

SPATIOTEMPORAL TRENDS AND VARIABILITY OF RAINFALL ANOMALIES ACROSS THE AGRO-ECOLOGICAL ZONES OF NORTHWESTERN NIGERIA

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ABSTRACT

This study analysed rainfall variability across selected states in northwestern Nigeria, namely Kaduna, Katsina, and Sokoto. Monthly rainfall records for the selected states were collected from secondary sources for a period of thirty (30) years (1995-2025) from the Nigerian Meteorological Agency (NIMET) at Nnamdi Azikiwe International Airport, Abuja. The objective is to determine the trends and variability of rainfall anomalies over a specific period. Both descriptive and inferential statistics were used. The trends, anomalies, and relationships among selected weather elements, particularly rainfall, were analysed. The statistical analyses employed were trend analysis, anomaly analysis, correlation analysis, and analysis of variance (ANOVA). Statistical Package for the Social Sciences (SPSS) was utilised. The results showed generally similar monthly rainfall trends across the states, while annual rainfall exhibited fluctuations and departures (anomalies) from the mean values throughout the study period (1995–2025). The study reveals a weak positive statistical relationship in rainfall within the states at the 95% confidence level. The study reveals a significant difference in rainfall across the states during the study period (1995- 2025). The study concludes that the observed variability in rainfall patterns over the years provides evidence of climate change in the agro-ecological region. The study concludes that the observed variability in rainfall patterns over the years provides evidence of climate change in the agro-ecological region.

Keywords: Anomaly, Climatic element, Rainfall, Temperature, Trend.

INTRODUCTION

Climate refers to the long-term average pattern of weather conditions over a specific area or region, typically assessed over an extended period. Climate is generally regarded as a synthesis of weather. The world climate has changed over the years and is continuously changing. Climate variability has always been one of the main environmental determinants of food production. Climate has an influence on the nature of natural vegetation, characteristics of soils, the crops that can be grown, and the type of farming that can be practiced in any region. Recent short-term climatic variability, particularly rainfall fluctuations, is becoming an increasing concern to the government and the people (Ologunorisa, 2004).

Climate determines what plant to cultivate, how to cultivate it, the yield of crops and the nature of livestock to keep. Ajadi et al. (2011) reported that temperature and moisture, among climatic elements, determine the global distribution of humans, crops, and livestock, as well as crop yield and livestock productivity.

The Intergovernmental Panel on Climate Change (IPCC) Working Group 1 Report (2013) affirmed that the quantity of these greenhouse gases (carbon dioxide (CO₂), methane (CH₄), chlorofluorocarbons (CFC-11, CFC-12, CFC-13), nitrous oxide (N₂O), ozone (O₃), and aerosol/particulates) contributes significantly to climate change. It is believed that variability, in terms of fluctuation or trend, is an inherent attribute of climate or weather. What is crucial is the degree of variability climate is subject to, as well as the duration of such variability (Ayoade, 2003). Ayoade (2003) also noted that minor fluctuations or variations constitute not more than “noise” in the climate series and that man can easily adapt to such minor variations. However, when climatic fluctuations deviate significantly from the normal conditions or persist long enough to establish a new climatic state, they create challenges of adjustment, making the environment, humans, and their activities increasingly vulnerable. The rapidity of variations or changes in climate also heightens the vulnerability of man, his socio-economic activities, and the ecosystems in general to the change.

Rainfall is the most important natural factor that determines agricultural production in Nigeria, particularly in the North Western part of Nigeria. The variability of rainfall and the pattern of extremely high or low precipitation are very important for agriculture as well as the economy of the state. It is well established that rainfall is changing on both global and regional scales due to global warming (Hulme et al., 1998; Kayano, 2008). Rainfall variability determines the planning horizons of agriculture and water resources in the country. Rainfall is the source of water supply for general economic activities in the tropics (Olaniran, 2002). According to Enete and Ebenebe (2009), rainfall is one element that influences the tropical ways of life; it dictates the agricultural calendar, impacts the hydrologic cycle, social life, and even food distribution and transportation. It relates to economic growth and development in Nigeria at large. Owing to these, among others, researchers have devoted worthwhile effort to investigating various ramifications of rainfall climatology.

