

# Observed and Future Spatiotemporal Changes of Rainfall Extreme Characteristics and Their Dynamic Driver in June-August Season over Africa

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How to cite this paper: Teshome, A., Zhang, J., Demissie, T. and Ma, Q.R. (2022) Observed and Future Spatiotemporal Changes of Rainfall Extreme Characteristics and Their Dynamic Driver in June-August Season over Africa. *Atmospheric and Climate Sciences*, **12**, 358-382. https://doi.org/10.4236/acs.2022.122022

**Received:** October 27, 2021 **Accepted:** April 4, 2022 **Published:** April 7, 2022

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Climate change has increased extreme events over globe and the most robust occurrences of concurrent drought and floods have become more common in Africa. This study focuses on the observed and projected analysis of rainfall extremes of consecutive dry day (CDD) and maximum monthly five day precipitation (RX5day) from Expert Team on Climate Change Detection and Indices (ETCCDI) in June-August season over Africa. The daily CORDEX Africa, reanalysis and CRU datasets were analyzed for extreme trends under RCP4.5 and RCP8.5 scenarios for the periods of 1980 to 2100. The spatiotemporal variability, trend, and magnitude of JJA seasonal rainfall performance exhibits a significant decreasing tendency over Eastern Africa compared to West Africa. The observed results of consecutive dry day (CDD) reveal that increasing trend and moreover RX5day shows that promising positive trend. Both rainfall extremes are influenced by the combined effect of large scale indexes and appear to be correlated negatively and positively with ENSO, NAO and AO. The CORDEX ensemble mean projections of JJA seasonal rainfall performance show a widespread significant change and the first mode of EOF depicts that 13.8% and 24.9% under the RCP4.5 and the highest variability is under RCP8.5 scenario. The projected CDD extreme exhibit an increasing trend in the coming periods and the percentage change revealed that increasing from 25.11%, 28.02% over West and 26.49%, 31.66% East Africa under RCP4.5 and RCP8.5 scenarios respectively. This situation will

exacerbate increasing of frequent and intensified drought extremes over Africa. Additionally, the future RX5day indicated that mixed trend and revealed that increasing 3.72%, 2.54% over West and decreases -16.12%, -22.47% over East Africa under RCP4.5 and RCP8.5 respectively. Generally, rainfall extremes of CDD are projected to increase and RX5day shows a mixed trend in the coming periods over Africa and calls for further verification by using high resolution datasets.

## **Keywords**

Africa, Extremes, JJA, Observed, Projected

## **1. Introduction**

There is strong evidence that enhanced greenhouse effect will result in not only changes in the mean weather conditions, but also in the increase of the variability of extreme climate [1] [2]. Climate change is already a reality in Africa and there are prolonged and intensified droughts in eastern Africa; unprecedented floods in western Africa and depletion of ecosystems in equatorial Africa [3]. Climate extremes exert a significant impact on the day to day economic development of Africa, particularly in traditional rain-fed agriculture and pastoralism and water resources at all scales [2]. Due to this floods and droughts can cause major human and environmental impacts on and disruptions to the economies of African countries, thus exacerbating vulnerability which is likely associated with regional climate change [4] [5] [6] [7]. Changes in rainfall extremes and patterns can have profound societal consequences, particularly across Africa where rainfall plays a crucial role in sustaining livelihoods and economic development and the change in rainfall across Africa have received much attention during the last 40 years [8]-[13]. Particularly, the Sahel regions of Africa were highly affected by continuous drought during the 1970s and 1980s due to its longevity and severity [8] [13] [14]. These changes in climate extremes of drought and flood affect human lives and have a large impact on society as a whole [15].

Knowledge on characteristics of climate extremes helps us to determine how the climate is changing, and also to identify the direction and prospect for the future. Many recent studies are based on extremes derived from precipitation [16] [17] [18] [19]. According to [2] report revealed that the 21<sup>st</sup> century warming due to anthropogenic forcing will be large in Africa, which is likely to increase the number, duration and amplitude of extremes of rainfall, especially in arid and semiarid regions of Africa. Africa is often considered to be the most vulnerable continent to climate change and extremes because of its higher vulnerability and lower adaptive capacity [20]. Therefore analysis of changes in extreme climate in terms of rainfall is particularly relevant for Africa because agriculture and food security are vulnerable sectors by the variability, intensity and frequency of extreme climate [21] [22]. Limited availability of long records of daily climate data in some parts of the world, including Africa, hampers efforts to analyze the impacts of climate change and variability on the frequency and severity of climate extremes [23]. The study of extreme weather and climate events, especially in Africa is still limited, with the main challenge being lack of or access to observed station data of daily resolution [24] [25].

