earth's climate system, broken into a number of grid boxes and levels in the atmosphere, ocean and land. At each of these grid points, equations are solved which describe the large-scale balances of the momentum, heat and moisture (Gebre *et al.*, 2015). General circulation models (GCMs) are useful for providing climate

change scenarios as a basis for estimating the impacts of climate change. To provide scenarios of water resources and extremes, results from GCMs can be applied in hydrological models to identify climate change impacts (Umesh and Pouyan, 2016; Ahmed *et al.*, 2017). According to IPCC (2014), the four representative concentration pathways (RCPs) consistent with certain socio-economic assumptions were the basis for climate change projection in the fifth Assessment Report (AR5). Based on this, RCP8.5 was consistent with a future with no policy changes to reduce emissions; RCP6.0 was consistent with the application of a range of technologies and strategies for reducing greenhouse gas emissions; RCP4.5 was consistent with a future with relatively ambitious emissions reductions, and in RCP2.6 ambitious greenhouse gas emissions reductions were required over time.

Table 1: Location and size of the study area

Ecological Zones	River Basin	Latitude (°N)	Longitude (°E)	Area (KM ²)	Elevation (ma.s.l.)
Guinea savanna	Kainji Lake Basin (KLB)	9° 51' - 10° 11'	4° 34' - 4° 36'	1,300	142
Sudan savanna	Sokoto - Rima Basin (SRB)	10° 12' - 12° 25'	3° 44' - 8° 14'	135,000	300
Sahel savanna	Komadugu - Yobe Basin (KYB)	12° 88' - 13° 31'	7° 90' - 11° 56'	84,138	294

Source: Ejjeji *et al.*, (2016)

The Expert Team on Climate Change Detection and Indices (ETCCDI) identified a number of temperature and precipitation

extreme indices. However, this study used a set of four extreme rainfall indices. The data

and computation were done using a web-based application of Royal Netherland Meteorological Institute known as KNMI Climate Explorer (<https://climexp.knmi.nl>) developed by Sillmann *et al.* (2013). Many climate change studies have been undertaken using data from this source (Nurmohamed and Donk 2017; Jacquelyn *et al.*, 2018 and Mitchell *et al.*, 2019). The coordinates of each of the three basins were used to derive the extreme rainfall indices considered herein (Table 1). Projections were produced for the three future periods namely: near-term 2019-2048, mid-term 2049-2078 and long-term 2079-2100 with reference to the 1959-1988 and 1989-2018 baselines. The multi-model ensemble mean of couple model intercomparison project 5 (CMIP5) under the representative concentration pathways (RCPs) 2.6, 4.5, and 8.5 were adopted. Furthermore, climate change indices regarding the occurrence of extreme rainfall trend using equation 1.7 and 1.10 were evaluated in order to determine the future trend at individual and regional locations. The extremes used in the trend analysis

(*Rx5day*, *R10mm*, *CWD* and *CDD*) are as follows:

$$Rx5day_j = \max (RR_{ij}) \quad 1.1$$

$$R10\text{ mm}_j = \text{days when } RR_{ij} \geq 10\text{mm} \quad 1.2$$

$$CWD_j = \text{Maximum length of wet spell} \quad 1.3$$

where $RR_{ij} \geq 1\text{mm}$

$$CDD_j = \text{Maximum length of dry spell} \quad 1.4$$

where $RR_{ij} < 1\text{mm}$

Where,

Rx5day is the annual maximum consecutive 5-day rainfall,

R10mm is the annual count of days when rainfall is more than 10 mm,

CWD is the maximum length of wet spell where daily rainfall is more than 1 mm,

CDD is the maximum length of dry spell where daily rainfall is less than 1 mm

RR_{ij} is the daily rainfall on day i in period j ,

$RR5_{ij}$ is the consecutive 5-day rainfall on day i in period j

To achieve the stated objective, Mann-Kendall test (Mann, 1945; Kendall, 1975) was applied to detect the monotonic trends in the projected water stress time series. The Mann-Kendall statistical test has been frequently used to quantify the significance of trends in hydro-meteorological time series (Pervez and Henebry, 2015; Abdussalam, 2015; Nahlah *et al.*, 2019). This is calculated as:

$$S = \sum_{k=1}^{n-1} \sum_{i=k+1}^n \text{sign} (x_j - x_k) \quad 1.5$$

$$\text{VAR} (S) = \frac{[n(n-1)(2n+5) - \sum_{i=1}^m t_i(t_i-1)(2t_i+5)]}{18} \quad 1.6$$

Where:

S = Mann-Kendall statistics

n = the number of data points

t_i = the number of ties for the i value and

m = the number of tied values (a tied group is a set of sample data having the same value)

$$z_s = \begin{cases} \frac{S-1}{\sqrt{VAR(S)}} if S > 0 \\ 0 & if S = 0 \\ \frac{S+1}{\sqrt{VAR(S)}} if S < 0 \end{cases} \quad 1.7$$

A positive value of z_s (standardized test statistics) indicates increasing trends while negative z_s value reflects decreasing trends, while 0 values indicate no trends. The testing trend was done at specific α significance level. When $|Z_s| > Z_{1-\alpha/2}$, the null hypothesis is rejected and a significant trend exists in the time series. $Z_{1-\alpha/2}$ is obtained from the standard normal distribution table. In this study, the significance level of $\alpha=0.05$ was used. Nahlah *et al.*, 2019 stated that at the 5% significance level, the null hypothesis of no trend is rejected if $|Z_s| > 1.96$ and concludes that there is a significant trend in the time series.

