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Research Article

Geospatial Variability of Vegetation Response to Meteorological Drought in North-East and North-West Nigeria

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Abstract

This research investigated extreme drought variability and future trends in North-East and North-West Nigeria, addressing essential questions regarding the temporal and spatial variations in rainy and dry seasons. Daily and Monthly observation datasets at (0.50 x 0.50) resolution was obtained from the global gridded climatology of Climate Research covering 1981 to 2019. Simulated daily datasets from the Rossby Centre for Atmospheric Regional Climate Model (RCA4-RCM) under two emission scenarios (RCP4.5 and RCP8.5) for the periods 1976-2005 (historical) and 2020-2100 (projection) were retrieved from CORDEX at a resolution of (0.440 x 0.440) over Africa. The Standardized Precipitation Evaporation Index (SPEI) assessed drought intensities, revealing near normal, moderate, and severe conditions within the range of 1.99 to -1.99. A linear regression model established the relationship between Normalized Difference Vegetation Index (NDVI) and rainfall. Spatial analysis of Consecutive dry days (Drought Index) over three 30-year periods (near, mid, and far future) set a critical/threshold level at -0.4 to 1.2, unveiling distinctive drought severity patterns. Findings highlighted regions with low vulnerability (Bornu, Kano, and Katsina) and high risk (Bauchi, Zamfara, Yobe) during the historical period. Projected trends indicated fewer consecutive dry days between 2020 and 2040 under RCP 4.5 and RCP 8.5, with greater emissions and warming in RCP 8.5 leading to increased dry days between 2041 and 2070. The mid-century outlook suggests a rise in dry days, signalling prolonged drought in the region. SPEI analysis revealed potential future aridity in Northern Nigeria due to rising Potential Evaporation (PET) and continuous Climatic Water Balance (CWB) deficits observed over West Africa, leading to increased evaporation losses and higher irrigation demands for drier soils.

Keywords: Standardized Precipitation Evaporation Index, Drought Intensity, Drought Projection, Consecutive Dry Days.

1. Introduction

This Climate patterns have showcased a dynamic history, exhibiting variability, fluctuations, trends, and both abrupt and gradual changes throughout Earth's existence. Proxy data, including tidal waves, changing sea and lake levels, pollen counts, and ice-core analyses, offer evidence of remarkable climatic changes over millennia [1].

The earth's susceptibility to ice-ages and concerns about unprecedented global warming, attributed to human activities like industrial by-product release and large-scale deforestation, underscore the non-static nature of climate [1]. Ayoade emphasizes that while variability is intrinsic to climate, the magnitude and duration of fluctuations determine their impact [2]. Minor variations are easily adaptable, but substantial deviations from the norm pose challenges, rendering the environment, humans, and activities highly vulnerable [2].

Insufficient precipitation leading to drought emerges as a natural disaster with global implications. Its impact on agriculture, ecosystems, and water resources triggers economic losses, famine, epidemics, and land degradation. Developing countries face structural problems like unemployment, poverty, reduced crop yields, and forced migration. According to Atedhor, analyzing drought conditions, including onset, end dates, magnitude, spatial extent, probabilities, and vulnerabilities, becomes crucial for assessing hazard and vulnerability [3].

Researchers utilize tools such as the Standardized Precipitation Index, Remote Sensing, and GIS to assess drought trends, generate risk maps, and analyze vegetation dynamics in Nigeria. Vegetation, a crucial ecosystem component, regulates water balance and carbon cycles, impacting earth's diverse ecosystems and their services. The relationship between climate and vegetation, reflected in Nigeria's zonal patterns, is now threatened by human activities, emphasizing the urgency for quantitative assessments of vegetation cover (FORMECU; Aweto; FAO).

The primary goal is to comprehend the interplay between rainfall and vegetation in the study area, employing remote sensing and GIS analysis. By utilizing the Normalized Difference Vegetation Index (NDVI), this research aims to discern vegetation changes. Drought assessment involves two indices, namely the Standardized Precipitation Index (SPI) and Standardized Precipitation Evapotranspiration Index (SPEI). The Consecutive Dry Days Theory is utilized to analyze drought characteristics such as severity, duration, and intensity. The study considers multiple time scales to grasp drought behaviour and projections under climate change scenarios.

In the context of Northeast and Northwest Nigeria, where rain-fed agriculture sustains livelihoods, understanding climate variations is pivotal. The study is prompted by the aridity increase, advancing Sahara Desert, and the shrinking Lake Chad, emphasizing the need for accurate climate change predictions in these regions. The study aligns with the Intergovernmental Panel on Climate Change's (IPCC) recognition of global climate change impacts and aims to address crucial questions related to climate variations in the targeted areas.

Justified by the significant impact of drought on vegetation dynamics, biodiversity, and ecosystem functioning, the research gains further importance. With agriculture being a key activity in these regions, the study offers insights into vulnerable areas, supporting the development of sustainable agricultural practices. As climate change intensifies global drought events, understanding vegetation responses becomes imperative for climate change adaptation efforts [4]. The research findings are expected to inform evidence-based policies and interventions, reducing drought vulnerability and ensuring sustainable development in Northeast and Northwest Nigeria.

This study endeavors to contribute to regional understanding of vegetation response to meteorological drought, impact assessment, identification of hotspots, spatial modeling, methodological advances, and knowledge for adaptation and management. By studying the geospatial variability of vegetation response to drought, the research aims to provide valuable information for effective decision-making and mitigation strategies in the face of climate change challenges in North-East and North-West Nigeria. Specifically, the study aims to assess the occurrence of drought and vegetation response in North-West and North-East Nigeria. The objectives include determining drought intensity, establishing its relationship with the Normalized Difference Vegetation Index (NDVI), and projecting future drought scenarios.

1.1. Study Area

Northwest and Northeast Nigeria comprises the Sudan Savannah grassland and the Guinea Savannah, with even topography and prevalent Precambrian igneous and metamorphic rocks and notable peaks like the Mambila Plateau and Adamawa highlands are primarily composed of granites and volcanic rocks [5]. Major rivers, including Rivers Benue and Niger in the South, and Rivers Rima, Hadejia, Nguru, Sokoto, Gana, Jamaare, and Lake Chad in the North-East, traverse the region [6].

Groundwater is extensively used, with boreholes reaching depths of up to 100 meters and static water commonly found at 40 meters. The area includes four prominent River Basins: Upper Benue, Lake Chad, Hadejia-Jamare, and Sokoto-Rima. Active deforestation contributes to desertification and drought. The climate features two distinct seasons: a dry season with northeast winds from October to April and a wet season from May to September, characterized by strong southwest winds and varying rainfall patterns [7]. Rainy seasons become shorter as one moves northward. The temperature ranges between 27°C and 30°C.