This study will provide an insight evidence of changes of basic rainfall extremes focusing on providing the most comprehensive analysis by using observed and projected rainfall extremes over Africa. Accordingly, our analysis is based on four ensemble Coordinated Regional Climate Downscaling Experiment (CORDEX) regional models for Africa and this paper focuses on a better understanding of characteristics of extreme rainfall in the changing climate over Africa. The analysis will examine the temporal and spatial correlation between the occurrences of high intensity extreme rainfall events with large scale climate indexes of El Niño-Southern Oscillation (ENSO3.4), Southern Oscillation Index (SOI), North Atlantic Oscillation (NAO), and Indian Ocean Dipole (IOD).

# 2. Materials and Methods

### 2.1. Study Area

Africa is the second largest continent and it is bounded on the west by the Atlantic Ocean, on the north by the Mediterranean Sea, on the east by the Red Sea and the Indian Ocean while on the south by the blending waters of the Atlantic and Indian Oceans. Africa is unique continent that, almost symmetrically, straddles the equator, and hence experiences such a varied climate with both northern and southern hemispheric climatic influences [26] [27]. Agriculture is considered the largest main economic activity in Africa and it provides employment for approximately 60 percent of the African population, and more than 50 percent of GDP in some countries [28]. In Africa, the distribution of rainfall is very uneven in both space and time and the climate of much of the continent can be classified as arid and semi-arid, receiving less than 700 mm of precipitation each year [29] [30] [31]. Figure 1 indicates a description our study domains and for



Figure 1. Digital elevation map of Africa unit (meter) and our study domains marked in red rectangles.

this study, we select two sub-domains mainly based on rainfall amount and distribution here after referred to as R1 with a domain of longitude  $9^{\circ}W - 13^{\circ}E$  and latitude 7 - 20°N (West Africa) and R2 with a domain of longitude 15 - 39°E and latitude 6 - 18°N (East Africa).

## 2.2. Data

The study employs daily rainfall from four ensemble Coordinated Downscaling Experiment (CORDEX) Africa domain for both historical (1980 to 2005) and projected (2020 to 2099) data to analyze rainfall extremes. The four regional CORDEX models which we used for this study includes CanESM2, CSIRO-Mk3.6.0, GFDLESM2 and MIROC5 and the model runs every 50 km (0.448) resolution over the CORDEX-Africa domain and accessed from

https://esgf-node.llnl.gov/search/esgf-llnl/ more information on model output can be obtained from [32] [33]. The gridded data from Climatic Research Unit (CRU TS4.01) also used to examine recent variability and trends of rainfall over Africa available from 1980 to 2017 and the dataset is clearly discussed by [34] and accessed from

https://data.ceda.ac.uk//badc/cru/data/cru\_ts/cru\_ts\_4.01/data/. The seasonal sea surface temperature indexes (SST) of ENSO3.4, North Atlantic Oscillation (NAO), Southern Oscillation Index (SOI) and Atlantic oscillation (AO) obtained from NOAA of Climate Prediction Center (CPC) and additionally the Indian Ocean Dipole (IOD) also used. The composite analysis of sea level pressure and vector winds are obtained from NOAA/NCEP reanalysis data and maproom were explored from the NOAA/OAR/ESRL PSD/, Boulder, Colorado, USA,

<u>http://www.esrl.noaa.gov/psd/</u>. The reanalysis of wind datasets are used and collected from ERA-Interim for JJA season for the periods of 1980-2017

(<u>http://apps.ecmwf.int/datasets/</u>) and accessed from the European Center Medium-Range Weather Forecasting (ECMWF), with a horizontal resolution of  $0.75^{\circ} \times 0.75^{\circ}$  [35].