In order to assess trend at a regional scale, the Regional Mann-Kendall test was employed to quantitatively combine results of the MK test for individual locations and to evaluate the regional trends. These statistical techniques have been adopted by Mohammed *et al.*, (2014); Michael *et al.*, (2017). In the regional MK test, the S_r of regional data is calculated as:

$$S_r = \sum_{i=1}^n S_i \quad 1.8$$

Where+

S_r is Kendall's S for the "ith" location in a region with m locations within the region. If S_r is estimated using independent identically distributed data, S_r is

approximately normally distributed for large m with mean equal to 0 and the variance as noted below.

$$Var(S_r) = \sum_{i=1}^n Var = \sigma^2 \quad 1.9$$

$$z_r = \begin{cases} \frac{S_r-1}{\sigma} for S_r > 0 \\ 0 & for S_r = 0 \\ \frac{S_r+1}{\sigma} for S_r < 0 \end{cases} \quad 1.10$$

To determine whether to reject or not the null hypothesis of no trend, the test statistics z_r is assessed against the critical value Z_{crit} corresponding to the specific significance level α of the test. For the two-tailed test, the critical value is defined as $\Phi^{-1}(1 - \alpha/2)$, where Φ is the cumulative distribution function of standard normal distribution (Helsel and Hirsch 2002; cited in Michael *et al.*, 2017). The null hypothesis is rejected and the trend is considered significant statistically if the value of $|z_r| \geq Z_{crit}$.

3 RESULTS & DISCUSSION

3.1: Changes in Maximum 5-day Rainfall (RX5day)

The maximum 5-day rainfall is projected to change differentially in space and time over the KLB, SRB and KYB as well as across the three scenarios between 2019 and 2100. The 2019-2048 near-term period shows that the maximum 5-day rainfall will increase within the range of 5 – 10 mm for all the three RCPs under the two baseline periods of 1959-1988 and 1989-2018 over the KLB.

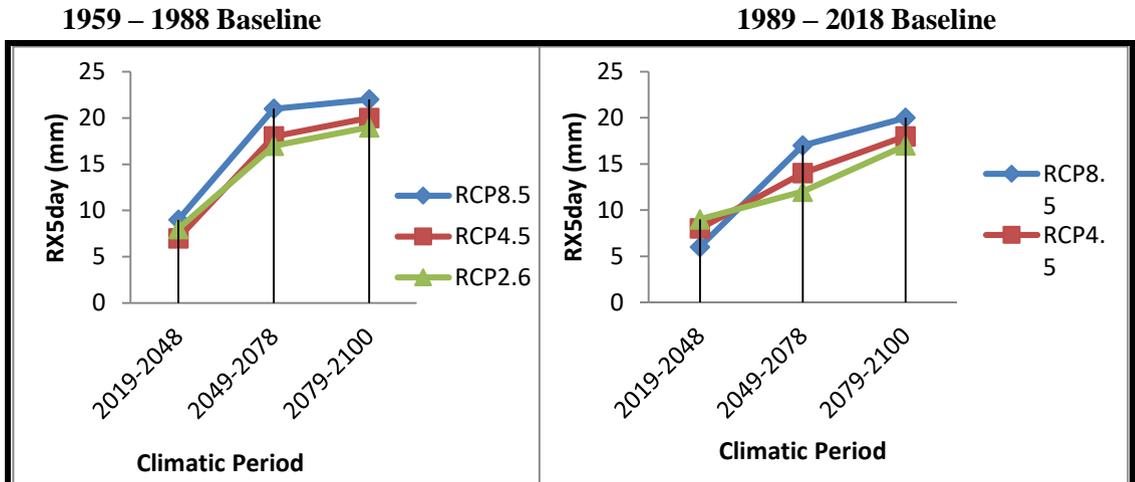


Figure 1.1a: Projected maximum 5-day rainfall for KLB

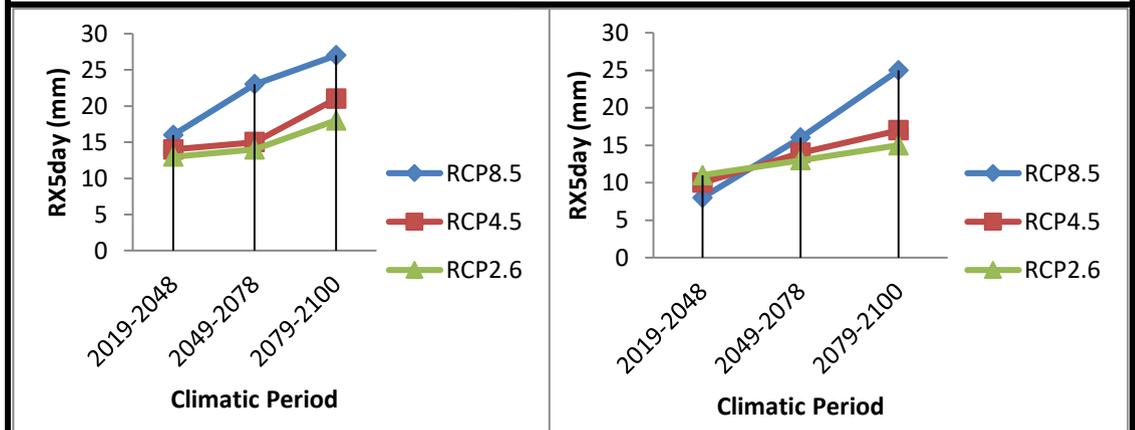


Figure 1.1b: Projected maximum 5-day rainfall for SRB

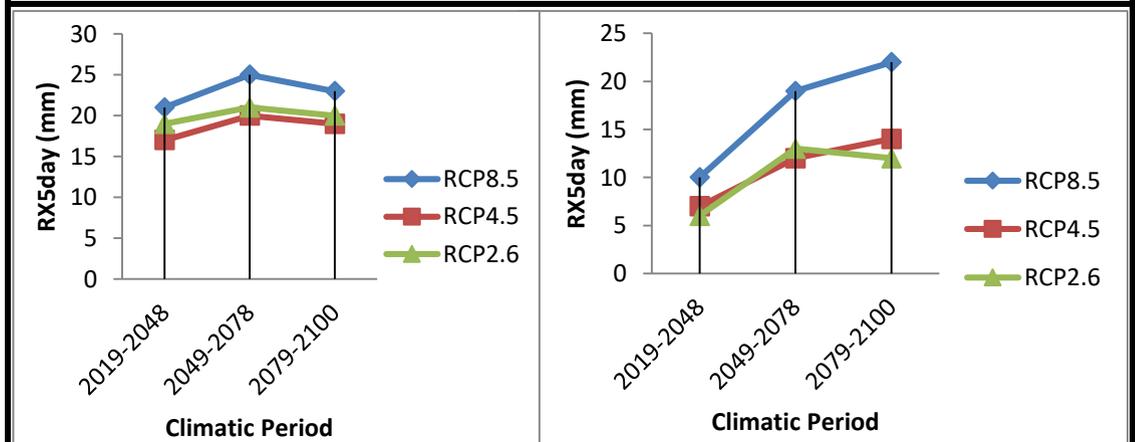


Figure 1.1c: Projected maximum 5-day rainfall for KYB

RCP8.5 accounts for the highest increase of 10 mm and lowest being RCP4.5 with 5

mm under the 1959-1988 baseline, while a contrasting pattern of increase is observed

