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Climate Change and Drought in Kano and Jigawa States, Nigeria

S.U. Usman[1*], Nura Umar Kura[1], I. Mallam[1], Muhammad Salisu Khalil[1,2], Da'u Abba Umar[1] &
A.I. Abdulhamed[1]
[1]Department of Environmental Sciences, Federal University Dutse, Jigawa State, Nigeria
[2]Kano State Watershed, Erosion and Climate Change Management Agency, Kano State, Nigeria
*sani.u@fud.edu.ng +2348067996739

Abstract

Emissions of greenhouse gases by human activities have been producing climate change. One of the manifestations of climate change is an increase in the frequency and intensity of extreme climate events such as drought. This study assesses the impact of climate change on drought events inJigawa and Kano states, Nigeria. Objectives of the study include determining the past and projected (i) drought frequency,and (ii) drought intensity and changes in temperatures in the study area. Historical (1901-2020) and projected (2021-2100) rainfall and temperature data (CMIP6 – SSP119 and SSP585) for the study area were downloaded from the World Bank Climate Change Knowledge Portal. The Standardized Precipitation Index characterized the rainfall conditions by drought and non-drought years.The temperature changes were portrayed using annual temperature anomaly. The results indicate comparatively wet conditions from the 1900s to the late 1960s, high drought frequency and intensity in the 1970s and 1980s and low occurrences in the last two decades. SSP119 indicates an increase in drought frequency toward the middle of the century (2021-2050) and a decrease toward the end. SSP585 indicates the opposite. Future increases in temperaturesportend an increase in drought intensity. This could be devastating in the study area because agriculture is the major occupation ofmost of the population. Therefore, it is capable of disrupting the socioeconomic stability of the states.In this area, a holistic approach to climate change adaptation should be vigorously pursued anddrought monitoring should be part of the environmental plan.

KEYWORDS: Climate change, drought, drought frequency, drought intensity, standardized precipitation index

INTRODUCTION

Progressive emissions of substantial amounts of greenhouse gases (GHG) from human activities such as power generation, industrial and agricultural production, transport and domestic activities over the last two centuries have been changing the chemistry of the Earth's atmosphere(Intergovernmental Panel on Climate Change [IPCC], 2023).Consequently,this has been producing changes in the physical properties of the atmosphere, especially its ability to delay the escape of terrestrial radiation into space. Consequently, heat has been building up in the atmosphere and the Earth's surface, known as global warming (GW) (Eyring et al., 2021). This warming has been affecting the Earth's climate by producing shifts in the global climate patterns, which is known as climate change. Some of the manifestations of climate change include increases in global temperatures, rainfall variability and rates of sea level rise. Others include exacerbating extreme climate events such as the frequency and intensity of floods, droughts, hurricanes heat waves and wildfires (Seneviratne et al., 2021). This paper examines the influence of climate change on drought in the Kano and Jigawa states of Nigeria.

Drought is a conditionwhen water supply (such as precipitation and/or stream flow or due to an increase in water demand) falls short of what is required for various water uses and the normal functioning of the environment.It occurs in all regions of the world, especially in areas that receive precipitation or rivers and streams flow due to precipitation or melting of glaciers and it is regarded as a component of natural climate variability. Drought has been and is still one of the foremost natural disasters that threaten human survival in many parts of the world. In recent times, Africa experienced the highest frequency of droughts. It has been reported that the continent experienced 42% of all the drought events that occurred since 1970 (CRED, 2019). Three consecutive years of drought in East Africa (Ethiopia, Kenya and Somalia) affected more than 36.5 million people out of which 20 million and 16.3 million experienced acute food and water shortages respectively while more than 2 million were displaced (United Nations IOM, 2023). Similarly, in 2018 and 2019, Europe experienced two of its worst drought events in the last 250 years (World Bank, 2023). However, better coping mechanisms, which include strong economies, advanced technologies and effective political settings made the effects to be less manifested than if the droughts occurred in developing countries. In 2022, about 19.1 people were affected by drought in Nigeria, which made the country to be ranked third among ten countries with the most affected population in the world (IAHO and WHO, 2024).

Drought in the Sudano-Sahelian region of Nigeria (within which Kano and Jigawa states are located) is a recurrent feature of the climate. Inhabitants of this environment have lived with it for centuries. Some of the worst drought events in this region and some other regions of Nigeria include those of 1883/1885, 1913/1915, 1942/1944, 1972/1973, 1982/1983 and 1991/1995 and their effects were reported to have been exacerbated by human activities which reduce the water retention capacity of the soils (Federal Republic of Nigeria, 2018). Severe droughts in this area are characterised by their multifaceted effects on water resources, food systems and the agrarian rural economy. Apart from its temporal variability, drought in this area is also highly variable over space.