1.2. Observation Dataset

As shown in Table 1, Observed rainfall and simulation dataset were used and analyzed in this study. Daily and Monthly observation dataset at a resolution of (0.50 x 0.50) was retrieved from the global gridded climatology of Climate Research Unit (CRU; version 4.01; Harris et al). The dataset provided by CRU covers the entire global land-surface over the period of (1981 to 2019).

1.3. Simulation Dataset

Daily dataset simulated by Rossby Center for Atmospheric Regional Climate Model (RCA4- RCM; Popke et al) driven by MPI-ESM-LR GCM was obtained from CORDEX (Nikulin et al. 2018) at a resolution of (0.440 x 0.440) horizontal grid size over Africa as shown in Table 1. The simulation RCA4 comprises of the historical (1976-2005) and the projection part (2020-2100) under two different emission scenarios (RCP4.5 and RCP8.5; Thomson et al; Riahi et al; Samuelsson et al.). Temperature (minimum and maximum) and precipitation over West Africa were analyzed for both datasets [8-10].

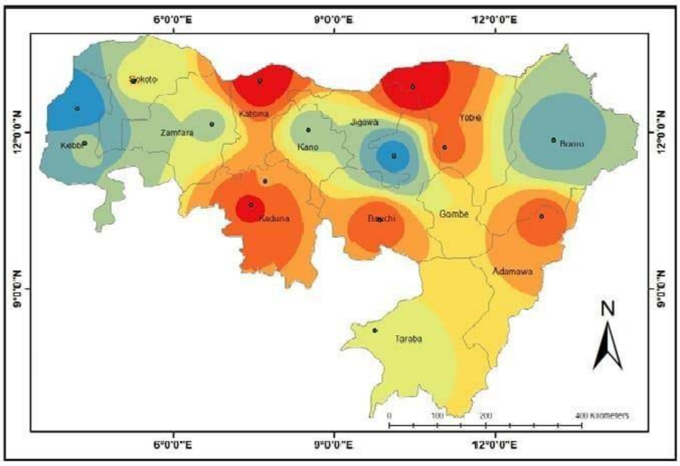


Figure 1: Map of the Study Area

Table 1: Detail Description of the Two Datasets used (Datasets).

Dataset Type	Observation	Simulation
Dataset Name	CRU	RCA
Dataset Version	4.01	
Period	1981-2019	1976-2005, 2020-2100
Historical/RCP	Historical	Historical, 4.5 and 8.5
Parameters	Precipitation, Minimum and Maximum Temperature	Precipitation, Minimum and Maximum Temperature
Resolution	0.5 x 0.5 degree	0.44 x 0.44 degree
Driving Model		MPI-ESM-LR

2. Methodology

Standardized Evapo-Transpiration was used to determine the occurrence of drought of different intensities particularly near normal, moderate, and severe drought in the study area for objective 1. As shown in Table 2, this is considered as relatively new drought index, SPEI makes use of the basis of SPI but includes a temperature parameter in its computation, which makes it necessary for the SPEI to give an account of the effect of temperature on drought development through a basic water balance calculation. The intensity scale of SPEI can be calculated in both positive and negative values, identifying wet and dry events. It can be calculated for time steps of 1-month up to 48-months and more [9-12]. The operational monthly update allows it to be useful, and the longer the time series of data available, the more robust the results will produce. Mathematically, it can be determined by the difference between precipitation (P) and potential evapotranspiration (PET) that can be computed using different methods and approaches. In this work, Hargreaves's temperature-based PET (Hargreaves; Hargreaves, and Samani) was used to calculate the potential evapotranspiration over the study area and periods. This is given below as

$$D = Pi - PETi \rightarrow (1)$$

Like SPI, SPEI is calculated at a different timescale of 3-, 6- and 12-month to determine short, mid and long-term drought over the study area.

$$PET = 0.0023 * Ra * (Tmax - Tmin) * \sqrt{(Tavg + 17.8)} \rightarrow (2)$$

Then it was standardized using the mean and standard deviation to obtain the Standardized Precipitation Evapo-Transpiration Index (SPEI) values.

$$SPEI = (\text{Precipitation Deficit} - \mu) / \sigma \rightarrow (3)$$

Drought conditions were classified using the SPI and SPEI. Table 2 shows the dryness/wetness grade categorized according to SPI and SPEI (McKeel et al; Vicente-Serrano et al); this standardization is a mechanism for applying both the SPEI and SPI to determine the rarity of a projected drought. An index of 0.0 to -1.0 indicates mildly dry; -1.0 to -1.49 is moderately dry; -1.5 to -1.99 regarded as severely dry; -2.0 or less depicts extremely dry [13-16].

A linear regression model was used to determine the existence of relationship between NDVI and rainfall in the study area for objective 2. The study made use of the near real time data of Moderate Resolution Imaging Spectroradiometer (MODIS)Terra and Aqua Normalized Difference Vegetation Index (NDVI) of 16 Day L3 Global 250 m resolution. NDVI imageries from 2000 to 2019 were considered for this study. One of the most used and implemented indices calculated from multispectral information as normalized ratio between the red and near infrared bands is the NDVI. A direct use of NDVI is to characterize vegetation canopy growth or vigor. It is a non- linear function that varies between −1 and +1 and is undefined when both Pred and Pnir are zero,Pred and Pnir are reflectance in red and near infrared bands of the satellite imageries respectively(Pettorelli et al).

Drought Index (Consecutive Dry Days) was used to determine the projection of drought in the study area for objective 3. Maximum number of consecutive dry days per time-period with daily precipitation amount of less than 1 mm. Consecutive dry days are included in the index as an indication of drought conditions. It is defined as the number of consecutive days with less than 1mm of rain up to a maximum of 365 days. A threshold value of 0.1 mm is used and days with precipitation less than this threshold are considered dry days. The duration of CDDs indicates the number of consecutive days with daily precipitation than this threshold [17-20].

$$CDD \text{ (days)} = \text{count} \sum_1^n (P_r \geq 0.1 \rightarrow (4)$$

For each day (r = 1 to n), check if the precipitation value P_r is greater than or equal to 0.1 (the threshold). If the condition is met, increase the count of consecutive dry days. If the condition is not met, reset the count to zero.