#### 2.3. Methods

Our study uses standard descriptive statistics, mean, standardized seasonal anomaly, linear regression and correlation to explore the linkage between circulations, anomalies of SST with CDD and RX5day extremes. According to the Expert Team on Climate Change Detection and Indices (ETCCDI) and World Meteorological Organization (WMO) recommended a total of 27 core extreme with primary focuses to be derived from station daily data [19] [36]. For this study we analyzed two basic rainfall extremes were selected to investigate extreme climate conditions over Africa (Table 1). The two rainfall extremes are consecutive dry days (CDD) which is important to indicate the drought intensity and frequency. Whereas monthly maximum five day precipitation amount (RX5day) helps to provide information for the occurrence of flood phenomena. Additionally RCP 4.5 and RCP 8.5 climate scenarios used in order to detect the

Elements	Indices name	Definition	
Precipitation	RX5day	Monthly maximum 5-day precipitation	mm
	CDD	number of consecutive days with RR < 1 mm	days

 Table 1. List of the ETCCDI extreme investigated in this study.

NB: Full definitions are available from http://etccdi.pacificclimate.org/list\_27\_indices.shtml.

potential impact of the projected extremes based on the recommendation of [37] [38]. A trend analysis for rainfall extremes was detected and carried out by using the Mann Kendall (MK) test as discussed in depth by [39]. The wind and rainfall anomaly is analyzed by using statistical method of empirical orthogonal function (EOF).

## 3. Result and Discussions

## **3.1. Seasonal Rainfall Characteristics**

Understanding the spatiotemporal variability, trend, and changes in precipitation in a changing climate are crucial mainly in the agricultural and other related socio-economic sectors. The June-August (JJA) season is the most vital rainy period for the equatorial and eastern portions of African countries. Figure 2 shows that the standardized seasonal rainfall anomaly and contour based seasonal rainfall change over each region in JJA season. The temporal rainfall trend plot depicts that significant variability during 1980-2017 and which is modulated by remote forcing (Figure 2(a) and Figure 2(b)). During the JJA, inconsistent temporal variability is portrayed, and the rainfall amount is lessening temporally and spatially over each region (Figures 2(a)-(c)). The normalized plot revealed that seasonal rainfall exhibits high spatiotemporal variability with the highest variation in east African regions (Figure 2(c)). In most recent years the spatiotemporal variability of JJA seasonal rainfall over east Africa shows that constantly decreasing trend compared to West African regions (Figures 2(a)-(c). Particularly, there was observed huge shifts in JJA season during 1998, 2010, 2011, 2013 and 2015/16 which was associated with varies teleconections including ENSO episode over East African regions. This decline in JJA seasonal rainfall over the region have also been observed in earlier studies which revealed accompaniment of severe and frequent occurrence of droughts during that period (Figure 5 and Table 2). Additionally noticeable variability of JJA seasonal rainfall observed over West African regions. This result is in agreement with [40] who observed that in some portions of African countries the seasonal rainfall performance depicts both increase and decrease but in general the rainfall trends are weak. Due to the variability of the seasonal rainfall during 1980-2017 severe to extreme drought occurred over each region and such types of rainfall extremes affect varies socio-economic activities over Africa (Table 2). Changes in extreme events of droughts and floods have already been observed due to deficit and heavy precipitation events globally including Africa [41]. As indicated by



**Figure 2.** Standardized precipitation anomaly of JJA season over (a) R1, (b) R2 and (c) contour based (CCTR) spatial trend precipitation change over Africa during 1980-2017 in June-August season. The black dot is the 95% significance confidence level.

**Table 2.** Drought and flood years over Africa and the events were obtained from EM-DAT: The OFDA/CRED International Disaster Database, <u>https://www.emdat.be/</u> and from [51] [52].

Year	R1	R2	Impact
1980, 1982, 1987, 1989, 1992 and 1996	Drought		Affected 1.1 million affected and various economic activities are damaged
1982, 1989, 1991, 1997, 2002 and 2015		Drought	Affected 1.263 million people from Kenya, Uganda, Sudan, Djibouti and Ethiopia
1995, 2000, 2007, 2010, 2011, 2014 and 2016	Flood		150 people are died due to sudden flood and more peoples displaced and various infrastructure damaged
1988, 1995, 1998, 2006, 2008 and 2010		Flood	Flood displaced more than one million peoples from Kenya and Somalia

[30] the African JJA seasonal rainfall is mainly influenced by the El Niño-Southern Oscillation (ENSO) and other large scale indexes which is described in (**Table 3**).