The major nexus between climate change and drought in the study area is the way the former affects moisture supply from the major source area (Gulf of Guinea and tropical Atlantic Ocean) in the area in question. Climate change affects the hydrological cycle, which influences latitudinal moisture transport (Soldatenko, 2019). This results in an increase in precipitation in some areas and a decrease in others. It also affects the extent ofthe northern incursion of the West African Monsoon (WAM) system, which is the major moisture transport media to the study area (Dey et al., 2021). These are mainly caused by the effects of climate change on the sea surface temperature gradient from north to south of the tropical Atlantic Ocean (Caminade&Terray, 2010) and the thermal contrast between the Gulf of Guinea and the Sahel

(Lavaysse et al., 2016). Other ways include the effects of climate change on the expansion of the Sahara Desert (Thomas & Nigam, 2018), and the southward displacement of the Sahara Heat Low (Biasutti et al., 2009). Through teleconnection, the Indian and Pacific Oceans surface temperature anomalies as well as the Pacific Ocean's El-Nino and La-Nina phenomena, affect moisture supply to the study area (Pomposi et al., 2020).

The Standardized Precipitation Index (SPI) was used in characterising drought conditionsusing the observed and projected annual rainfall of the area. The temperature anomalywas used in analyzing the observed and projected annualtemperature of the area. The objectives of the study are to (i) Examine observed and projected drought intensity in the study area, and (ii) Assess observed and projected drought frequency in the study area. The findings of this study will be useful as a basis for water resources and agricultural planning for the area.

2. MATERIALS AND METHODS

2.1 Study Area

The study area (Kano and Jigawa states) is located in the Northwest zone of Nigeria between latitudes 10°32'16.17"N to 13°00'23.96"N and longitudes07°040'12.60"E to 10°13'35.90"E (Figure 1).It covers 43,569 km^2 (National Bureau of Statistics, 2017), representing 4.78% of Nigeria's total land area.The estimated combined population of these states as of 2019 was 19,706,675 (National Bureau of Statistics, 2020), representing 9.78% of the total population of Nigeria. Kano and Jigawa state 2,369,000 and 1,187,000 agricultural households respectively (National Bureau of Statistics, 2024) representing 8.84% of the total agricultural households in the country.This implies that thepopulation of the two states is highly agrarian and is characterised by smallholder subsistence agricultural (crop and livestock) production. The area is traversed by rivers and streams for instance,the Kano River (in Kano State) andthe Hadejia and Jama'are rivers (in Jigawa State). This allows for the construction of many earth dams, which are being used for urban water supply irrigation agriculture and fishing. Hydrologically, the area falls within the Lake Chad Basin,and groundwater is the major source of water supply for the majority of the population.The area has a tropical continental (Aw) type of climate characterised by wet (June – September) and dry (October – May) seasons (Usman et al., 2023).