The drought index measures low precipitation, where high values indicate prolonged periods of little rainfall and conditions favorable for drought. If the index increases over time, it indicates a growing likelihood of drought condition [21-26].

Table 2: Drought Classification from Standardized Precipitation Index (SPI) and Standardized Precipitation Evapo-Transpiration Index (SPEI) Values (Mckee et al. 1993).

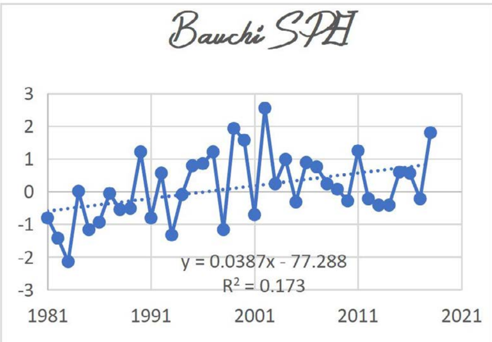
SPI/SPEI Value	Classification
-0.49 to 0.49	Near Normal
-0.99 to -0.50	Mildly Dry
-1.49 to -1.00	Moderately Dry
-1.99 to -1.50	Severely Dry
Less than -2.00	Extremely Dry

3. Result and Discussion

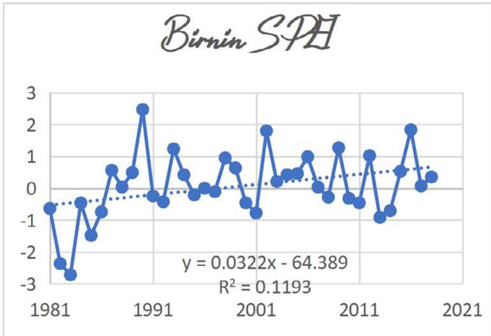
3.1. Time Series Variation from 1981 to 2019 (figure 2(a-o))

The SPEI is a drought index that measures the balance between precipitation and evapotranspiration. It is calculated by comparing the actual moisture levels in an area to what is considered the normal or average moisture levels.