Extremes	Index	R1	R2
	ENSO3.4	0.085	0.544**
CDD	NAO	-0.511**	-0.46**
CDD	AO	0.276**	0.29
	IOD	0.315**	0.322*
DX5 1	SOI	0.365**	0.185**
KX5day	NAO	-0.385**	-0.281**

**Table 3.** Correlation of standardized CDD and Rx5day with indexes over each region (\*0.05, \*\*0.01 confidence level).

#### 3.1.1. Observed Seasonal Extremes

The selected observed rainfall extremes of consecutive dry days (CDD) and maximum rainfall five day precipitation (RX5day) are computed based on ETCCDI definitions for each study region (Table 1). CDD (maximum number of consecutive days with rainfall intensity < 1 mm/day) and the result has been shown an increasing trend during 1980-2017. Furthermore, significant enhancement of CDD was observed starting from 1995 and onwards over both regions (Figure 3(a), Figure 3(b) and Table 5). The current result is in agreement with [42] [43] who reported trends in precipitation extremes, including the number of days with precipitation and continuous reduction of the number of heavy rainy days and increasing of consecutive dry days over Greater Horn of Africa. The increment of continuous dry days over the African regions increases the frequency and magnitude of drought and which influences various socio-economic activities. Drought has negative impacts on most of the countries, with developing countries such as those in Africa being affected the most [44] [45]. Previous works of [1] noted that changes in climate over recent decades continue to cause impacts on natural and human systems globally mainly in developing countries.

The result of RX5day revealed that slightly promising positive trend mainly over R1 compared to R2 regions (Figure 3(c), Figure 3(d) and Table 5). Overall it is seen that the observed consecutive dry day's and RX5day trend shows that increasing trend and which is conducive for the occurrence of extremes like drought and sudden flood over our study area. [46] noted that there has been an increase in rainfall extremes across African regions in latest years. Climate extremes are one of the grand challenges proposed by the World Climate Research Programme (WCRP) and documented by the World Meteorological Organization [47].

The Sequential Mann-Kendall (SMK) test was used to determine the abrupt changes in CDD and RX5day (Figures 4(a)-(d)). According to [48], abrupt shifts refer to the alteration of climate variables from one stable state to another. When these shifts exceed a certain threshold, due to external forces which aggravate a change of state at a frequency governed by the climate systems, it signifies an abrupt change in the climate variable [49]. Abrupt change is considered



**Figure 3.** Time series plots of consecutive dry days (a) R1, (b) R2 dotted dashed red color shows 85 percentiles and black line shows CDD trend and maximum five day precipitation (c) R1 and (d) R2 blue color shows 85 percentile, black line indicates RX5DAY trend and red line indicates ten year moving average.



**Figure 4.** Abrupt change in consecutive dry days (a) R1CDD, (b) R2CDD and maximum monthly 5-day precipitation (c) R1RX5DAY and (d) R2RX5DAY from 1980 to 2017 over Africa. The dotted lines indicate confidence band at  $\alpha = 0.05$ .

to occur if the intersection of the progressive (UBK) and retrograde (UFK) curve occurs above the confident band. The confident band is marked by the dotted lines at 95% confidence interval, which corresponds to  $\pm 1.96$  tabulated values. To this end, Figure 4 shows the change points of consecutive dry days and monthly maximum 5-day precipitation during 1980-2017 the study period (Figure 4(a) and Figure 4(b)). During summer season the CDD was rapidly changing starting from 1995 over both regions. Moreover, RX5day result shows that enhancement during the period of 2000 and onwards over R1 and R2 (Figure 4(c) and Figure 4(d)).

## 3.1.2. Palmer Drought Severity Index In JJA Season

Extreme precipitation events of drought and flood have major impacts on various socio-economic activities [50]. The Palmer drought severity indicator shows that extreme to severe drought phenomena occurred during 1980-2017 over Africa. Moreover, the intensity and frequency are high over Eastern Africa (Figure 5). Similarly, the selected anomalies years indicated that drought and flood extreme events are affecting various socio-economic activities over Africa (Table 2).