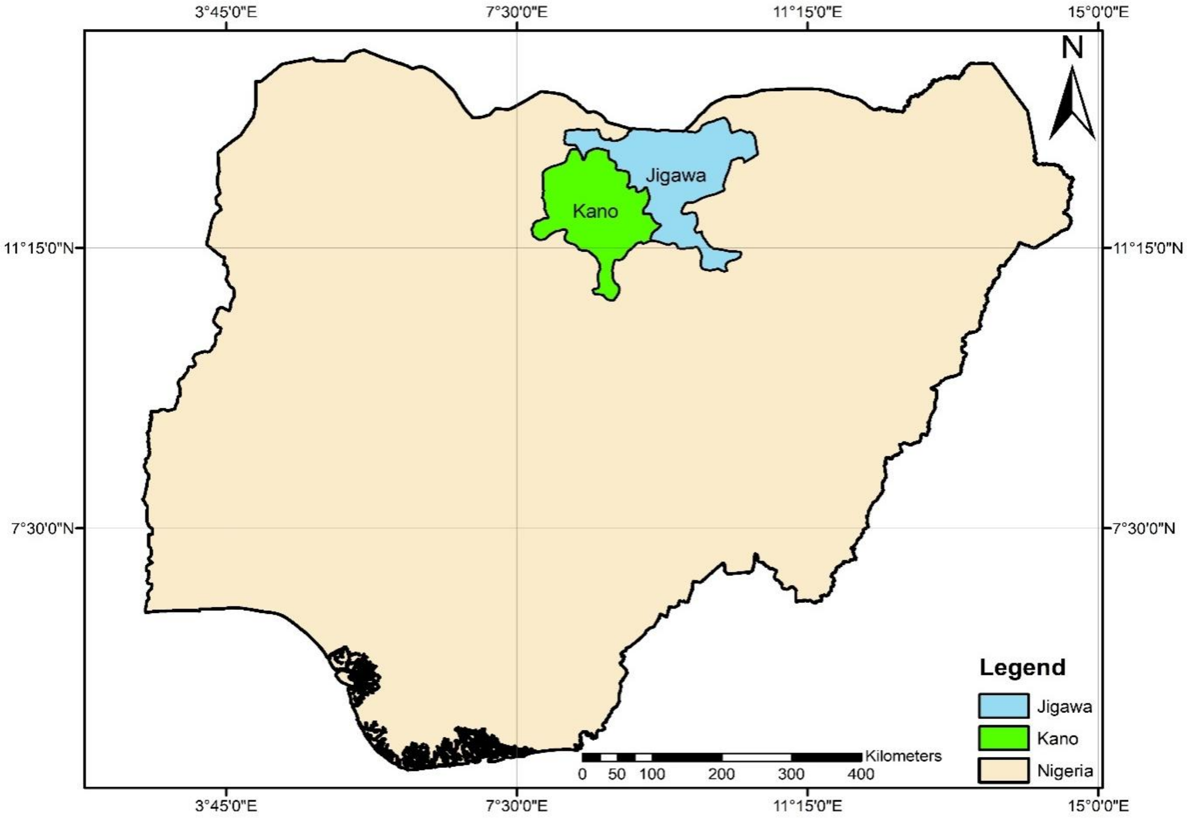


Figure 1: Map of the Study Area

2.3 Methods

Observed (1901 to 2023) and projectedCMIP6 (SSP119 and SSP585) annual rainfall and mean temperature data for the period 2024 to 2100 were downloaded from the World Bank Group Climate Change Knowledge Portal (https://climateknowledgeportal.worldbank.org/download-data).The SSP119 refers to the low emission scenario and it refers to the likely climate conditions expected if global GHG emissions are reduced in conformity with the Paris Agreement commitments. In the same vein, the SSP585 refers to the climate conditions expected if the current GHG emission trajectory is maintained unabated. Thus, SSP119 is the desired scenario while SSP585 is the worst-case or the most undesirable condition.The annual rainfall data of each state were fittedto a gamma distribution, which probability density function is defined as:

$$g(x) = \frac{1}{\beta^{\alpha}\,\Gamma(\alpha)} x^{\alpha-1} e^{-x/\beta} \qquad (1)$$

Where $\alpha > 0$ and$\beta > 0$ are shape and scale parameterswhile$x > 0$ is the amount of rainfall. $\Gamma(\alpha)$ defines the gamma function which is defined as:

$$\Gamma(\alpha) = \lim_{n\to\infty} \prod_{v=0}^{n-1} \frac{n!n^{y-1}}{y+v} \equiv \int_0^{\infty} y^{\alpha-1}\, e^{-y} \mathrm{d}y \qquad (2)$$

The Maximum Likelihood method was used in estimatingα and βas:

$$\widehat{\alpha} = \frac{1}{4A}\left(1 + \sqrt{1 + \frac{4A}{3}}\right) \tag{3}$$

$$\widehat{\beta} = \frac{\overline{x}}{\widehat{\alpha}} \tag{4}$$

where for *n* observations

$$A = \ln(\overline{x}) - \frac{\sum \ln(x)}{n} \tag{5}$$

Substituting the estimated values of α and β while integrating the probability density function with respect to $x$yields an expression for the cumulative probability G(x) of an observed amount of rainfall occurring for a given year as:

$$G(x) = \int_0^x g(x)\,dx = \frac{1}{\widehat{\beta}^{\widehat{\alpha}}\Gamma(\widehat{\alpha})}\int_0^x x^{\widehat{\alpha}} e^{-x/\widehat{\beta}}\,\mathrm{d}x \tag{6}$$

Substituting *t* for $x/\widehat{\beta}$ reduces equation (6) to

$$G(x) = \frac{1}{\Gamma(\widehat{\alpha})}\int_0^x t^{\widehat{\alpha}-1}\, e^{-1}\,\mathrm{d}t \tag{7}$$

The cumulative probability is then transformed to the standard normal random variable *z* with a mean of 0 and variance of 1, and *z* is the SPI. Positive SPI values indicate greater than median precipitation and negative values indicate less than median precipitation. Table 1 is the SPI value table used to define drought intensities resulting from the SPI.The annual temperature anomaly was computed as:

$$A = x - \overline{x} \tag{8}$$

Where A is the annual temperature anomaly, x is the annual temperature value and $\overline{x}$ is the long-term mean of the annual mean temperature.

Table 1: Drought classification by SPI value

SPI value	Category
≥ 2.00	Extremely wet
1.50 to 1.99	Very wet
1.00 to 1.49	Moderately wet
-0.99 to 0.99	Near normal
-1.00 to -1.49	Moderate drought
-1.50 to -1.99	Severe drought
≤ -2.0	Extreme drought

Source: McKee *et al* (1993)

3. RESULTS AND DISCUSSION

Drought frequency

Historical period

The result of SPI computations is presented in Figure 2. For both states, three drought events were experienced during the first standard reference period (1901-1930), which comprised two moderate and one severe drought. The second reference period (1931-1960) experienced three moderate drought events. The highest drought frequency was recorded during the third reference period (1961-1990). Six drought events occurred out of which three were extreme (in 1972, 1984 and 1987) while the other three were severe (1977, 1985 and 1990). A wetter period (1991-20200 followed, during which two and five moderate droughts were recorded in Kano and Jigawa states respectively. The period (1960-1990) was the driest in the study area and the entire Sudano-Sahelian region of Nigeria during the last century. It wasgenerally characterised by the prevalence of below-average rainfall amounts. This affected agriculture and water resources negatively in the area. Low crop harvests and livestock productivity were recorded. In the same vein, low stream flow and reservoir levels were also recorded. To supplement the dwindling crop yields and watering points for livestock, several earth dams were constructed, especially in Kano State for irrigation projects. These dams and irrigation projects have implications on the water resources of the downstream areas including wetlands (such as Baturiya and Hadejia/Nguru wetlands), Lake Chad and its flooded savanna (Lake Chad Basin Commission, 2000).