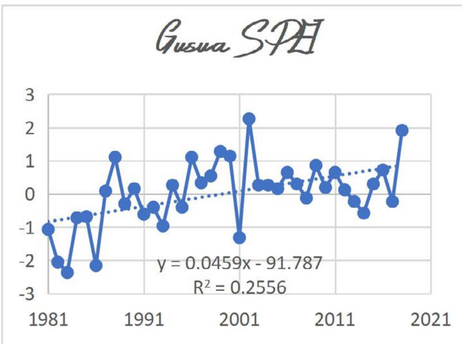
a) Variation in SPEI over Bauchi



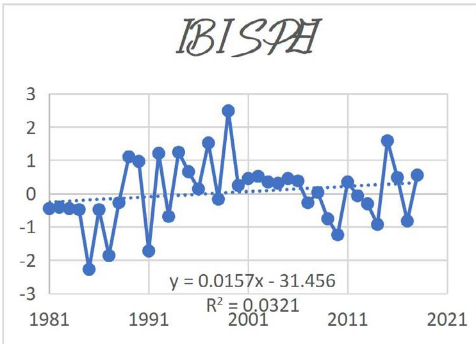
b) Variation in SPEI over Birnin



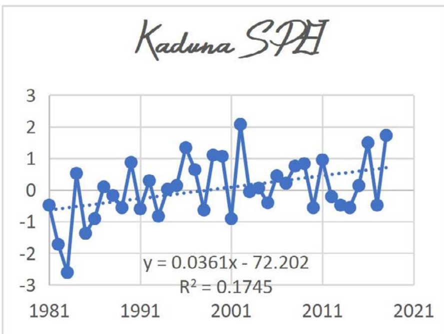
c) Variation in SPEI over Gusua



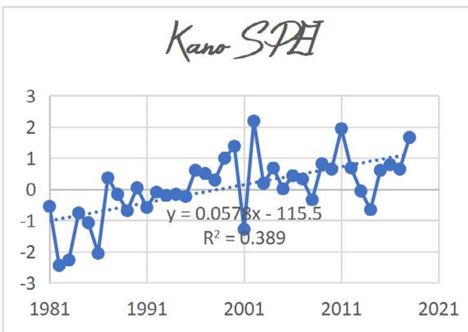
d) Variation in SPEI over Ibi



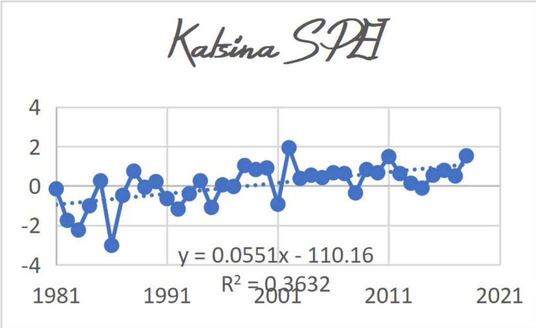
e) Variation in SPEI over Kadun



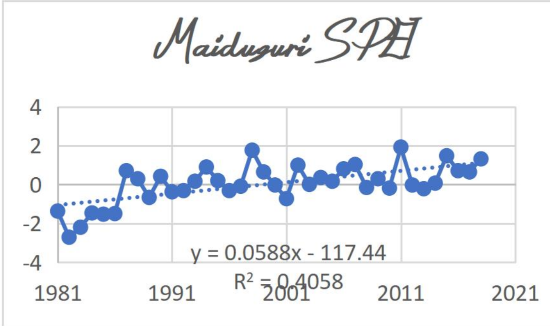
f) Variation in SPEI over Kano



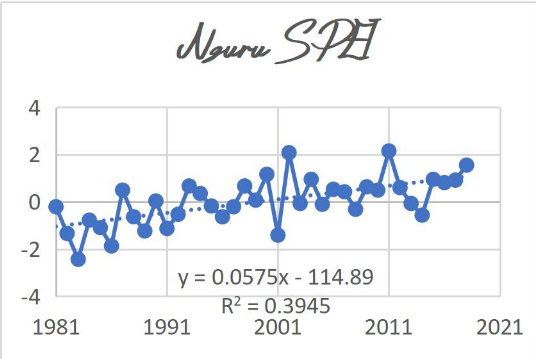
g) Variation in SPEI over Katsina



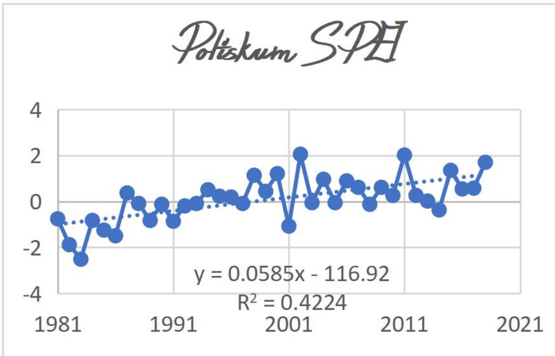
h) Variation in SPEI over Maiduguri



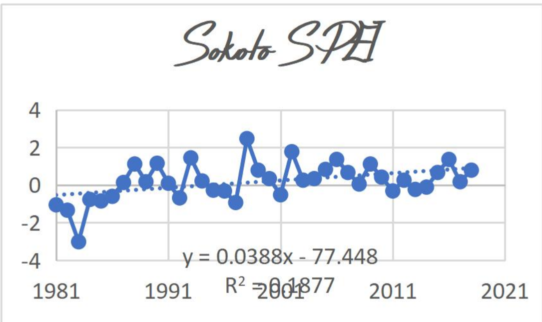
i) Variation in SPEI over Nguru



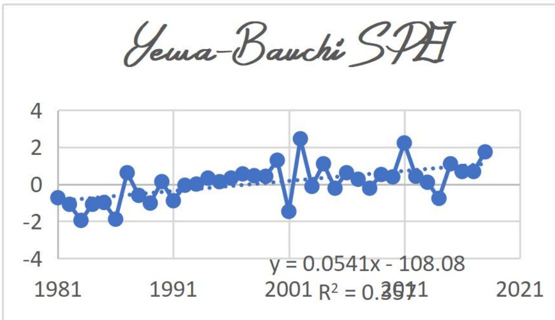
J) Variation in SPEI over Potiskum



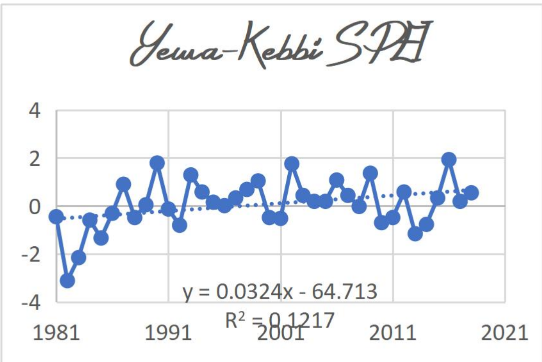
k) Variation in SPEI over Sokoto



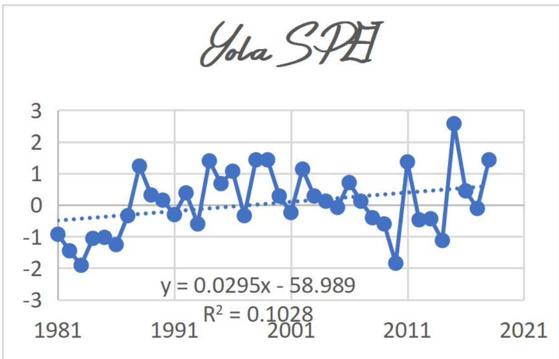
l) Variation in SPEI over Yewa-Bauchi



m) Variation in SPEI over Yewa-Kebbi



n) Variation in SPEI over Yola



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o) Variation in SPEI over Zaria

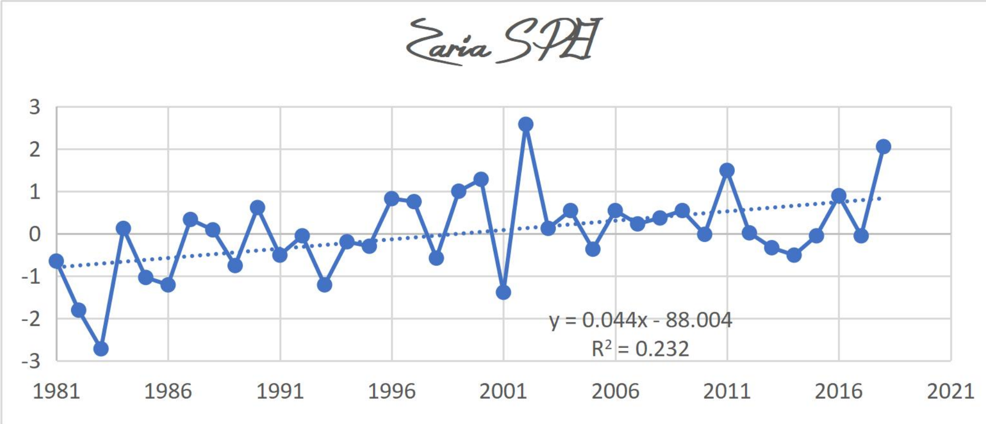

Figure 2

Over Bauchi, the SPEI ranges between 2.5 and -2.5, with the highest value of 2.5 recorded in the year 2002 and the lowest value of -2.4 in the year 1983. A value of 2.5 indicates a significant amount of moisture in the area, which is well above the average. This could be due to above- average rainfall levels or higher levels of evapotranspiration, which is the release of moisture from the ground and vegetation into the atmosphere.

In figure 2a, It is interesting to note that the SPEI value in Bauchi has shown a decreasing trend over the years, with its highest value recorded in 1984 decreasing progressively and close to zero between 2001 to 2019. The decrease in drought severity over the years is a positive sign, as it means that the area has become more resilient to the impacts of drought. This can have significant benefits for the local communities, as they are less likely to experience water shortages and crop failures. In figure 2a, 2b and 2c; Like Bauchi, Birnin Kebbi and Gusua also have a similar pattern in the SPEI index, ranging between - 3 to 3. The highest index was recorded at 2.5 in 1990-1991 in Birnin Kebbi and at 2.3 in 2002- 2003 in Gusua. The lowest index was -2.8 in 1983-1984 in Birnin Kebbi and in both 1983-1984 and 1986-1987 in Gusua, which were severe droughts in these regions [27-30].

From 1984 to 1986, the SPEI value in both Birnin Kebbi and Gusua decreased progressively, which indicates an increase in the severity of the droughts. This trend continued and both regions remained close to zero, which is considered normal, from 1988 to 2019.