#### 3.2. Drivers of Drought and Flood in the JJA Seasonal Rainfall

1) Correlation of seasonal rainfall with sea surface temperature (SSTs)

In this section, we analyzed different large scale atmospheric indexes and their relation with CDD and RX5DAY. The variability of Sea Surface Temperature (SST) is considered to be one of the factors that control the variability of the African monsoon rainfall. The ENSO3.4 correlates negatively and NAO positively over East African JJA seasonal rainfall. Moreover ENSO3.4 and NAO correlate positively over Western Africa regions (Figure 6(a) and Figure 6(b)). Li *et al.* 2012 correlates the SST to the African monsoon seasonal rain and found that more rain occurred over West African region in the years with warmer SST. The seasonal rainfall variability over Africa is mostly influenced by large scale atmospheric phenomena of ENSO3.4 and NAO. The JJA seasonal and interannual variability of precipitation extremes over Africa results from complex interactions of forced and free atmospheric variations [30].



**Figure 5.** Palmer drought severity indicator (PDSI) during June-August season over Africa and accessed from https://www.esrl.noaa.gov/psd/.



Figure 6. Correlation between JJA seasonal rainfall and (a) ENSO3.4 and (b) NAO sea surface temperature indices.

Previous works of [53] depict that a complex influence of SSTs is responsible for rainfall patterns and trends in the Sahel at different frequency scales, including SSTs-ENSO in the Indian Ocean [54] and the Mediterranean Sea [55]. Furthermore, land-surface-moisture feedbacks play an important role [56].

2) Association of CDD and RX5day extremes with large scale SST anomalies

Understanding the clear relation extremes with various large scale climate indexes is very important to minimize the impact of drought and flood events.

The CDD and RX5DAY have been significantly associated with several large scale climate indexes which include ENSO3.4, SOI, NAO, AO and IOD (Figure 7, Figure 8 and Table 3). As pointed out in Figure 7 the standardized anomaly of CDD and RX5DAY shows enhancement after 1995 and is highly governed and associated by large scale indexes of ENSO, SOI, NAO, AO and IOD. The ENSO3.4, AO and IOD index has positively correlated with CDD over R1 and R2 and whereas NAO correlates negatively over both study regions (Table 3). The extent to which these large scale indexes influence the seasonal cumulative precipitation over Africa has been widely studied by [30] [57] [58]. The Southern Oscillation Index (SOI) and North Atlantic Oscillation (NAO) correlate positively and negatively with RX5day over each region respectively (Table 3). Previous studies of [59] indicated that ENSO is the primary source of variability in the tropical and global precipitation record and therefore variations in ENSO affect perceptions about changes in drought [60] [61] and their possible links to climate change and extremes. Moreover, the daily and seasonal rainfall of African region is influenced by the Inter-Tropical Convergence Zone (ITCZ) and ITCZ passes the equator twice in a year; the passages of the ITCZ coincide with the two distinct rainy seasons experienced in the area [62].

3) Atmospheric circulation features associated with extremes

**Figure 9** shows the first EOF modes of 150 hPa v-wind and geo-potential height anomalies over Africa in JJA season. The mid-latitude flow which indicates that a wavelike structure propagating towards African continent approximately extends from northern Atlantic and Europe which have negative signals over eastern African portions (**Figure 9**). The EOF wind anomalies revealed that higher variability and the variance of the first mode is 37.4% (**Figure 9(a)** and **Figure 9(c)**) and the first mode of EOF of geo-potential height indicates 45.1%



**Figure 7.** Standardized anomaly plots of CDD (top R1 and R2) and RX5day (bottom R1 and R2) with large scale indexes during 1980-2017 over the study area.





**Figure 8.** Taylor diagram plot that summarize correlation coefficient and root-mean-square (RMSE) between Consecutive dry days (left panel) and RX5DAY (right panel) with large scale atmospheric indexes over each region.