Projected period

Figure 2 also comprises the result of SPI computations for the projected period. The low emission scenario (SSP119) indicates a wetter period for the whole study areathus, it portends a respite from drought from the mid-2020s to mid-2050s. From then, a downturn in rainfall amounts is expected, which is likely to last until the end of the century. Conversely, the high emission scenario (SSP585) indicates a reduction in rainfall amounts hence, a possible increase in drought occurrences from mid-2020s to mid-2050s. The late 2050s is likely to be a turning point in rainfall amounts in the area. A decrease in drought frequency is likely to be experienced, which will continue up to the end of the century. The increases in drought frequency as indicated by both scenarios portend serious environmental and socioeconomic problems in the area

Drought intensity

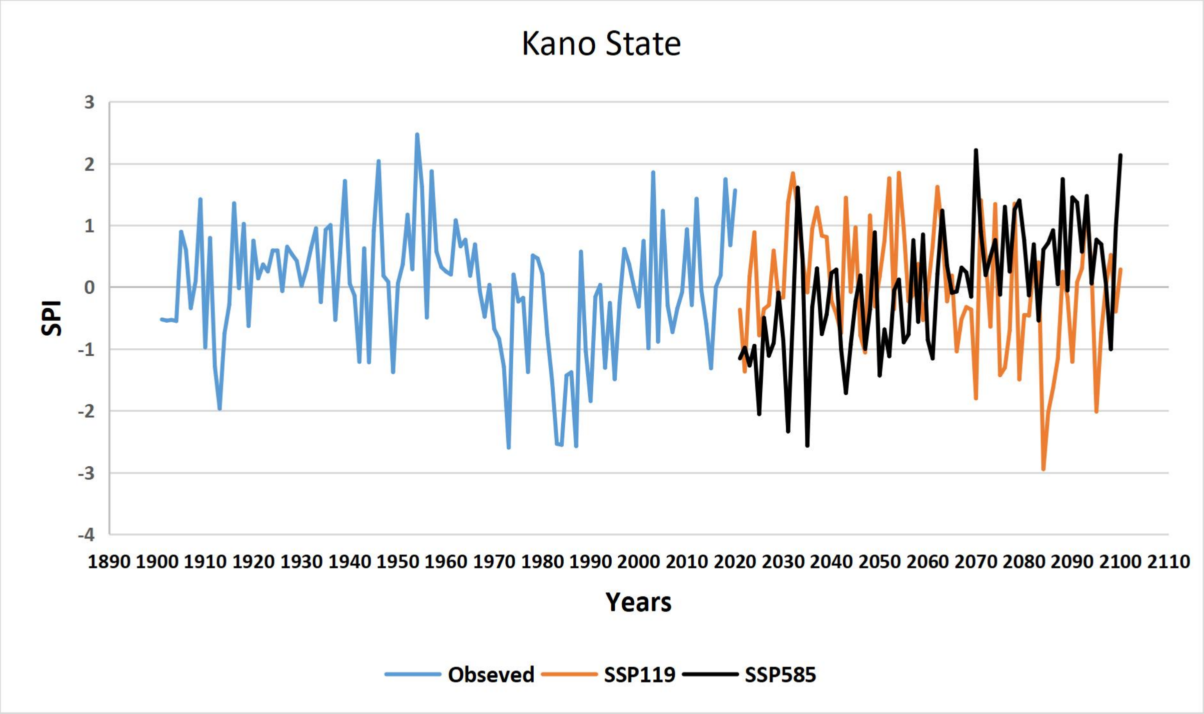
Historical period

The first and second reference periods (1901-1930 and 1931-1960) of the historical period are characterised by the absence of high intensity (extreme and severe) droughts except those of 1913/1914, 1942/1944 and 1946. In contrast, the next reference period (1961-1990) was characterised by severe and extreme droughts, especially those of 1972, 1984 and 1987.The spatial variability of drought in this area triggered waves of migration and immigration within and from outside the study area in the past. For instance, the 1913/1914 drought led to the exodus of drought migrants numbering more than 60,000 people from Katagum and Hadejia Emirates and more than 50,000 from Niger Republic into Kano Province (Weiss, 2003).