under 1989-2018 baseline where RCP2.6 accounts for the highest with 10 mm and lowest being RCP8.5 (Figure 1.1a). Trend analysis of maximum 5-day rainfall within the 2019-2048 period over KLB indicates that it is not significant at 0.05 significant levels for all the three RCPs (Table 2). SRB maximum 5-day rainfall reveals that the range of increase is between 12 – 16 mm for all the RCPs under 1959-1988 baseline but decreases to the range of 7 – 10 mm under the 1989-2018 baseline. RCP8.5 accounts for the highest with 16 mm under 1959-1988 baseline but lowest with 8mm under 1989-2018 baseline. While RCP2.6 accounts for the lowest with 12 mm under 1959-1988 baseline but highest with 10 mm under 1989-2018 baseline (Figure 1.1b).

Trend analysis of maximum 5-day rainfall in SRB under the 2019-2048 period shows no significant trend at the 0.05 significance level for RCPs (2.6 and 4.5) but significant for RCP8.5 (Table 2). Similarly, maximum 5-day rainfall in KYB reveals 16 – 21 mm range of increase under the 1959-1988 baseline for all the RCPs, but sharply decreases to the range of 5 – 10 mm under 1989-2018 baseline with RCP8.5 having the highest value and least being RCP2.6. It is important to point out that the range of increase under 1989-2018 baseline is the same for KLB and KYB but differ greatly with SRB. However, the trend analysis of maximum 5-day rainfall over KYB under the 2019-2048 period shows that there is a significant trend for all the three RCPs at the 0.05 significance level. Therefore, maximum 5-day rainfall will be mostly felt in KYB than the other two basins.

Table 2: Mann–Kendall Trend Analysis of Extreme Rainfall Indices for KLB, SRB and KYB

Climatic Period	Extreme Rainfall Indices											
	RCP2.6			RCP4.5			RCP8.5			Regional Trend		
	Maximum 5-day rainfall (Rx5day)											
	KLB	SRB	KYB	KLB	SRB	KYB	KLB	SRB	KYB	rcp2.6	rcp4.5	rcp8.5
2019-2048	0.67	1.62	2.36*	1.30	1.48	2.35*	1.82	2.39*	2.31*	1.39	1.36	2.86*
2049-2078	2.06*	1.31	2.67*	1.98*	1.39	1.94*	2.19*	2.63*	2.53*	2.05*	1.97*	2.31*
2079-2100	1.92*	0.61	2.88*	2.56*	2.05*	2.64*	2.33*	2.24*	2.51*	1.94*	2.33*	2.38*
	Heavy rainfall days (R10mm)											
	KLB	SRB	KYB	KLB	SRB	KYB	KLB	SRB	KYB	rcp2.6	rcp4.5	rcp8.5
2019-2048	0.67	1.62	1.36	1.30	1.48	1.35	1.98*	0.39	0.31	1.39	0.36	1.86
2049-2078	1.06	1.31	1.67	0.89	2.39*	1.74	0.19*	2.63*	2.53*	0.05	1.75	2.31*
2079-2100	0.82	2.61*	1.88	2.56*	2.05*	1.94*	0.33*	2.24*	1.91*	1.84	2.33*	1.98*
	Consecutive wet days (CWD)											

	KLB	SRB	KYB	KLB	SRB	KYB	KLB	SRB	KYB	rcp2.6	rcp4.5	rcp8.5
2019-2048	0.67	-1.62	-1.36	-1.30	-1.48	-1.35	-1.82	-0.39	-0.31	-1.39	2.36	2.86*
2049-2078	1.06	-1.31	-1.67	-0.89	-2.39	-1.74	-1.96	-0.63	-1.53	-0.05	1.75	0.31
2079-2100	-0.82	-2.61*	-1.88	-1.56	-2.05*	-1.64	-2.33*	-2.24*	-2.51*	-1.84	2.33	2.38*
Consecutive dry days (CDD)												
	KLB	SRB	KYB	KLB	SRB	KYB	KLB	SRB	KYB	rcp2.6	rcp4.5	rcp8.5
2019-2048	0.67	1.62	1.36	1.30	1.48	1.35	1.82	0.39	0.31	1.39	1.36	0.86
2049-2078	1.06	1.31	1.67	0.89	1.39	1.74	0.19	0.63	2.53*	0.05	1.75	0.31
2079-2100	0.82	1.61	1.88	0.56	1.05	1.64	2.33*	1.94*	1.95*	1.84	1.33	2.38*

(*) = Statistically significant trends at the 0.05 significance level.

(+) = increasing extreme rainfall indices (-) = decreasing extreme rainfall indices

By the 2049-2078 mid-term projection period, maximum 5-day rainfall in KLB will increase steadily to a range of 16 – 21 mm under 1959-1988 baseline such that RCP8.5 accounts for highest and lowest being RCP2.6 with values of 20 mm and 15 mm respectively. While under 1989-2018 baseline, it varies between 12 – 17 mm with RCP8.5 being the highest and lowest will be RCP2.6. This is not surprising considering the fact that at this period, the increases in CO₂ emission suppose to stabilize and start declining with respect to the lowest emission scenario (RCP2.6). SRB projected maximum 5-day rainfall indicates a slight increase of just between 12 – 22 mm for all the RCPs under 1959-1988 baseline with RCP8.5 having the highest value and lowest being RCP2.6 (Figure 1.1b). While under 1989-2018 baseline, the range of 11 – 7 mm is imminent which is similar to that obtained under the same baseline in KLB. As for the KYB, projected maximum 5-day rainfall ranges between 19 – 24 mm under 1959-1988 baseline with just a little margin between RCP8.5 and RCP2.6 but ranges between 10 – 20 mm under 1989-2018 baseline which has the widest margin

between RCP8.5 and RCP2.6 (figure 1.1c). The trend analysis shows that there is a significant trend at 0.05 significant levels for all the RCPs (Table 2).