Figure 9. The first leading modes of EOF (a) 150 hPa wind (b) geo-potential height (c) PC1 of 150 hPa and (d) PC1 of geo-potential height in the JJA season.

and it shows that positive anomalies over R1 than R2 (Figure 9(b) and Figure 9(d)). Previous works of [63] showed that the drought and flood episodes in the

African Sahel regions has been occurred and intensified by the intensity and frequency of various atmospheric features.

**Figure 10** depicts that the dominant wind climatology at 850 mb, 700 mb, 150 mb and their anomalous years of drought and flood extremes over R1 of West Africa. The low level westerlies are the main features during JJA season which transport moisture from Tropical Atlantic towards inlands of African continent and the maximum strengthen of the wind speed is ~16 m/s (**Figures 10(a)-(c)**). The African Easterly Jet (AEJ) at 700 hPa located between 10°N and 15°N which resulted from thermal difference between the Saharan and Atlantic Ocean and it is sustained by the contrasting moist convection to the south and a dry convection to the north and the strengthening of the AEJ is usually connected with a decrease precipitation for the African summer rainfall and this situation exacerbate



Figure 10. Composite wind climatology of (a) 850 mb; (b) 700 mb; (c) 150 mb, rainfall (mm) and wind anomalies (m/s) for drought years; (d) 850 mb; (e) 700 mb; (f) 150 mb and rainfall and wind anomalies for flood years; (g) 850 mb; (h) 700 mb; (i) 150 mb over R1.

increasing of rainfall extremes (Figure 10(b), Figure 10(e), Figure 11(b) and Figure 11(e)). Atmospheric circulation is an important component of the African summer monsoon [64]. It drives the monsoon inland from the coast and contributes to vertical moisture transport, a crucial requirement for African summer rainfall [65]. The JJA rainfall in the Sahel region exhibits significant variability and the region is particularly vulnerable to major droughts such as occurred in the 1970s and 1980s [66].

The anomaly field of velocity potential/divergence (convergence) associated with the composite wet and dry years are analyzed during June-August seasonal rainfall over Africa (Figure 12). The shaded lines of Omega over East Africa show that negative trend at all pressure levels and while weak positive over West Africa (Figures 12(a)-(c)). The wet events are characterized by convergence



Figure 11. The same as Figure 9 but for R2 Composite wind climatology of (a) 850 mb; (b) 700 mb; (c) 150 mb, rainfall (mm) and wind anomalies (m/s) for drought years; (d) 850 mb; (e) 700 mb; (f) 150 mb and rainfall and wind anomalies for flood years; (g) 850 mb; (h) 700 mb; (i) 150 mb over R2.



**Figure 12.** Wind climatology of June-August same as **Figures 10(a)-(c)** (m/s) and omega velocity (10<sup>3</sup> m/s) at (a) 850 hPa (Low level Jet); (b) 700 hPa (African easterly jet); (c) 150 hPa (Tropical easterly jet).

(divergence) at low level (upper level) winds respectively (Figures 12(a)-(c)). Mainly over our study domains, thus the composite velocity potential during wet years is associated with rising/upward motion over West Africa (R1) and the dry years indicates that which are opposite to the wet years it is associated by divergence (convergence) over the study region (Figures 12(a)-(c)). The composite dry years are therefore characterized with sinking/downward motion mainly over Eastern Africa (R2).

# 3.3. Projected Rainfall Extremes

# 3.3.1. June-August Seasonal Rainfall Performance

Seasonal variations were investigated to provide more detail about the changes in seasonal rainfall over Africa using the empirical orthogonal function (EOF). Understanding the future changes in the seasonal cycle of rainfall over Africa is crucial for establishing appropriate mechanisms to minimize the impact of future rainfall extremes like drought and flood. The analysis of the results obtained by the rainfall changes is presented in **Figure 13** under RCP4.5 and RCP8.5 climate scenarios. The results of EOF indicate that the future JJA seasonal rainfall revealed spatial and temporal variability is high for the coming periods over Africa (**Figure 13**). The EOF plot of first-third mode revealed that the June-August



**Figure 13.** EOF plot of projected JJA seasonal rainfall change over Africa under RCP4.5 (left panel) and RCP8.5 (right panel) climate scenario from 2020-2100.

seasonal rainfall varies by 13.8%, 10.7% and 8.4% respectively under RCP4.5 climate scenario.