The 1972/1973 drought stands out from the others. It affected the whole West African Sudan and Sahel ecological zones and is often referred to as the Great Sahelian Drought. It was so severe in some parts of this study area that it ravaged the food systems and led to increased rural-urban migration due to widespread famine and loss of livelihoods among the rural agrarian people.During this drought and its aftermath, famine in some parts of this study area was very severe that many people were forced to resort to eating some herbaceous plants (Mortimore, 2009). The international community came to the rescue of victims of this drought in the other affected Sahelian countries through provision of food and other relief materials. In addition, many of the affected people in the neighbouring Sahelian countries moved into Nigeria (Watts, 1977). Unfortunately, despite this and the fact that the number of affected people in Nigeria outnumbered the combined numbers of affected people in all the other affected countries, the Nigerian victims were left out of the relief provision on the pretext that their country has oil wealth (Mortimore, 2009).The last reference period of the historical period marked the return of normal and above-normal annual rainfall amounts in the area thus, only two moderate drought events were experiencedin 2002 and 2015.

Projected period

In the case of the projected period (for the whole study area), a respite from drought occurrences is indicated by the SSP119 scenario during the first half of the period and a return of severe and extreme droughtsduring the last half. This is attributable to two possible reasons. One, the likely increases in rainfall amounts all over the globe due to rise in temperature-related increases in evaporation from oceans. Two, a temperature rise-related increase in the water holding capacity of the atmosphere in accordance with the Clausius-Clapeyron relationship, which is about 7% per degree Celsius rise in temperature (Douville et al., 2021).However, high-intensity droughts are expected during the second half of the study period. In contrast, the high emission scenario (SSP585)indicates an increase in drought intensity during the first half of the study period and a decrease in the last half.



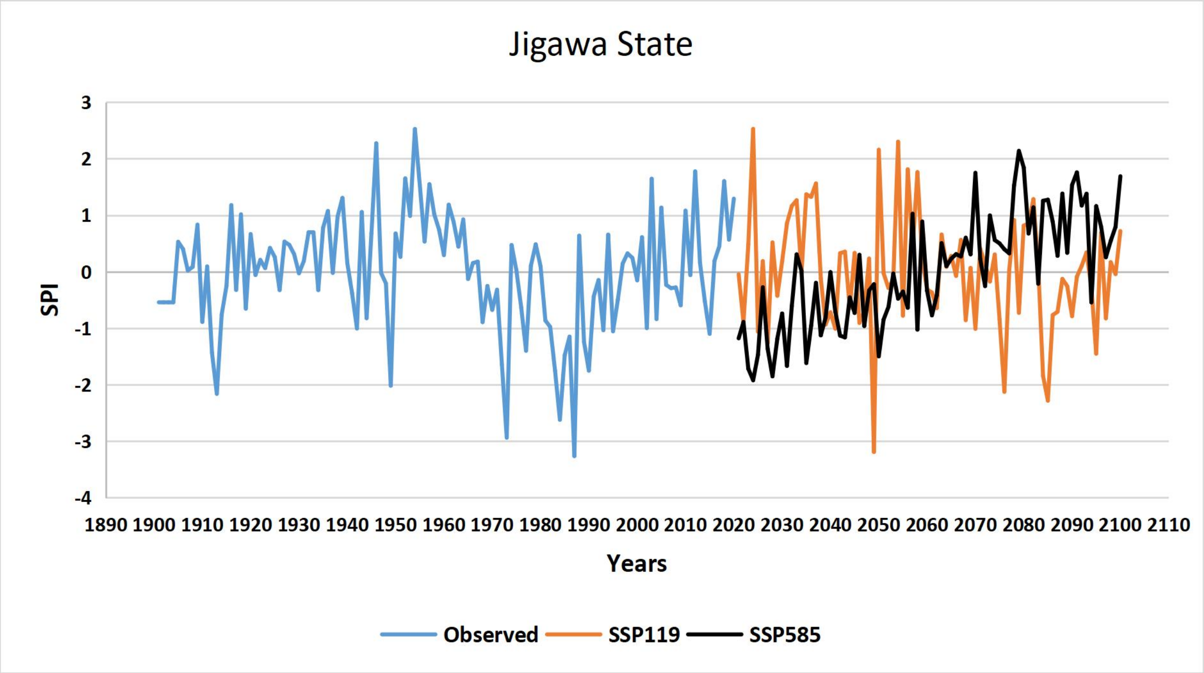
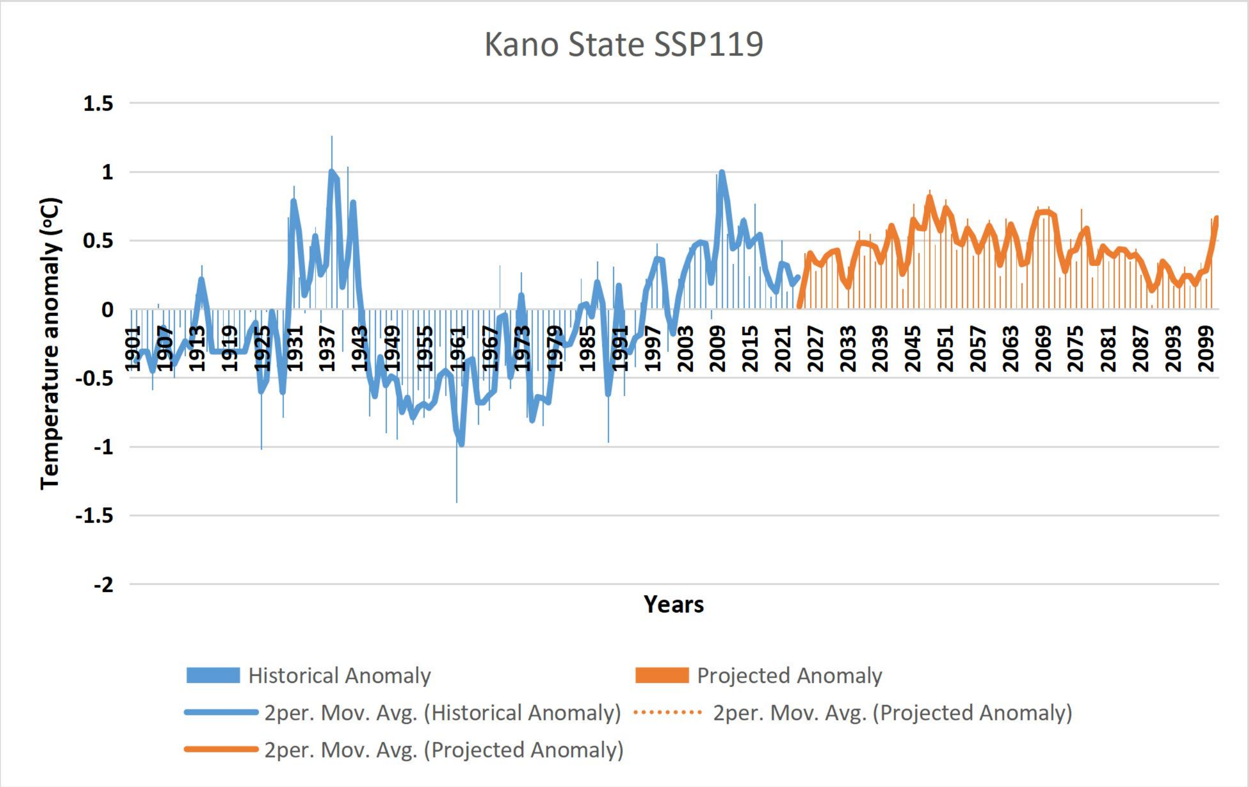