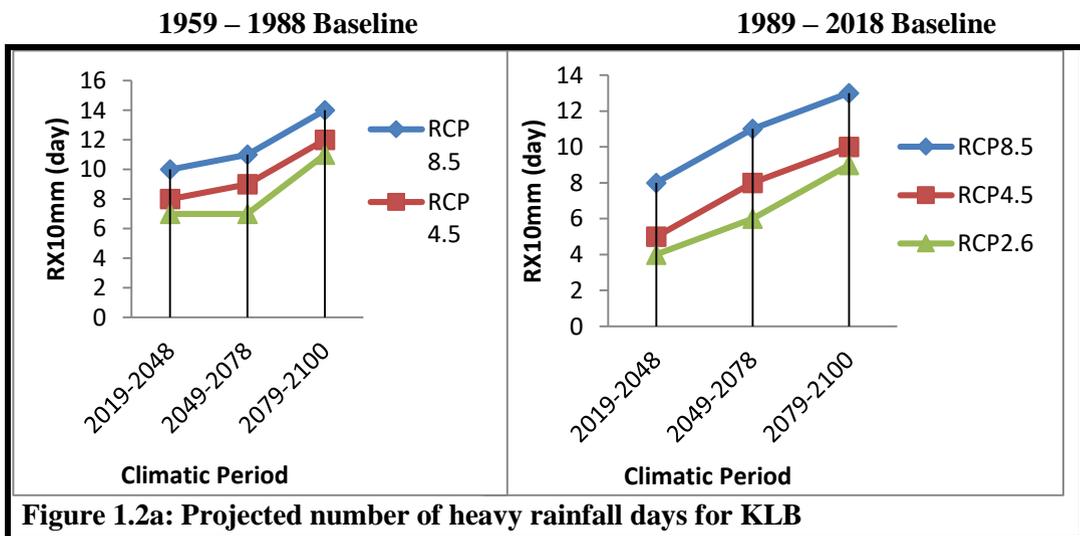
In the 2079-2100 long-term period, anticipated condition in KLB mirror a similar pattern as obtained in the two preceding periods where there is a consistent increase in maximum 5-day rainfall. That is to say maximum 5-day rainfall increases from the first projected period of 2019-2048 through 2049-2078 to third projected period of 2079-2100 in KLB (Figure 1.1a). Trend analysis of the 2079-2100 period in KLB reveals that there is a significant trend at the 0.05 significant level (Table 1.2). SRB pattern of maximum 5-day rainfall under the 2079-2100 period is in contrast with that observed over KLB such that the range of 17 – 25 mm of maximum 5-day rainfall in SRB is far wider with a difference of 5 mm (Figure 1.1b). Thus, trend analysis of the 2079-2100 period over SRB shows a significant upward trend at the 0.05 significance level (Table 2). The situation over KYB in the 2079-2100 period is the similitude of the projected pattern in KLB. This is because the range of 19 – 23 mm

for all the RCPs over KYB is the lowest among the three periods. Therefore, trend analysis of the 2079-2100 period over KYB reveals significant upward trend at the 0.05 significance level. Regional trend analysis of the maximum 5-day rainfall over KLB, SRB and KYB as a whole which constitutes the Guinea and Sudano-Sahelian ecological zones of Nigeria reveals that under the 2019-2048 period there is no significant positive trend at the 0.05 significance level. This is with respect to lower emission scenarios (RCP2.6 and RCP4.5) but significant in higher emission scenario of RCP8.5 (Table 2). By 2049-2078 through 2079-2100 periods, there are significant positive trends in the whole Guinea and Sudano-Sahelian ecological zones as a region for maximum 5-day rainfall time series with respect to all the

three RCPs. This is in tandem with Abdullah (2015) that reveals in Turkey statistically significant trends of maximum 5-day. Furthermore, Libanda and Chilekana (2018) contend that extreme precipitation exerts a damaging impact on both society and ecosystems over Zambia. That understanding projections of extreme precipitation is part of a resilient response to its impacts.

3.2: Changes in Number of Heavy Rainfall Days (RX10mm)

The total number of days in a year with rainfall >10mm (heavy rainfall days) in the KLB, SRB and KYB as well as across the three scenarios between 2019 and 2100 are shown (Figure 1. 2a-c).