The right panel of **Figure 13** indicates that the seasonal rainfall varies by 24.9%, 9.1% and 7.3% respectively under RCP8.5 climate scenario. The projected spatiotemporal seasonal rainfall performance depicts that strong variability under RCP8.5 compared to RCP4.5 scenario. Previous studies of [67], found that strong decrease in precipitation by 2100 under the RCP8.5 scenario. Thus, the results of this investigation depict that the projected rainfall over the study area is towards decreasing trend. Our results are in agreement with [68] who reported that regional climate model, have predicted a significant reduction of precipitation at the end of the century over Africa. Additionally, IPCC reported that Africa will likely experience longer and more intense droughts in the near future [2] [69].

#### 3.3.2. Projected CDD and RX5day Change

Projecting the future climate extremes is important for providing the general information on the trend, intensity, frequency, characteristics and changes of climate extremes and their impact over socio-economic activities [1]. The consecutive dry days over Africa shows that significantly increasing trend in the coming periods under both scenarios and with the higher under RCP8.5 (Figure 14, Table 4 and Table 5). The projected mean increment of CDD range shows

**Table 4.** Summary of the projected percentage change of precipitation extremes under RCP4.5 and RCP8.5 scenarios compared to the baseline.

Indices	CDD (%	CDD (% change)		(% change)
Scenarios	R1	R2	R1	R2
RCP4.5	25.11	26.49	3.78	-16.12
 RCP8.5	28.02	31.66	2.54	-22.47

Regions	Category	Indices	Z score	Sen's slope estimator
	Baseline	CDD	6.48	1.152**
R1		RX5DAY	4.22	0.237**
	RCP4.5	CDD	7.43	0.462**
		RX5DAY	9.58	0.542**
	RCP8.5	CDD	7.66	0.464**
		RX5DAY	2.21	0.031*
	Baseline	CDD	4.67	1.01*
R2		RX5DAY	1.71	0.112*
	RCP4.5	CDD	8.37	0.484
		RX5DAY	-0.44	-0.011
	RCP8.5	CDD	8.98	0.5**
		RX5DAY	-0.02	-0.025

**Table 5.** Summary of the MK test statistic for precipitation extremes (\*0.05, \*\*0.01 confidence level).



**Figure 14.** Time series plots of projected consecutive dry days under RCP4.5 (left panel) and RCP8.5 (right panel) the redline indicates ten year moving average, blue line represent average of CDD and pink color shows that trend of projected CDD.

that 43 - 44 for R1 and 49 - 51 for R2 under RCP4.5 and RCP8.5 respectively (Figure 14). Moreover, the CDD percentage change shows that increases by 25.11%, 28.02% and increases by 26.49%, 31.66% over R1 and R2 respectively under RCP 4.5 and RCP 8.5 scenarios. This phenomenon indicates that a significant change of precipitation and tending to drying trend over Africa (Table 4). The current result is quite good agreement with [70] who reported that precipitation decreases more than 50% at the end of 21st century and leads to increase of hydro-meteorological disasters in JJA over Africa. Similarly [71] indicated that under global warming the occurrence of extreme climate disasters is predicted to become more frequent with droughts being one of the most severe disasters.

The projected maximum monthly five day precipitation amount (RX5day) revealed that mixed trend of decreasing and increasing under both RCP 4.5 and RCP 8.5 scenarios (Figure 15, Table 4 and Table 5). RX5day shows that increasing trend over R1 by 3.72% and 2.54%, decreases by -16.12% and -22.47% over R2 under RCP4.5 and RCP8.5 respectively. This fluctuation of RX5day may lead to sudden and intensified flood events over Africa (Table 4). Previous studies of [72] revealed that precipitation extremes such as floods and drought are projected to increase in the coming periods over globe including Africa.

Overall the projected CDD and RX5day precipitation extreme events indicated that significant variability and enhancement for the coming periods over



**Figure 15.** Comparison of projected and baseline monthly maximum 5-day precipitation (RX5day) red line shows baselines, blue represent RCP4.5 and black indicates RCP8.5.

Africa. The frequency of extreme precipitation events is projected to increase globally in the coming periods, including Africa [73] [74], which will also increase the risks of drought, floods, landslides, agricultural and environmental disasters [75].