Figure 2: Drought Intensity for the Observed (1901-2020) and Projected (2021-2100) Periods

Temperature condition

Low emission scenario

In both states, the historical period is chequered by positive and negative mean temperature anomalies as shown in Figure 3.From the mid-2020s, the projected changes in the mean temperature under low emission scenarioarelikely to continue increasing from about 0.4^{o}C and 0.09^{o}C above the long-term mean in Kano and Jigawa states respectively and will climax around 2050. From then, the temperature anomalies are likely to start ebbing down to about 0.5^{o}C in Kano State and about 0^{o}C in Jigawa state by the end of the century.These increases in temperature magnify the intensity and detrimental effects of dry spells and droughts by enhancing evapotranspiration thus, increasing crop water demand.



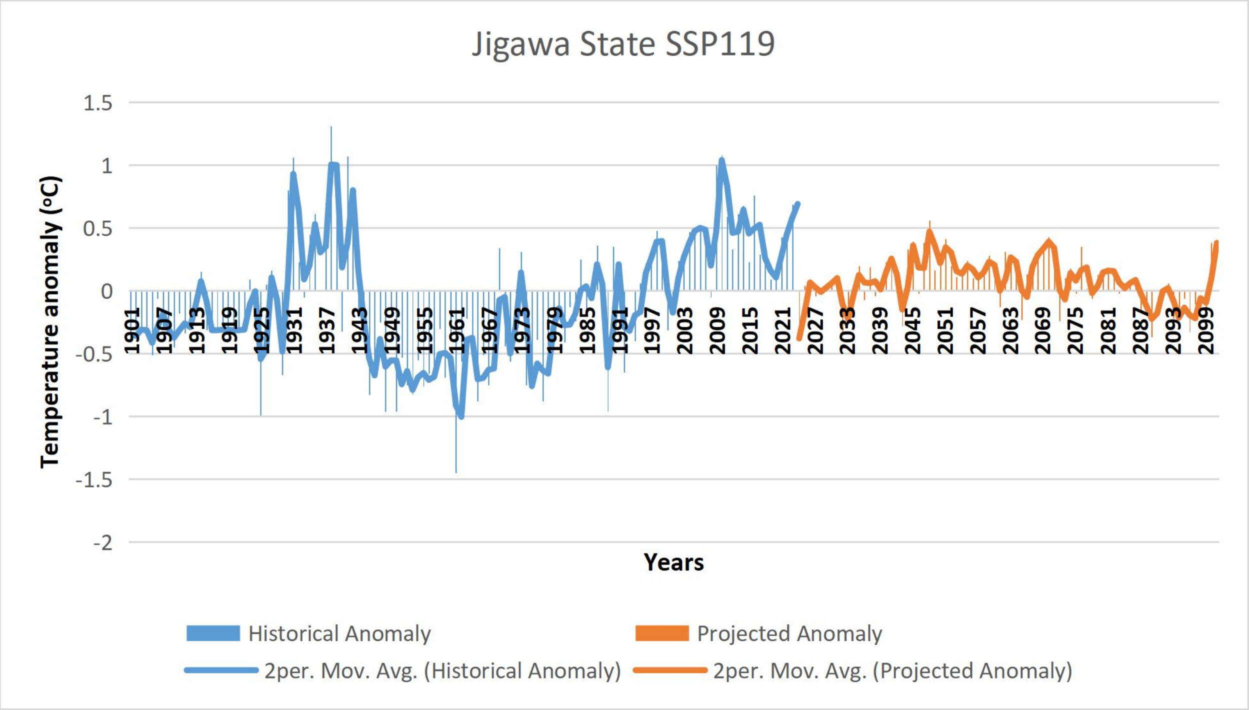
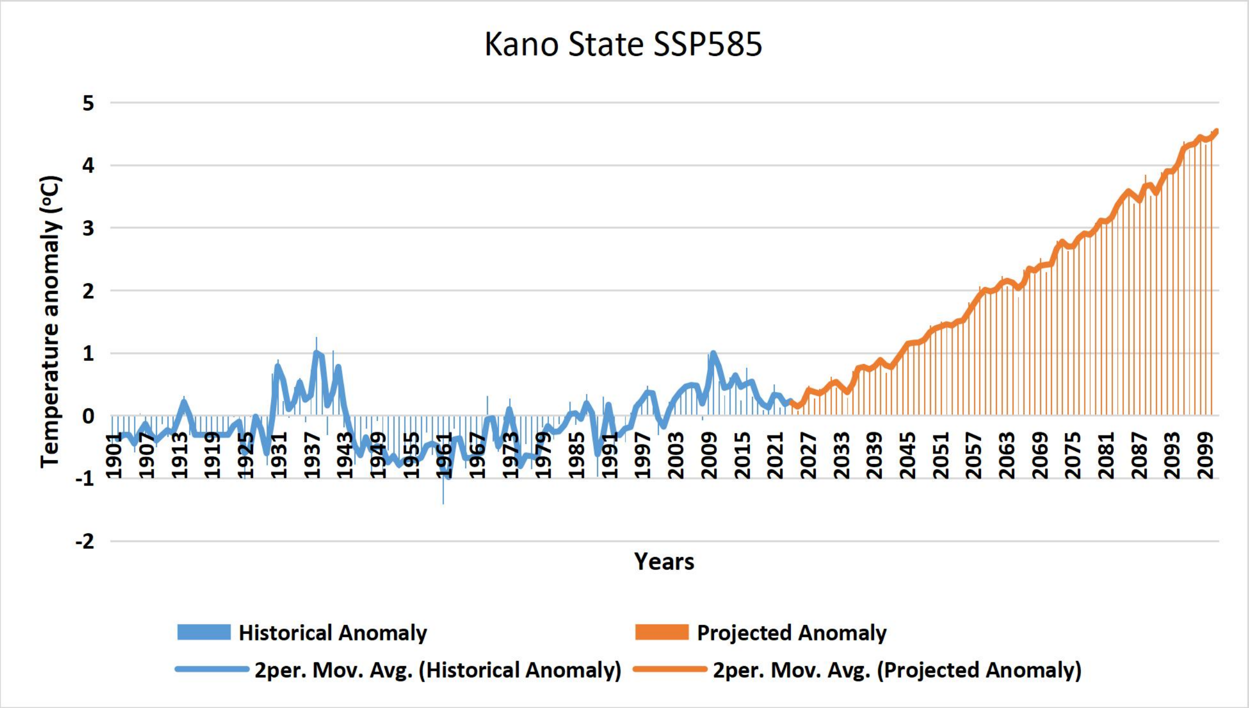


Figure 3: Observed (1901-2020) and SSP119 Projected (2021-2100) Annual Temperature Anomaly

High emission scenario

Projected mean annual temperature anomalies under high emission scenario (SSP585) are shown in Figure 4. In both states, steady increases are likely to be recorded starting from 2024 and will be sustained up to the end of the century. These involve anomalies from about 0.2^{o}C in both states in 2025 to about 4.3^{o}C and 4.5^{o}C in Jigawa and Kano states respectively. Such high increases in the mean annual temperature are likely to have serious negative effects on food security in the study area. This is because high temperatures accentuate the intensity of dry spells and droughts and increase irrigation water demand. Given the semi-arid nature of the study area, these will be highly detrimental to agriculture in the area. Research has established that in dry areas, even slight increases in temperatures can result in significant increases in soil moisture loss through increased evaporation. For instance, a 1^{o}C increase in temperature is capable of producing a 10% (about 0.07mm per day) increase in soil water evaporation (Kidron&Kronenfeld, 2015).As such, the envisaged increase in temperatures of more than 4^{o}C in the area are likely to result in more than 40% increase in soil water loss. By implication, the future increases in temperature will makeevenmoderate droughts to have worst impacts than those of past severe or extreme droughts. This also means the future severe and extreme droughts will be producing unprecedented impacts. All these are bound to have detrimental effects on agricultural production thus, food security n the area and beyond.