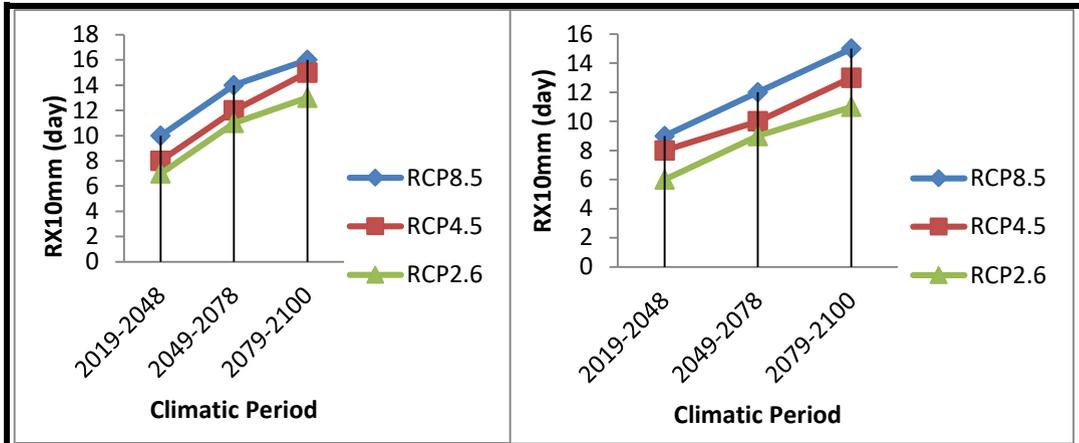


Figure 1.2b: Projected number of heavy rainfall days for SRB

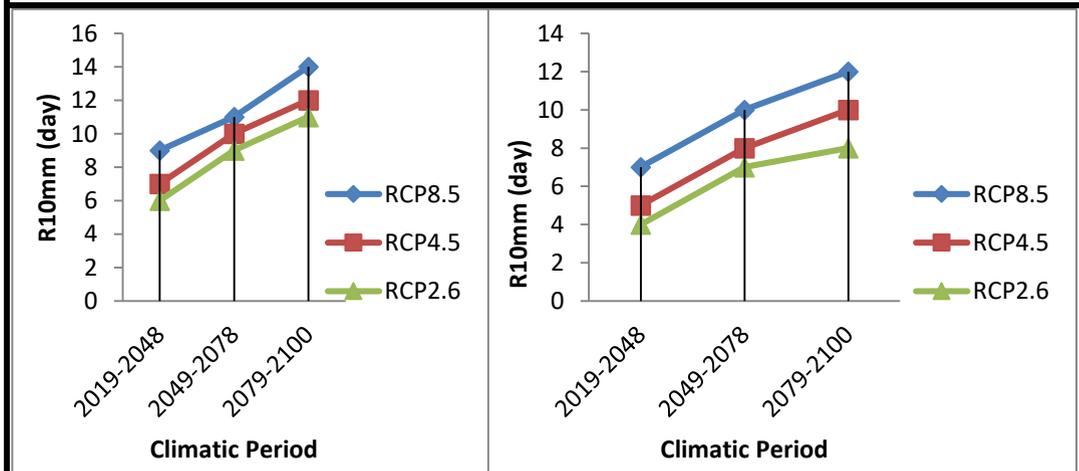


Figure 1.2c: Projected number of heavy rainfall days for KYB

The 2019-2048 period shows that the heavy rainfall days will increase within the range of 7–10 days and 3-8 days for all the three RCPs under the two baseline periods of the 1959-1988 and 1989-2018 respectively over the KLB. RCP8.5 accounts for the highest increase, while RCP2.6 accounts for the lowest under the two baselines (Figure 1.2a). Trend analysis of heavy rainfall days within the 2019-2048 periods over KLB indicates that it is not significant at the 0.05 significance level for RCP2.6 and RCP4.5 but the significant upward trend is observed in a

number of days with rainfall >10mm with respect to RCP8.5 (Table 2). SRB heavy rainfall days reveals that the range of increase is between 6 – 10 days for all the RCPs under 1959-1988 baseline but decreases to the range of 5 – 8 days under the 1989-2018 baseline. RCP8.5 accounts for the highest under the two baselines. While RCP2.6 accounts for the lowest number of heavy rainfall days (Figure 1.2b). Trend analysis of heavy rainfall days in SRB under the 2019-2048 periods shows no significant trend at 0.05 significant levels for all the three emission

trajectories (Table 2). Likewise, the number of days with rainfall >10 mm in KYB reveals 5 – 9 days range of increase under the 1959-1988 baseline for all the RCPs, but sharply decreases to the range of 3 – 7 days under 1989-2018 baseline with RCP8.5 having the highest value and least being RCP2.6. However, the trend analysis of heavy rainfall days over KYB under the 2019-2048 period shows that there is a significant positive trend for all the three RCPs at the 0.05 significance level.

By the 2049-2078 projection period, heavy rainfall days in KLB maintain a stable condition for RCP2.6 under 1959-1988 baseline but variable under 1989-2018 baseline. RCP8.5 sustains the lead under the two baselines. Trend analysis result indicates that though no significant positive trend exists under the low emission pathways but becomes significant with respect to the highest emission scenario at the 0.05 significance level (Table 2). SRB projected rainfall days with >10mm signifies an increase of just between 10 – 14 days for all the RCPs under 1959-1988 baseline (Figure 1.2b). While under 1989-2018 baseline, the range of 8 – 11 days is visible. The projected increase is statistically significant at the 0.05 significance level with respect to RCP4.5 and RCP8.5 but not for RCP2.6. On the other hand, the KYB projected a number of days with rainfall >10mm ranges between 8 – 10 days under 1959-1988 baseline with just a little margin between RCP8.5 and RCP2.6 but ranges between 6 – 10 days under 1989-2018 baseline (Figure 1.2c). The trend analysis shows that there is a significant upward trend at the 0.05 significance level for

RCP8.5 nevertheless; RCP2.6 and RCP4.5 have no significant trend (Table 2).