Studies on global, regional, and local-scale trends in monthly, seasonal, and annual mean maximum and minimum temperatures as well as diurnal temperature range have been done (Jackson et al., 2014; Oguntude et al., 2012; Uko & Ari, 2013; Salako, 2017). Most of these studies came to the conclusion that changes in temperature influence hydrological cycle processes either directly or indirectly. An increase in temperature intensifies the hydrological cycle due to an increase in evaporation and precipitation (Jain & Kumar, 2012).

At the local scale, and particularly in Nigeria, the state of knowledge on these variables is far from satisfactory (Orimogunje, 2010).

Although there have appeared some useful publications on Nigeria, for example, Adakayi (2012) who assessed the rainfall of northern Nigeria; Ismail and Oke (2012) who worked on the agro-climatology of northern Nigeria and produced an agro-climatological Atlas of northern States of Nigeria; trend analyses and/or distribution (Odumodu, 1982), onset and cessation (Olaniran, 2002), seasonality (Ayoade, 2001), among others.

The extent of rainfall variation across space and time is a defining feature of an area's climate. There are consequences of rainfall variability for agriculture and water resources. Ayoade (2001) further explained that rainfall not only varies from year to year but also as an element of seasonality in its occurrence within a given year.

MATERIALS AND METHODS

Study Area

The study covered selected states of the Northwestern region of Nigeria. The states covered include Kaduna, Katsina, and Sokoto states. Geographically, the Northwest extends from 08°28'N to 13°20'N in latitude and from 04°29'E to 09°11'E in longitude (Fig. 1). The Northwestern region covers approximately 122,94km². The North-West Zone comprises seven states: Kano, Jigawa, Kaduna, Zamfara, Kebbi, Sokoto, and Katsina. The growth and development between the seven states have not been equal, for various historical and geographical reasons.

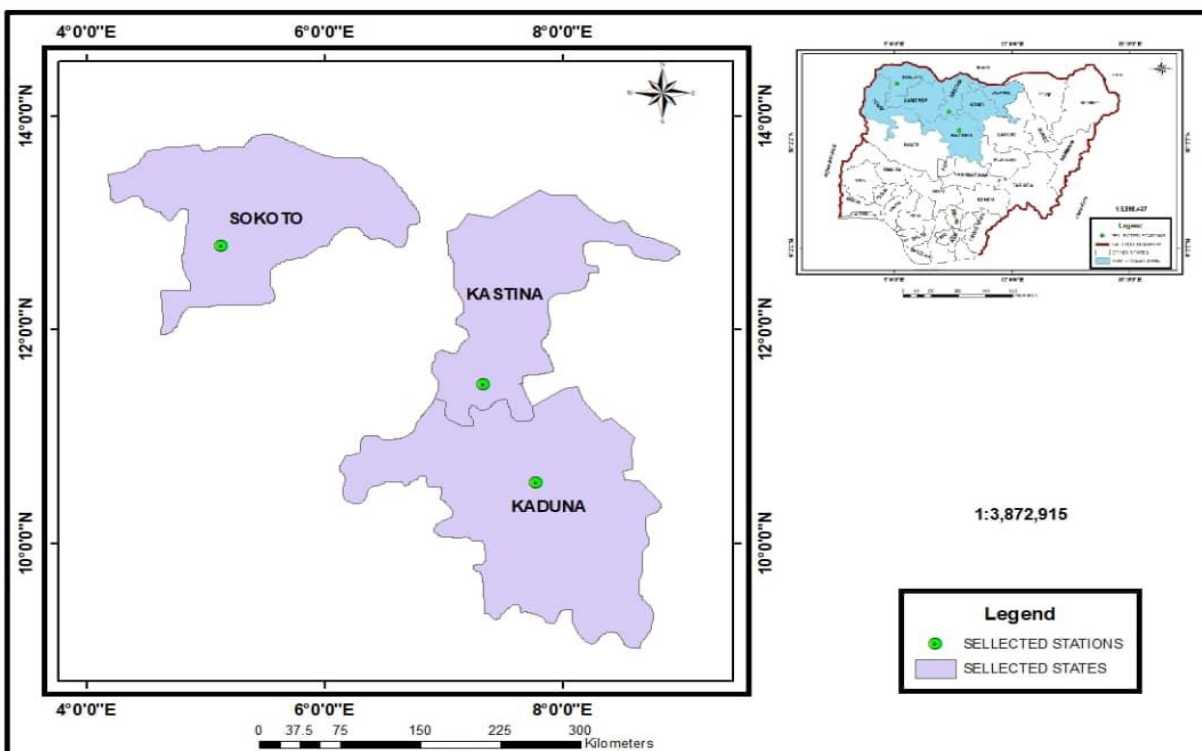


Figure 1: Map of the study area

Data Collection

The research basically relied on secondary data. The dataset comprises monthly rainfall records, measured in millimetres (mm), covering 30 years from 1995 to 2025, and obtained from the Nigerian Meteorological Agency (NIMET) at Nnamdi Azikiwe International Airport, Abuja.