Noting that the two regions experienced severe droughts in the years 1983-1984, 1986-1987, and 2001-2002, as reflected in the low SPEI values during these periods. These droughts might have an impact on the local communities, including water shortages, crop failures, and economic losses. Also, in figure 2d, like Birnin Kebbi and Gusua, also experiences severe droughts as indicated by low SPEI values. The severe droughts in Ibi were recorded in the years 1985-1986, 1987-1988, 1991- 1992, and 2010-2011. It is also worth noting that Ibi experienced a similar SPEI value of -0.5 between 1981 to 1985, which indicates a below-average moisture balance in the area during this period. Conversely, the SPEI value was +0.5 from 2000 to 2007, which indicates above-average moisture levels in the area [30-36].

In figure 2k, on the other hand, had a moderate drought from 1982-1999 with the highest index recorded at 2.5 in 1990-1991 and lowest at -2.8 in 1983-1984. This shows that Sokoto was less affected by the extreme drought compared to other regions. It was also observed that the trend of drought occurrence in Sokoto was decreasing progressively from 1984 to 1986 and maintained close to zero, which is considered normal from 1988 to 2019.

Comparing the SPEI over these regions, it is observed that 2f, 2g, 2h, 2i, 2j, 2n and 2o; have the highest vulnerability to drought, with extreme drought occurrences observed in the 1980s and 1990s. On the other hand, figure 2l and 2m had a moderate to wet period between 1993-2000, followed by an extreme drought period in 2002. Sokoto had a moderate to wet period between 1997-2002.

However, Maiduguri experienced severe drought in the years 1983-1984, 1986-1987, and 2001- 2002. The SPEI index showed a low value of -0.5 between 1981 to 1985 and a value of +0.5 from 2000 to 2007. In general, the SPEI index indicates that the regions of Kano, Katsina, Nguru, Potiskum, Yola, and Zaria had a higher vulnerability to drought compared to other regions.

3.2. Spatial Distribution Drought Risk Classification (figure 3a-d)

The risk level and vulnerability were determined by analyzing the SPEI values in the region over different time intervals.

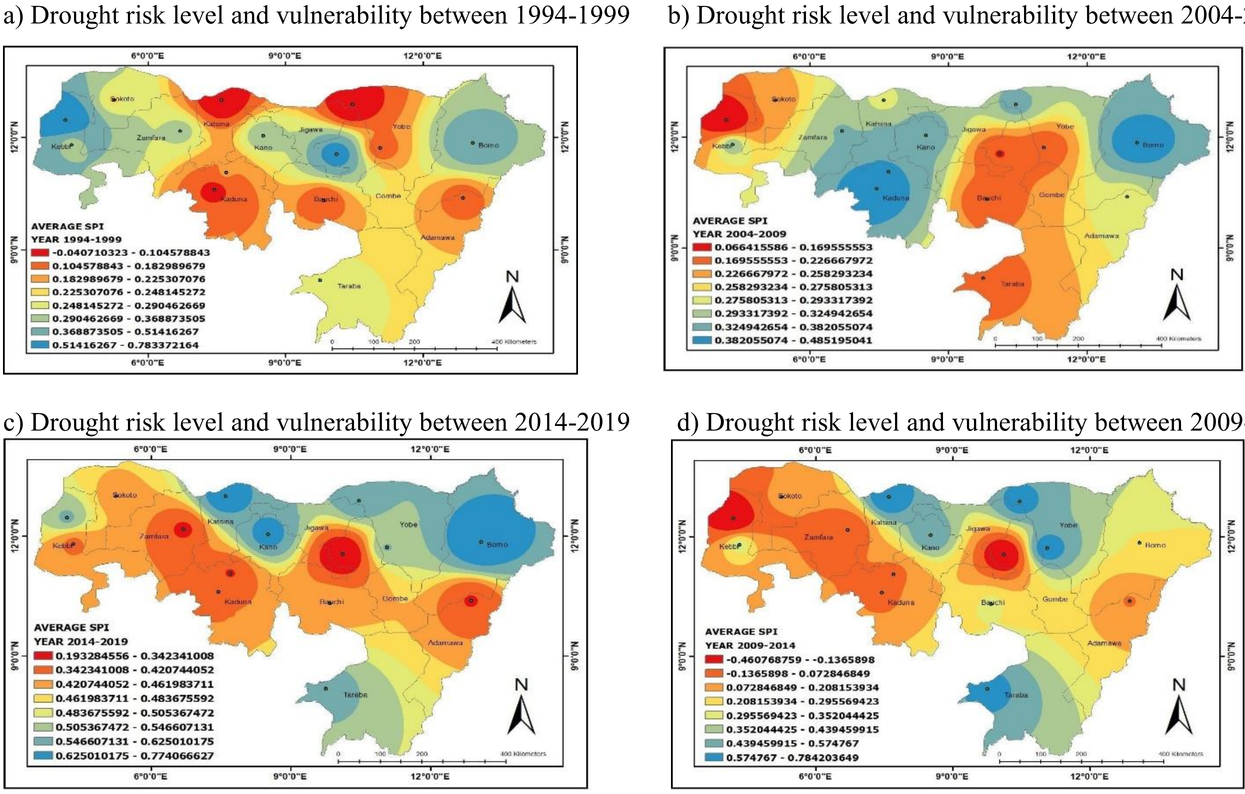

Figure 3

Figure 3a shows the vulnerability level Between 1994 and 1999, Katsina, Kaduna, Bauchi, Yobe, and Adamawa experienced extremely dry conditions with negative SPEI values, indicating that these regions were at a high risk of drought and highly vulnerable to the negative impacts of below-average moisture balance [37-39].

Sokoto, Gombe, Taraba, and Kano had a moderately dry occurrence with moderate SPEI values, suggesting that these regions were at a moderate risk of drought and moderately vulnerable to the negative impacts of below-average moisture balance.

Bornu, Zamfara, Kebbi, and Jigawa had a normal occurrence with close-to-zero SPEI values, indicating that these regions were at a low risk of drought and less vulnerable to the negative impacts of below-average moisture balance. The eastern and western part is less vulnerable to drought while the central is highly vulnerable to drought as observed in figure 3a.

From fig. 3b, which depicts between 2004 and 2009, Sokoto, Bauchi, Yobe, Taraba, and Gombe had extremely dry conditions with no negative SPEI values. Kebbi, Zamfara, Katsina, Jigawa, and Adamawa had moderately extreme conditions while Kaduna, Kano, and Borno had normal conditions.

Deductions from fig 3c, between 2009 and 2014, Sokoto, Zamfara, Kaduna, Jigawa, Adamawa, had extreme dry conditions with negative SPEI values while Kebbi, Katsina, Bauchi, Gombe, and Borno had moderate dry conditions and Kano, Yobe, and Taraba had low vulnerability to drought.
Also, Figure 3d shows vulnerability Between 2014 and 2019, extreme dry conditions were observed in Kebbi, Sokoto, Zamfara, Kaduna, Jigawa, Gombe, and Adamawa, moderate dry conditions in Yobe and Taraba, and low vulnerability to drought in Borno, Kano, and Katsina.