# 4. Conclusions

This paper describes trends of two basic rainfall extremes over Africa by using daily rainfall of historical and projected datasets from CORDEX Africa and CRU TS4.01 for the periods of 1980 to 2100 under RCP4.5 and RCP8.5 in June-August season. The result of standardized rainfall anomaly shows that significantly variable spatiotemporally within regions and the seasonal rainfall performance is towards declining trend, especially over east Africa of R2. Due to the variability of seasonal rainfall over Africa slight to extreme drought occurred and which affects various socio-economic activities. The observed rainfall extreme of consecutive dry days (CDD) shows that significantly increasing trend over the study regions during 1980-2017. Similarly [46] reported a statistically significant increase in consecutive dry days and dry spell duration over Africa. Moreover, the observed monthly maximum five day precipitation amount (RX5day) shows that promising positive trend over Africa. Both rainfall extremes were affected and influenced by large scale atmospheric indexes of ENSO3.4, NAO and IOD in JJA season and correlated negatively and positively.

The projected EOF result of June-August rainfall performance indicates that significance variability spatiotemporally with the highest variability under RCP8.5 than RCP4.5 climate scenario. The first-third mode of EOF result exhibit 13.8%, 10.7%, 8.4% and 24.9%, 9.1% and 7.3% variation under RCP4.5 and RCP8.5 respectively. The projected consecutive dry day (CDD) revealed that significantly increasing trend over Africa during 2020-2100 under RCP4.5 and RCP8.5 climate scenarios compared to the observed CDD. The future increment of CDD is

relatively higher over East Africa than West Africa regions. Moreover, the percentage change shows that increasing 25.11%, 28.02% over R1 of West Africa and increasing 26.49%, 31.66% over R2 of East Africa under both RCP4.5 and RCP8.5 scenarios respectively. This phenomenon indicates a significant change of precipitation and tending to the drying trend over Africa in JJA season. The enhancement of consecutive dry days has a direct impact on soil moisture and which leads to the decreasing of agricultural activities and this may cause devastating impact mainly over agricultural and related socio-economic activities. Similarly [76] observed that reduction in soil moisture content as a result of warming could decrease agricultural production. The African countries are consistently projected to become global hotspots for drought by the end of the 21st century under the Representative Concentration Pathway (RCP) 8.5 scenario and changes in the global climate are already, and are projected to continue, adding pressure on the profile of various socio-economic activities [77] [78].

Whereas the projected monthly maximum five day precipitation amount (RX5DAY) shows that variable from region to region and the result indicates both mixed trends of decreasing and increasing under RCP4.5 and RCP8.5 scenarios. The percentage change revealed that increasing by 3.72% and 2.54% over R1 of West Africa, decreases by -16.12% and -22.47% over R2 of East Africa under RCP4.5 and RCP8.5 respectively in the coming periods.

Overall the observed and projected extreme rainfall of CDD shows that significantly increasing trend and RX5day shows mixed trends of increasing and decreasing. The variability of these extreme events may lead towards the increment of intensified drought cases and are most likely to devastate and reduce the socio-economic activities of the study area. The intensity and frequency of extreme rainfall events like drought and flood are projected to increase under climate warming [79] [80] [81]. Generally, the variation of rainfall extremes like CDD is high and calls for further verification by using high-resolution datasets.

Acknowledgments: We acknowledge the funding from the International Development Association (IDA) of the World Bank to the Accelerating Impact of CGIAR Climate Research for Africa (AICCRA) project and by the National Key R&D Program of China (2018YFC1507101). The authors express their appreciation to Nanjing University of Information Science and Technology (NUIST) for encouraging and supporting research. The first author is indebted to Chinese Scholarship Council (CSC) for sponsoring his Ph.D. study. Sincere appreciation goes to Coordinated Regional Climate Downscaling Experiment Africa groups and the respective modelling centers for providing the CORDEX Africa, Climate Research Unit (CRU), European Center Medium-Range Weather Forecasting (ECMWF) and Climate Prediction Center of National Oceanic Administration (NOAA) data.

# **Conflicts of Interest**

The authors declare that they have no conflict of interest.

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