Data Analysis

Descriptive statistics were used to determine the mean monthly and annual values as well as standard deviation. Time series analysis was employed to show rainfall distribution patterns within the temporal scale. Correlation analysis was used to determine the relationship of rainfall within the study areas.

RESULTS AND DISCUSSION

Pattern of Monthly Rainfall

The rainfall patterns of Kaduna, Katsina and Sokoto states are characterized by a brief dry spell in August, commonly referred to as the "August break," a notable feature of the seasonal rainfall regime in these areas. Mean monthly rainfall measures the uniformity and spread in rainfall distribution and gives the mean value of accumulated rainfall over time. The rainfall peak (mm), months of occurrence, and pattern exhibited for each state, i.e., Kaduna, Katsina, and Sokoto states, respectively (Table 1. Kaduna State exhibited a single peak with a mean value (314.63mm) in August; Katsina State exhibited a single peak with a mean value (193.25mm) in August; while Sokoto State exhibited double peaks with a mean value (188.92mm, 205.10mm) in July and August, respectively

Table 1: Peak Monthly Rainfall and Month of Occurrence

States	Peak Rainfall (mm)	Pattern	Month
Kaduna	314.63mm	Single peak	August
Katsina	193.25mm	Single peak	August
Sokoto	188.92mm, 205.10mm	Double peak	July, August

Source: Author's work, 2025

Rainfall Anomalies

The trend mean of annual rainfall anomaly of Kaduna State is shown in Figure 2. It is evident from the figure that the rainfall pattern fluctuated above and below the mean value (101.9mm),

showing years of surplus and deficit over the study area until it reached its peak in 2005 and 2010 (134.14mm), after which it dropped to record the lowest value in 2009 (68.42mm).

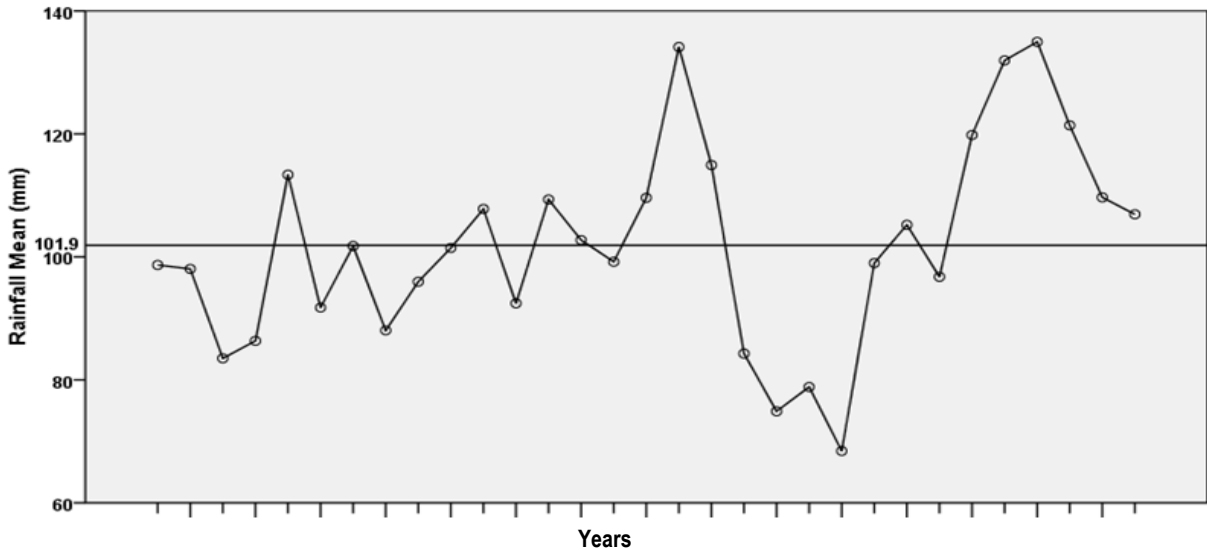


Figure 2: Annual rainfall anomaly of Kaduna State.