Generally, it is observed that the eastern part of the region has low susceptibility to drought. Throughout the study period, it is observed that Bornu, Kano, Katsina has extremely low vulnerability to drought while Bauchi, Zamfara and Yobe has a very high vulnerability to drought. The vulnerability and risk level of each station to drought in Nigeria is a critical issue in view of the growing concern over global climate change and its impacts. Several studies have been conducted to assess the vulnerability and risk of Nigeria's regions to drought, particularly in the northern regions [40].

Adelekan and Oke, in a study, assessed the vulnerability and risk of drought in Nigeria using the Standardized Precipitation Evapotranspiration Index (SPEI) and a combination of biophysical and socioeconomic indicators. The study found that the northern regions are more vulnerable to drought compared to the southern regions due to their relatively lower rainfall patterns and high levels of poverty. The study also found that Bauchi, Kaduna, Katsina, Yobe and Adamawa are the most vulnerable regions to drought in Nigeria.

Also, Olaniran et al. analyzed the risk and vulnerability of Nigeria's agricultural sector to drought using the SPEI. The study found that the northern regions, particularly Zamfara, Sokoto and Kebbi, are at higher risk of drought due to the frequency of droughts and the lack of agricultural adaptation measures.

In agreement with the two authors, Nigeria's northern regions are more susceptible to drought and face a higher risk and vulnerability to drought due to their low rainfall patterns, poverty levels and lack of adequate adaptation measures. It is crucial that effective measures are taken to reduce the risk and vulnerability of these regions to drought through the development of drought early warning systems, the promotion of drought-resilient agricultural practices and the improvement of socio-economic [41-44].

3.3. Relationship between Rainfall and Ndvi

Table 3: Correlation Coefficient of NDVI Values with Rainfall

Season	Min. NDVI value	Max. NDVI value	Correlation coefficient with rainfall
ANNUAL	0.40	0.71	0.46
JJA	0.49	0.70	0.20
MAM	0.43	0.77	0.56
DJF	0.20	0.46	0.16

The relationship between Annual Normalized Difference Vegetation Index (NDVI) and Annual Rainfall in Northern Nigeria exhibits interesting patterns and variations across different stations.

In Figure 4a, we can observe two prominent patterns. The first pattern reveals that Bauchi, Birnin Kebbi, Gusua, Ibi, and Kaduna exhibit no correlation between Annual NDVI and Annual Rainfall. This indicates that changes in rainfall do not have a substantial impact on the overall health of vegetation, as indicated by NDVI, in these regions. Several factors might contribute to this absence of a relationship, such as soil characteristics, vegetation types, and local climate dynamics.

On the other hand, figure 4b also shows a linear relationship between DJF NDVI and DJF rainfall in Kano, Katsina, Maiduguri, Nguru, Potiskum, Sokoto, and Yelwa-Bauchi. Specifically, as NDVI decreases, rainfall also decreases. This suggests that in these areas, a decrease in rainfall directly impacts vegetation health, resulting in a decline in NDVI values.

During the onset of the rainy season (March, April, May - MAM) as observed in Figure 4c, from Kano to Zaria, the linear relationship between NDVI and rainfall is observed to be maintained. This indicates that as rainfall increases during the MAM season, NDVI also increases, reflecting a positive impact on vegetation growth and health. This finding highlights the significance of the early stages of the rainy season in supporting vegetation in these regions [45-47].

Furthermore, figure 4d emphasizes the JJA season (June, July, August), which is the predominant season with the highest rainfall over Nigeria. During this period, a more pronounced linear relationship between NDVI and rainfall is observed, especially in Maiduguri, Nguru, Potiskum, Sokoto, Yola, and Yelwa-Kebbi. This indicates that the high rainfall during JJA significantly influences vegetation growth, resulting in higher NDVI values.

It is important to consider various factors that can influence the relationship between NDVI and rainfall. Soil characteristics, such as water-holding capacity and nutrient availability, can impact vegetation response to rainfall. Additionally, temperature, solar radiation, and evapotranspiration rates can affect the overall moisture availability for plants. Vegetation types, such as grasslands, forests, or croplands, may respond differently to changes in rainfall. Land use changes and human activities, such as irrigation or deforestation, can also influence the relationship between NDVI and rainfall.