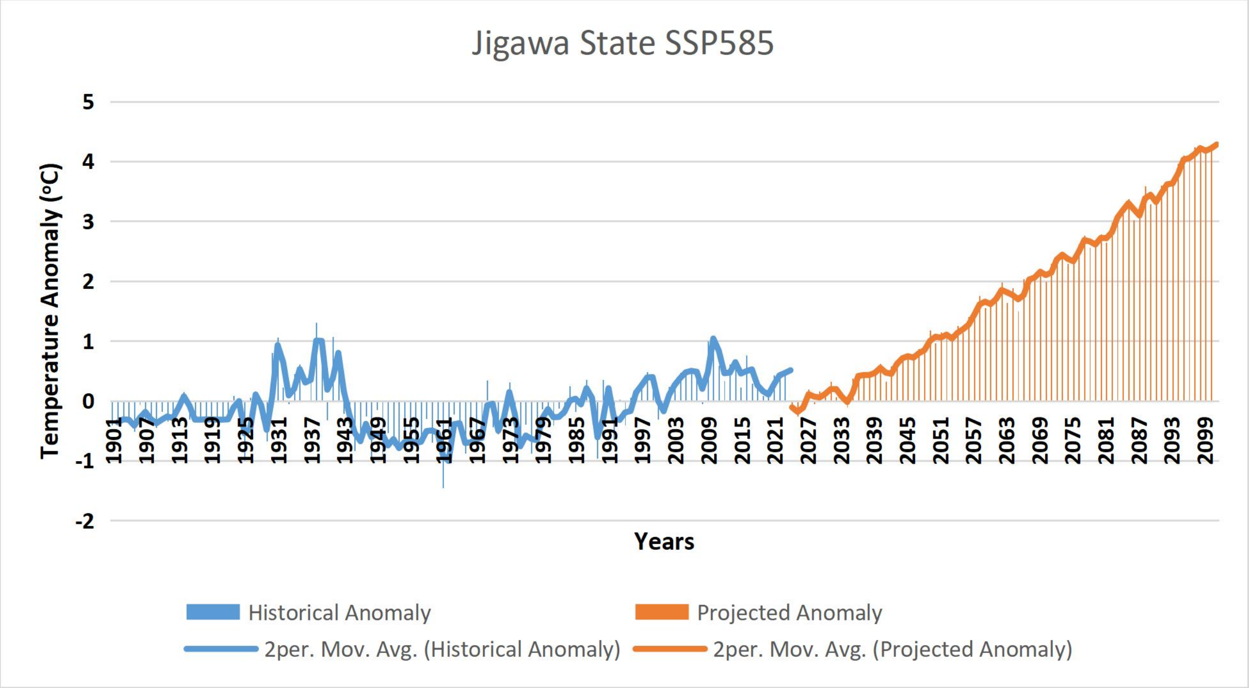


Figure 4: Observed (1901-2020) and SSP585 Projected (2021-2100) Annual Temperature Anomaly

4. CONCLUSION AND RECOMMENDATIONS

Results of this study indicate temporal variations in drought occurrences, which when viewed against the backdrop of changing climate in the area point to a looming threat to food and water security. Higher drought frequency and intensity were recorded from the 1970s to the 1990s than in any other segment of the study period. This affected agricultural production and water resources negatively in most parts of the area. On one hand, future increases in drought frequency coupled with increasing human and livestock populations are likely to result in a series of environmental and socioeconomic problems in the area. On the other, future increases in drought intensity are likely to be accentuated by increases in temperatures through an increase in evaporation and evapotranspiration rates. Apart from accentuating the intensity of droughts in the study area, the projected increases in temperatures are likely to give rise to increases in heat and water stress in human, crops and livestock.In addition, the likely increases in temperature, drought frequency and intensity are bound to affect surface water bodies through increased evaporation, groundwater through decreased aquifer recharge, crops and livestockproductivity through increased heat and water stresses. They are also likely to aggravate land degradation through an increase in the rate of desertification, shrinking of wetlands and stream flow, which are bound to affect the productivity of crop and grazing lands as well as livestock productivity. Having considered all these, it becomes clear that without adequate adaptation plans; future climate change constitutes a looming water and food crisis in the area.

To counteract the effects of increasing drought frequency we recommend widespread adoption of climate-smart agriculture in the area. This should include the production of early maturing as well as drought and heat-resistantcrops and livestock varieties. The number and capacities of strategic grain reserves in the area should be increased to be commensurate with the human population of the area. To lessen the effects of increasing drought intensity, appropriate water conservation techniques should be adopted in agricultural production. Irrigation techniques involving the use of less amount such as drip and subsurface irrigation should be widely adopted. More irrigation projects and facilities including the construction of more dams and irrigation canalsshould be provided in the area. We also recommend that the existing drought plans in the area should be reviewed to be risk-informed based on the climate realities of the time and the near future.

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