The trend mean of annual rainfall anomaly of Katsina State is shown in Figure 3. It is evident from the figure that rainfall patterns fluctuated above and below the mean value (47.9mm), showing

years of surplus and deficit over the study area until it reached its peak in 2013 and 2022 (77.36mm). The state also recorded its lowest value in 2001 (21.84mm)

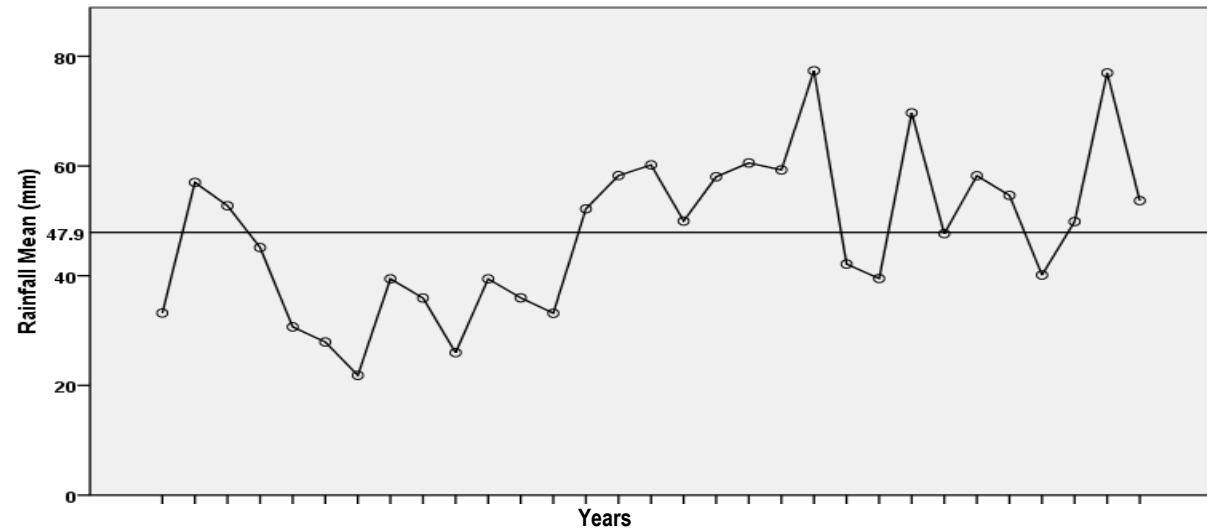


Figure 3: Annual rainfall anomaly of Katsina State.

The trend mean of the annual rainfall anomaly for Sokoto State is shown in Figure 4. It is evident from the figure that the rainfall pattern fluctuated above and below the mean value (56.1mm),

showing years of surplus and deficit over the study area until it reached its peak in 2025 (89.61mm), after which it dropped to record its lowest value in 2023 (36.69mm)