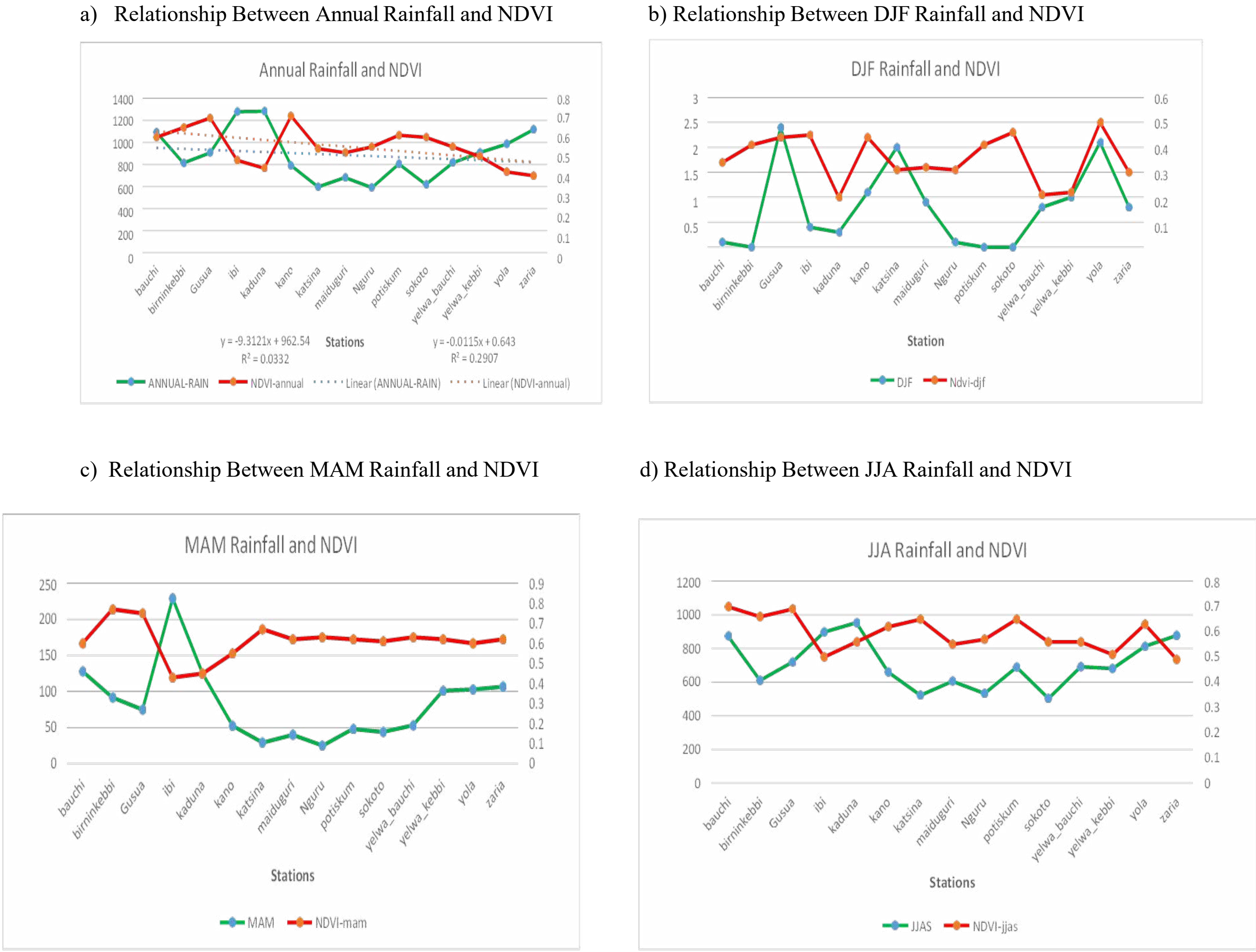

Figure 4

Differences in elevation across the Northern Nigerian region can lead to variations in rainfall distribution and intensity, further influencing the relationship between NDVI and rainfall.

Generally, as shown on Table 3, the relationship between Annual NDVI and Annual Rainfall in Northern Nigeria exhibits regional variations. Bauchi, Birnin Kebbi, Gusua, Ibi, and Kaduna: These regions show no relationship between Annual NDVI and Annual Rainfall. This suggests that variations in rainfall do not significantly influence vegetation health, as measured by NDVI, in these areas.

While some areas show no significant relationship between NDVI and rainfall, others demonstrate a clear linear relationship, indicating the impact of rainfall on vegetation health. The information provided emphasizes the influence of the MAM and JJA seasons, reflecting the importance of the onset of the rainy season and the high rainfall period on vegetation growth.

3.5. Projection of Consecutive Dry Days

Future Projected Change of Consecutive Dry days under RCP4.5 Warming Scenario: Based on the projected distribution of consecutive dry days in the future, RCP4.5 warming scenario, in Figure 5(a), it describes the projection change of CDD for the near future, which is expected to be within a range of -0.8 to 1.2. This range indicates that some areas may experience fewer consecutive dry days, while others may have more extended dry periods as observed in the southern borders of the study area, the projection shows mild dryness across the study map. However, the overall range of the CDD values is relatively narrow, suggesting that the changes in the number of consecutive dry days may not be significant compared to the present.

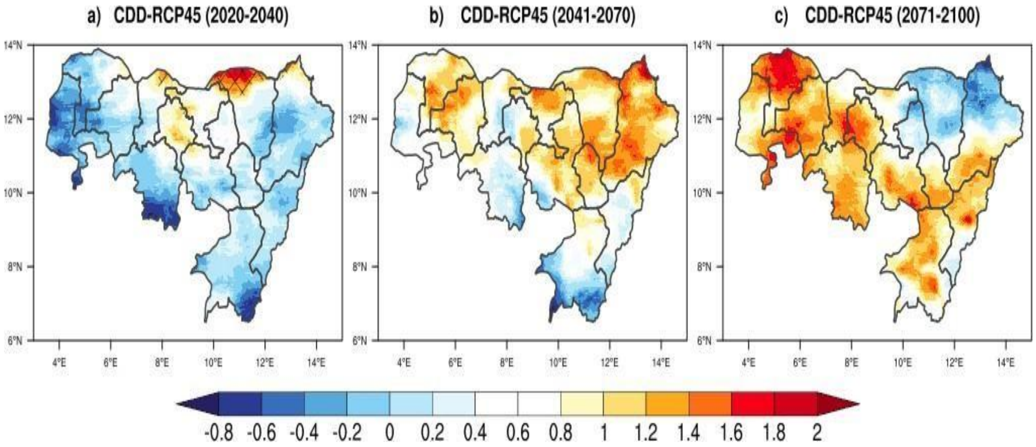

Figure 5: (a) Near Future Projected change of CDD (2020 to 2040) (b) Middle Future Projected change of CDD (2041 to 2070) (c) Far future Projected change (2071 to 2100) under RCP4.5

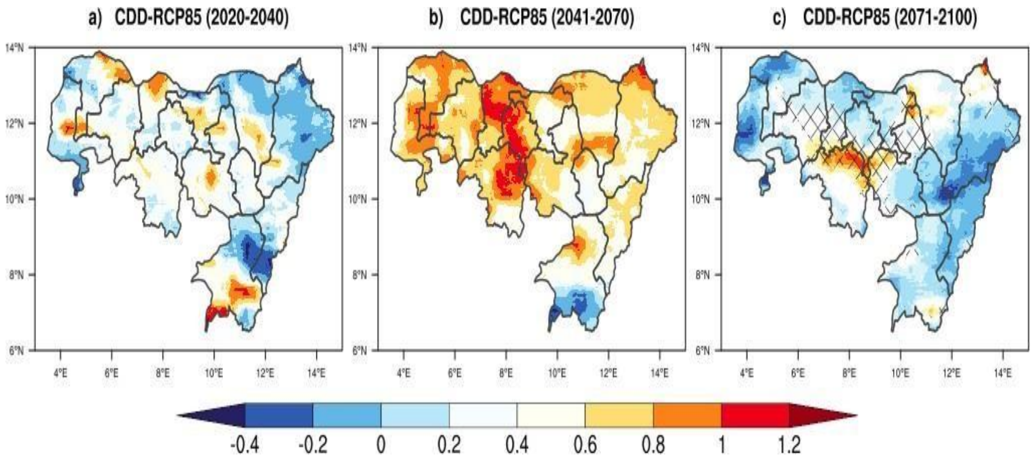

Figure 6: (a) Near Future Projected change of CDD (2020 to 2040) (b) Middle Future Projected change of CDD (2041 to 2070) (c) Far future Projected change (2071 to 2100) under RCP8.5

In contrast, Figure 5(b) shows the projected change of CDD for the mid-future, which appears to be relatively drier than the near future. The range of CDD values widens, ranging from -0.4 to 1.6, indicating a more significant variation in the number of consecutive dry days across the region. The northern region is expected to have more dryness than the southern region. The positive values suggest that some areas may experience longer dry periods.