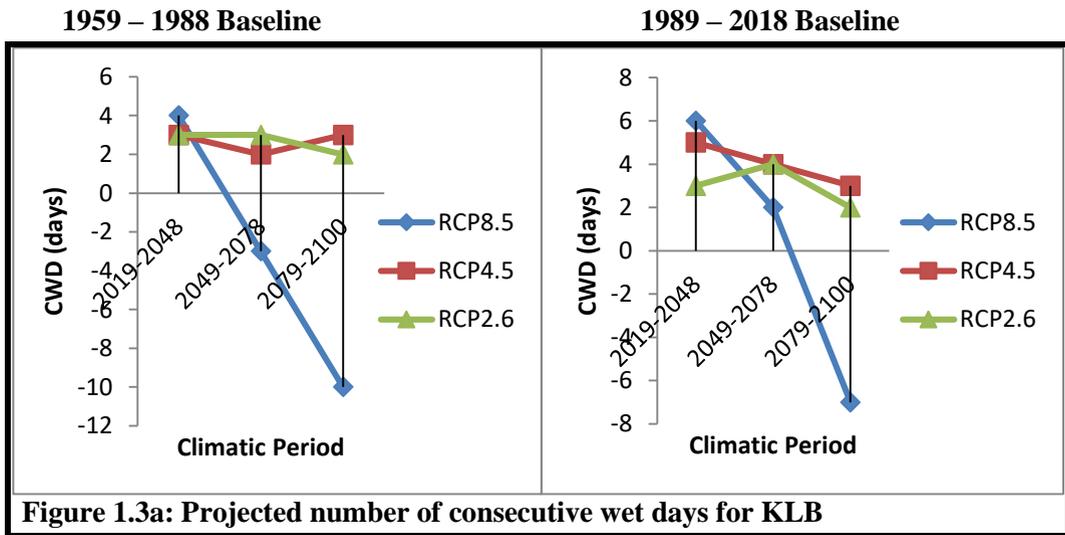
During the 2079-2100 period, the estimated provision in KLB reflects a consistent increase in a number of days with rainfall >10mm. That is to say it increases from first projected period of 2019-2048 all the way through 2049-2078 toward the third projected period of 2079-2100 in KLB. The range for 2079-2100 period is between 10 – 13 days (Figure 1.2a). Trend analysis of 2079-2100 period in KLB discloses that there are significant positive trends at the 0.05 significance level for RCP4.5 and RCP8.5 and no trend for RCP2.6 (Table 2). A similar pattern of upward trends is noticeable for SRB and KYB. As for SRB, there is a significant positive trend in rainfall days >10 mm for all the three RCPs but not for RCP2.6 across KYB. Regional trend analysis of heavy rainfall days over KLB, SRB and KYB as a whole which constitutes the Guinea and Sudano-Sahelian ecological zones of Nigeria reveals that there is no significant trend for RCP2.6 with respect to the three projected periods under consideration but significant with respect to 2049-2078 for RCP4.5 as well as RCP8.5 with respect to the 2049-2078 and 2079-2100 periods. This is consistent with the finding of Xiaojun *et al.* (2016) where precipitation extremes in China were projected to be more frequent and more intense and to increase by 25.81 and 69.14 % relative to the baseline climate of 1971–2000 for a 1.5°C warming target, and by 95.52 and 162.00 % for a 4.0°C warming target, respectively. More so, Libanda and Chilekana, 2018 stated that with intensified precipitation, adaptive

strategies against flooding will be of major importance. Inundation of floodwater into homes, displacement of people, mudslides and erosion of stream banks and lakeshores are common in the wake of intensified precipitation.

3.3: Changes in Number of Consecutive Wet Days (CWD)

The total number of wet days projected in the near-term 2019-2048, mid-term 2049-2078 and long-terms 2079-2100 recorded at three different basins namely KLB, SRB and KYB are shown on figure 1.3a-c. For each period, the projection was done with reference to two baselines as well as under three CO₂ emission trajectories namely RCP2.6, RCP4.5 and RCP8.5. By the near-term 2019-2048, projection over KLB reveals that CWD will increase at first

during this period with a range of 3 – 4 days with reference to 1959-1988 while under 1989-2018 baseline the increase ranges between 3 – 6 days. Under the two baselines, RCP8.5 accounts for highest with an increase of 4 and 6 days while RCP2.6 accounts for lowest days (Figure 1.3a). These increases were subjected to trend analysis but found no significant positive trends over this basin at the 0.05 significance level (Table 2). More so, projection over SRB indicates a similar pattern of increase in CWD with respect to the two baselines. The increase is within the range of 5 – 8 days for all the three RCPs and none was found significant at the 0.05 significance level. This trend continues over KYB though not significant but, with a slightly higher magnitude which ranges between 4 – 7 days for lower and highest emission pathways.