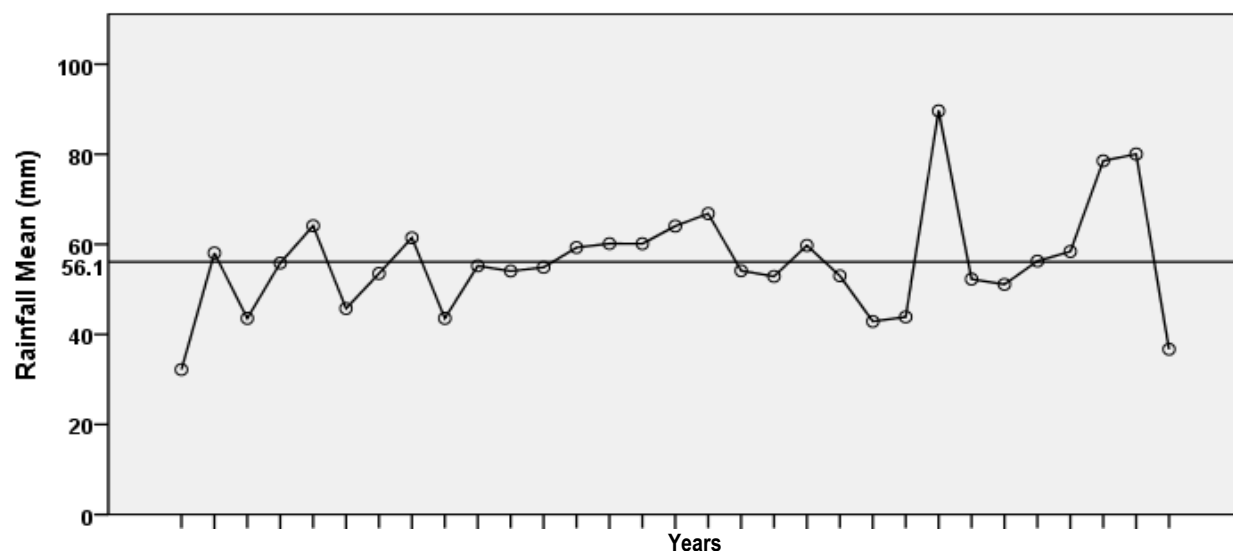


Figure 4: Annual rainfall anomaly of Sokoto State.

Analysis of Monthly Rainfall

The monthly time series analysis of rainfall showed similar rainfall patterns across the study areas, i.e., Kaduna, Katsina and Sokoto states. The months of January, February, and March show no rainfall, with a mean value of 0.00mm. It experiences a steady increase from June until it reaches its peak in August. The monthly mean rainfall results for the Northwestern region indicate that rainfall peaked across the selected states during June, July, and August. It showed a steady increase from June until it reached its peak in August. It also showed that the months of rainfall surplus were June, July, and August, and the months of deficit were January, February, March, April, October, November, and December. This finding confirms earlier claims in NOAA (2007) that the June, July, and August season is common to both the southern and northern parts of the country and poor rainfall can cause considerable stress on maturing crops and other economic activities. The findings were at variance with those of Odumodu (1982), who worked on rainfall distribution, variability, and probability in the Jos Area, Plateau State.

The research findings were based on studies conducted by Enete and Ebenebe (2009) in Nigeria. The results showed that the trends suggested a general decline in rainfall values in recent times. Following the pattern, they reported a noticeable and significant decline in rainfall frequency in September and October, which coincide with the end of the rainy season in almost every part of the country, especially in the Northern and Central parts of Nigeria. This supports the findings of Olaniran & Summer (1989, 1990), who found a progressive early decline in rainfall in the country.

Abdulrahim et al. (2013) analysed the characteristics of rainfall data for Sokoto Metropolis over 40 years (1970–2009) to assess drought risk. The results showed an increasing trend in rainfall amount over the metropolis within the period under review. Analysis of monthly rainfall data revealed that rainfall was

concentrated in June, July, and August, followed by a decline in September. Obviously, the rainfall analysis showed that January, February, March, April, May, November, and December are dry months. The result is in line with the research findings of rainfall trend/pattern in the Northwestern region of Nigeria.

Annual Rainfall Anomalies

The annual trend analysis of rainfall anomalies shows the annual rainfall trend within the study areas, i.e., Kaduna, Katsina and Sokoto states. Kaduna State, the years 2003, 2006, 2007, 2010, 2011, 2017, 2020, 2021, 2021, 2023, 2024, and 2025 were periods of rainfall surplus, i.e., years with rainfall above the mean. The periods of rainfall deficit were 1995, 1996, 1997, 1998, 2000, 2001, 2003, 2006, 2009, 2013, 2014, 2015, 2016, 2017, and 2018. It also recorded the highest annual mean rainfall in 2011, with a value of 134.14mm, while the lowest annual mean rainfall of 68.42mm was recorded in 2016.

Katsina State revealed that the years 1996, 1997, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2018, 2019, 2020, 2021, 2022 1995, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2016, 2017 and 2021. It recorded the highest annual mean rainfall in 2015, with a mean value of 77.36 mm, and the lowest mean value of 21.84mm in 2001.

Sokoto State revealed that 1996, 1999, 2002, 2007, 2008, 2009, 2010, 2011, 2014, 2018, 2021, 2022 and 2023 were periods of rainfall surplus. The periods of rainfall deficit include 1995, 1997, 2000, 2001, 2003, 2005, 2006, 2011, 2012, 2013, 2014, 2015, 2016, 2017 and 2018. It recorded the highest annual mean rainfall in 2017, with a value of 89.61 mm, and the lowest in 2025, with a value of 36.69 mm.