Figure 5(c) further shows the projected change of CDD for the far future under the RCP 4.5 warming scenario. The range of CDD values widens even further, ranging from -0.6 to 1.8. This range suggests that there may be significant changes in the number of consecutive dry days across northern Nigeria, with major areas in the south experiencing more extended and severe dry periods than the north. The potential impacts of these changes could be severe, affecting agriculture, water resources, and natural ecosystems in the region.

Figure 6 also describes the future distribution of consecutive dry days (CDD) under RCP 8.5 warming scenario over northern Nigeria. The RCP 8.5 scenario is a high-emission scenario that assumes no climate change mitigation measures are taken, leading to a significant increase in greenhouse gas emissions and warming of the planet.

Figure 6(a) shows the near future of projected change of CDD over northern Nigeria under the RCP 8.5 scenario. The range of CDD is between -0.3 and 1, indicating an overall increase in the number of consecutive dry days. This finding is consistent with the projections made by Adeniyi et al. in their study on the impact of climate change on CDD in Nigeria under various climate scenario. Figure 6(b) shows the projected change of CDD for the mid-future, which is relatively drier than the near future, with a range of -0.4 to 0.8. Figure 6(c) shows the far- future projected change of CDD under the RCP 8.5 scenario, with a range of -0.4 to 1.

In conclusion, the projected change depicted in Figure 5 suggest that northern Nigeria is likely to experience changes in the number of consecutive dry days under the RCP 4.5 warming scenario. The changes may vary in the near, mid, and far future, with some areas experiencing longer and more severe dry periods than others. It's crucial for policymakers and individuals to take action to mitigate the impacts of climate change and reduce greenhouse gas emissions to limit global warming and its adverse impacts on northern Nigeria and other regions of the world.

Comparing the projected change of CDD under RCP 4.5 and RCP 8.5 warming scenarios, Figure 5 and Figure 6 respectively, it is observed that the range of CDD values in Figure 6 is slightly lower than that of Figure 5, particularly for the near and far future. This is because the RCP 8.5 scenario assumes a higher rate of greenhouse gas emissions and warming than the RCP 4.5 scenario, resulting in a more significant increase in CDD. In both scenarios, however, there is a clear trend towards increased CDD, in the mid-future indicating a more extended period of dry conditions.

Adeniyi et al in it study examined the impact of climate change on CDD in Nigeria under various climate scenarios. The study projected that CDD would increase across Nigeria under the RCP 4.5 and RCP 8.5 scenarios, with the most significant increases occurring in the northern regions. This finding is consistent with the trends depicted in Figure 5.

4. Conclusion and Recommendation

4.1. Conclusion

This study assesses the projected drought characteristics and climate extremes over North-East and North-West Nigeria. The data used consists of observation (CRU) and simulation dataset for projection years from 2020-2100 (cordex; daily rainfall and minimum and maximum temperature). The latter was further divided into three classifications for projection (Near future, mid future and far future) to provide possible climate change trend in the future. Two drought indicators (SPI and consecutive dry days) were used to characterize historical and projected droughts variability. The result indicated that during the present climate period (1981-2019), it is observed that the eastern part of the study region has low susceptibility to drought. Throughout the study period, it is observed that Bornu, Kano, Katsina has very low vulnerability to drought while Bauchi, Zamfara and Yobe has a very high vulnerability to drought.

The projection of drought characteristics shows an increasing trend over time and a noticeable change in the area to be affected. Drought duration is projected to increase from 2020 till 2100. The study further indicated that the frequency of consecutive dry days in northern Nigeria is projected to increase under the RCP 4.5 warming scenario. In the near (2020 to 2040), mid (2041 to 2070), and far future (2071 to 2100), the changes may vary, with some locations having longer and more severe dry periods than others. To prevent global warming and its negative implications on northern Nigeria and other parts of the world, policymakers and individuals must take action to mitigate the effects of climate change and reduce greenhouse gas emissions.

When the trend pattern of consecutive dry days is compared under RCP 4.5 and RCP 8.5 warming scenarios, the increasing trend in near future (2020 to 2040) is slightly lower than thatof mid future (2041 to 2070). This is because the RCP 8.5 scenario forecasts a higher pace of greenhouse gas emissions and warming than the RCP 4.5 scenario, resulting in a greater increasein CDD. However, in both scenarios, there is a definite trend towards higher CDD in the mid- future, indicating a longer duration of dry conditions over the study region.

The analysis of SPEI indicates that a greater proportion of the Northern Nigeria may become drierin the future, because of increasing PET together with continuous CWB deficit observed over West Africa would enhance evaporation losses and increase irrigation demands for drier soils. This will have negative impacts on regional development, as economic activities (e.g., agriculture, home, and industrial water supply, tourism) will take longer than usual to recover after each drought episode.

4.2. Recommendation

The result of this work provides a basis for developing policy and strategy to reduce future drought risks over Northern Nigeria. At the same time, it advocates for a more proactive response to increase adaptive and resilience options at multi-national and local levels. For instance, the analysis of SPEI indicates that a greater area of Northern Nigeria may become drier in the future, because of increasing PET together with continuous CWB deficit observed would enhance evaporation losses and increase irrigation demands for drier soils. However, based on the result, it is also suggested that a well-planned land-use change targeted at limiting evaporation losses could help to reduce the impacts of the projected droughts. Hence, there is a need for the formulation of strategic policy that can accommodate or encourage such a land-use change.

Also, policies are needed to cope with the increasingly complex interaction between climate stresses, not only in the short term but importantly, in the long term. There is a need for better stakeholder engagement in timely planning and implementation of climate autonomous and planned adaptation strategies in Northern Nigeria to address cross-regional and cross- sectoral issues in tackling the potential impacts of projected climatic changes under increasing global warming.

Lastly, this study results can be improved and applied to reduce future drought risks over Northern Nigeria by examining the role of atmospheric processes in the discrepancies observed between consecutive dry days projections; the absence of important upper-level data in the archive of CORDEX did not make such investigation possible in this work.

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