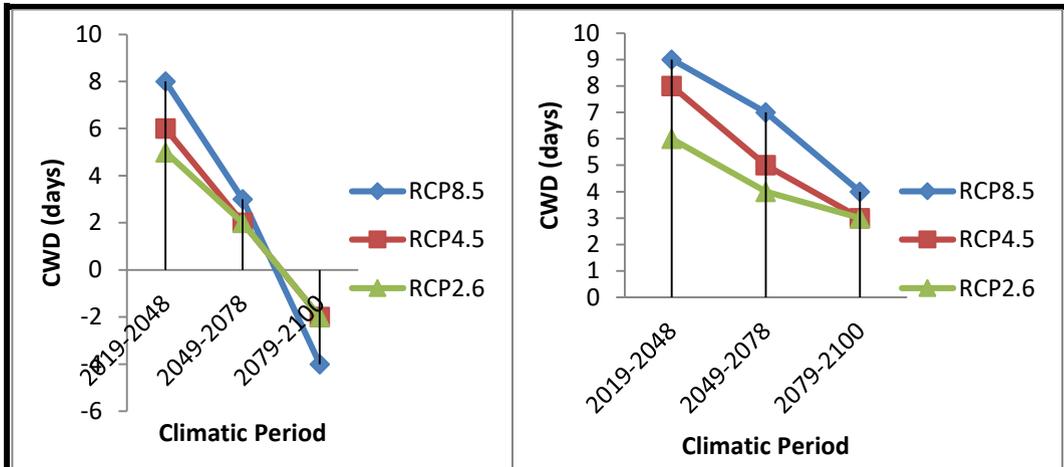


Figure 1.3b: Projected number of consecutive wet days for SRB

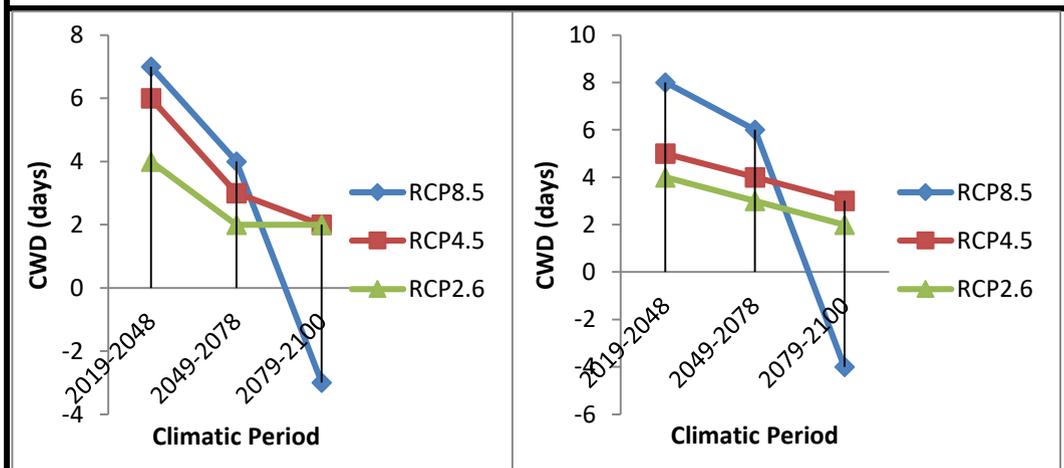


Figure 1.3c: Projected number of consecutive wet days for KYB

RCP8.5 (Figure 1.3b). As for the 1989-2018 baseline, it ranges between 4 days for RCPs 2.6 and 4.5, but an increase to 5 days with respect to RCP8.5. Trend analysis proves that there is no significant negative trend at the 0.05 significance level. At KYB, the long-term projection ascertains that CWD will decrease with higher magnitudes under the two baselines of the 1959-1988 and 1989-2018 with -3 and -4 days for RCP8.5 but just 2-3 days under RCPs 2.6 and 4.5 (Figure 1.3c). The negative trends observed were subjected to trend analysis, though not significant with

respect to RCPs 2.6 and 4.5 but indeed significant for RCP8.5 at the 0.05 significance level (Table 2). Regional trend analysis of CWD over KLB, SRB and KYB as a whole which constitute the Guinea and Sudano-Sahelian ecological zones of Nigeria established that there are no significant negative trends. These are with respect to the three projected periods for RCPs 2.6 and 4.5, except RCP8.5 that was significant at the 0.05 significance level for the long-term projection period. This agrees with Sun *et al.* (2015) that confirmed the negative trend of CWD in

China under the RCP8.5 scenario but that there were little trends under the RCP2.6 and RCP4.5 scenarios. In addition, Carlos and Veronica (2017) demonstrated related trends in Brazil. This, therefore, entails that Guinea and Sudano-Sahelian ecological zones of Nigeria will experience episodes of drought in the near, mid and long-term future if the rate of global emission of CO₂ maintains a steady rise with no commensurate policies to address the issue at stake. However, if stringent measures are put in place it will go a long way to curb the imminent drought devastation that will be ensued.

3.4: Changes in Number of Consecutive Dry Days (CDD)

Consecutive dry days (CDD) are the total number of days in a year with rainfall (<1 mm). This is shown in figure 1.4a-c for KLB, SRB and KYB respectively. As well as across the three scenarios and between 2019 and 2100 divided into near-term, mid-term and long-term projected periods. For the near-term 2019-2048, projected CDD will increase within the range of 2-5 days and 6-10 days for all the three RCPs under the two baseline periods of 1959-1988 and 1989-2018 respectively over the KLB. RCP8.5 accounts for the highest increase, while RCP2.6 accounts for the lowest under the two baselines (Figure 1.4a). SRB CDD reveals that the range of increase is between 1 – 3 days for all the RCPs under 1959-1988 baseline but further increases to the range of 2 – 5 days under the 1989-2018 baseline. RCP8.5 accounts for the highest, followed by RCP4.5 under the two baselines. While RCP2.6 accounts for the lowest number of

days with rainfall <1 mm (Figure 1.4b). Likewise, the number of CDD in KYB reveals 4 – 6 days range of increase under the 1959-1988 baseline for all the RCPs, but slightly increases to the range of 3 – 7 days under 1989-2018 baseline with RCP8.5 having the highest value and least being RCP2.6 (Figure 1.4c). However, the trend analysis of CDD over individual basins under the 2019-2048 period shows that there is no significant positive trend for all the three RCPs at the 0.05 significance level.

By the 2049-2078 projection period, CDD in KLB increases within a range of 3 – 6 days for the three RCPs under the 1959-1988 baseline but ranges between 7 – 10 days under the 1989-2018 baseline. RCP8.5 sustains the lead under the two baselines. Trend analysis results indicate that no significant positive trend exists under the three CO₂ emission pathways at the 0.05 significance level (Table 2). However, SRB projected CDD signifies an increase of 1 – 7 days for all the RCPs under 1959-1988 baseline (Figure 1.4b). While under 1989-2018 baseline, the range of 3 – 8 days is visible. Under the two baselines, emission trajectories follow the same pattern from lowest to highest. The projected increase is statistically tested and found no significant upward trend at the 0.05 significance level. Similarly, the KYB projected number of CDD ranges between 4 – 10 days under the 1959-1988 baseline but ranges between 3 – 11 days under the 1989-2018 baseline (figure 1.4c). The trend analysis shows that there is no significant upward trend at the 0.05 significance level for RCPs 2.6, 4.5 but

significant with respect to RCP8.5 (Table 2).