The trends observed agreed with what Ayoade (2003) reported on annual climatic trends and periodicities in Nigeria. These findings were at variance with those of Odumodu (1982), who examined rainfall distribution, variability, and probability in the Jos area of Plateau State. It was also supported by the findings of Olaniran and

Summer (1990), who analyzed the spatial and temporal variation in rainy days and mean daily rainfall intensity in Northern and Southern Nigeria; they observed a decreasing trend in the number of rainy days over the years.

The findings were consistent with those of Ismail and Oke (2012), who conducted a statistical and trend analysis of rainfall in Sokoto. Rainfall data in the city for the period 2002 - 2022 were collected from the archives of the Nigerian Meteorological Agency (NIMET). The study reveals that overall averages of yearly and monthly total

rainfall were 726 ± 24.03 mm and 61.75 ± 25.31 mm, respectively. It was concluded that there is a significant downward trend in the yearly total and mean at Sokoto in the last three decades (30 years), which was attributed to climate change.

The summary of rainfall anomalies (Table 2) revealed the years with rainfall above the mean (surplus), below the mean (deficit), the highest deviation above the mean, and the highest deviation below the mean.

Table 2: Summary of Annual Rainfall Anomalies (mm)

States	Years above the mean(surplus)	Years below the mean(deficit)	Year(s) with highest deviation above the mean	Year(s) with highest deviation below the mean
Kaduna	1999, 2005, 2007, 2010, 2011, 2012, 2018, 2020, 2020, 2021, 2022, 2022, and 2025	1995, 1996, 1997, 1998, 2003, 2002, 2003, 2004, 2009, 2013, 2014, 2015, 2016, 2017 and 2025.	2018, 2021	2016
Katsina	1996, 1997, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2021, 2018, 2019, 2020, 2022, 2023& 2025	1995, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2021, 2016 and 2021	2015, 2023	2001
Sokoto	1996, 1999, 2002, 2007, 2008, 2009, 2010, 2011, 2014, 2018, 2021, 2022 and 2023	1995, 1997, 2000, 2001, 2003, 2005, 2006, 2012, 2013, 2015, 2016, 2017, 2018, 2019 and 2023	2017	2025

Source: Author's Analysis (2025)

Generally, following Adakayi (2012), it is observed from trend analysis (as a time series) that rainfall displayed a similar upward cyclical trend over the period of study. From his assessment of rainfall in northern Nigeria, he reported that climatic elements will continue to increase until about 2030, which is at variance with what Ismail and Oke (2012) reported in Sokoto and is attributed to climate change.

Conclusion

The study revealed that the monthly rainfall trend showed similarities, with the highest in August and lowest in January, February, November and December. The annual rainfall trend showed fluctuations, with a decline in 2018, similar across the three states in the study years. The study therefore concludes that variations in rainfall in the Northwestern region were a result of changes in climatic elements in the region, showing deviation. This region's main occupation is farming, mainly rain-fed agriculture. Any change, variation, or fluctuation in climate, whether slow or rapid, will seriously affect the occupation of the inhabitants of this region.

Additionally, the results could provide a strong indication of climate change in the region. Therefore, concerted efforts by policymakers are needed to address this issue by developing effective mitigation and adaptation strategies to reduce vulnerability to the impacts of climate change. Finally, the current analysis was limited to two climatic elements; future research should include other climatic elements and strive to cover more geographical areas.

Nigeria is a country that depends heavily on agriculture for the existence of its populace. The farmers practice small-scale farming on individual holdings, use traditional cultivation methods, and rely

on rainfall as their only source of water. From the study, there is a South-to-North latitudinal decrease in rainfall, which is clear evidence of climate change, and their normal trend there has deviated.

Recommendations

From the analysis of rainfall, it shows a concentration of rainfall in the months of June, July, August and September in the selected states of the Northwest. This means planting of crops should be focused within these months to ensure a good harvest, since the benefits of these water resources are best optimized during this period.

In this study, only three states were used. It is thus suggested that studies involving more states of the Northwest zone should be carried out for better results.

Also, more climatic elements such as evaporation, relative humidity, cloud cover and many other climatic elements should be studied to understand the effects of climate change in a region.

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