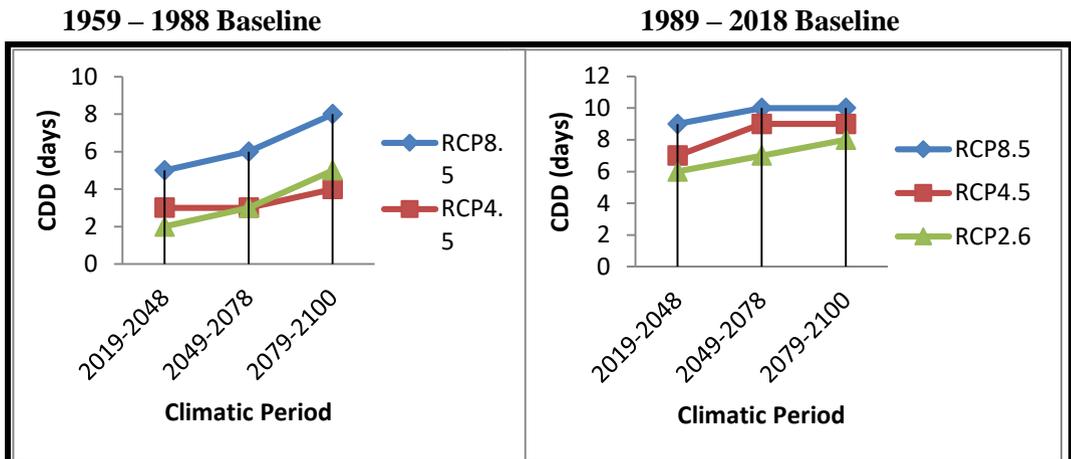


Figure 1.4a: Projected number of consecutive dry days for KLB

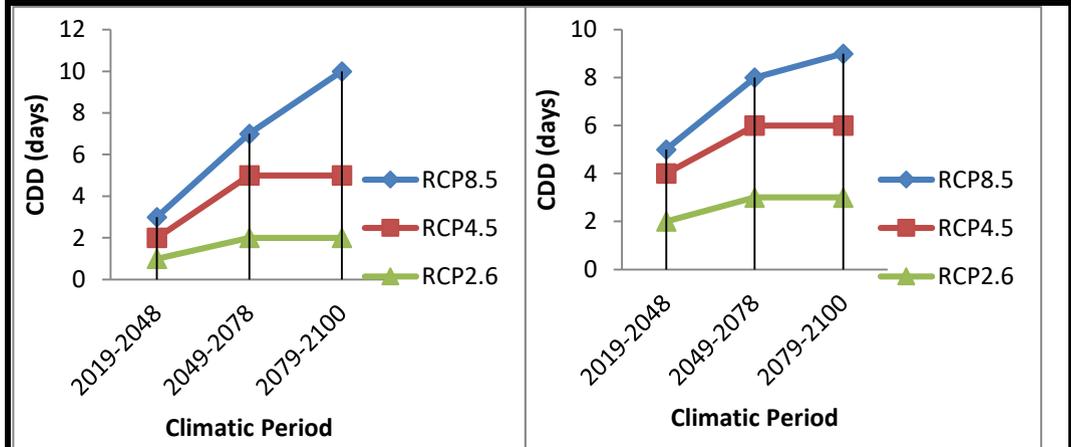


Figure 1.4b: Projected number of consecutive dry days for SRB

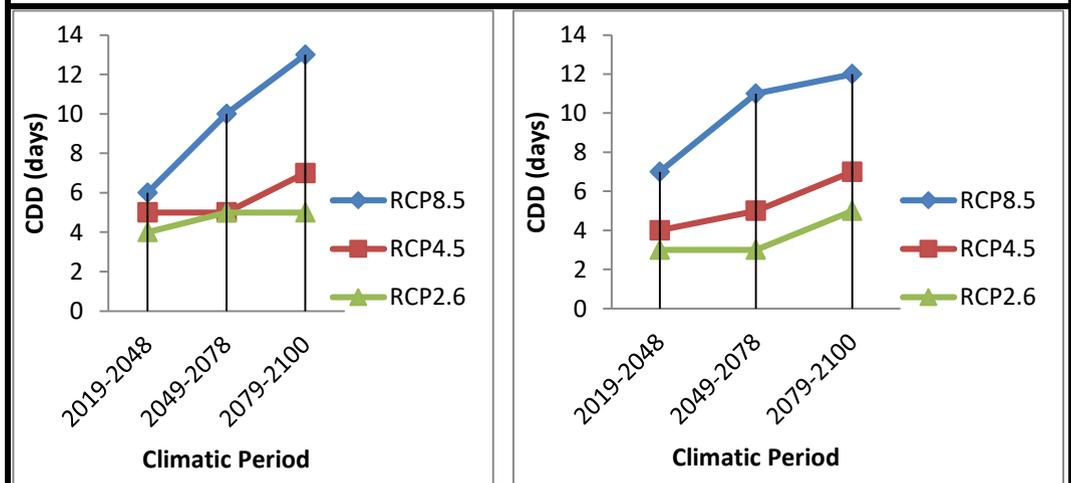


Figure 1.4c: Projected number of consecutive dry days for KYB

During the 2079-2100 period, the estimated provision in KLB reflects a consistent increase in CDD. That is to say, it increases from the first projected period of 2019-2048 all the way through 2049-2078 toward the third projected period of 2079-2100. The range for the 2079-2100 period is between 3 – 8 days (Figure 1.4a). Trend analysis of the 2079-2100 period in KLB discloses that there are no significant positive trends at the 0.05 significance level for the RCP2.6 and RCP4.5 but significant for the RCP8.5 (Table 2). A similar pattern of positive trends is noticeable for SRB and KYB. These trends were found not to be significant under lower CO₂ emissions of 2.6 and 4.5 but become significant with respect to the RCP8.5. Regional trend analysis of CDD over KLB, SRB and KYB as a whole which constitutes the Guinea and Sudano-Sahelian ecological zones of Nigeria reveals that there are no significant positive trends with respect to the three projected periods and emission pathways except the RCP8.5 that is significant at the 0.05 significance level for the long-term projection period. This corroborates with the work of Chan *et al.* (2016) that attested significant increase in CDD for the 21st century was inevitable in Hong Kong under RCP8.5 but not with regard to lower emission trajectories. Abdullah (2015) discovered similar increasing trends of CDD in Turkey. While Libanda and Chilekana (2018) reported results from the spatial analysis show that the greatest increase in the number of consecutive dry days is around Siavonga, Kasama and

Isoka, up to the border of Zambia and Tanzania.

4 CONCLUSIONS

Based on the results generated from the analysis of the extreme rainfall indices, it can be deduced that there are significant upward trends in the whole Guinea and Sudano-Sahelian ecological zones as a region for maximum 5-day rainfall time series with respect to all the three RCPs. Heavy rainfall days reveal that there are no significant positive trends for RCP2.6 with respect to the three projected periods under consideration but significant positive trends with respect to 2049-2078 for RCP4.5 as well as RCP8.5 with respect to (2049-2078) and (2079-2100) periods. Increase in CDD, as well as a decrease in CWD, are both not significant at the 0.05 confidence level indicate that extreme rainfall in the region will become more evenly distributed over the coming periods. Therefore, it is expected that this study will aid guidance to the understanding of the ongoing changes as well as possible changes in rainfall and rainfall-related extremes in the study area, which in turn will help in adopting necessary adaptation measures to mitigate the negative impacts of climate change in the Guinea and Sudano-Sahelian ecological zones of Nigeria. Therefore, these results are important for future planning of water resources management and agriculture been the sectors that will be adversely affected in Guinea and Sudano-Sahelian ecological zones of Nigeria.

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