

Inter-Annual Variability of Rainfall, Temperature and Agroclimatic Indices in Kaduna State, Nigeria (2010–2025)

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Abstract

This study examined the inter-annual variability of rainfall, temperature and agroclimatic indices in Kaduna State, Nigeria, over sixteen years, 2010 to 2025. Daily rainfall and temperature records from the Nigerian Meteorological Agency were aggregated into monthly and annual values and analysed for variability in rainfall onset, cessation, length of the growing season, and early and late season dry spells, using Instat, Microsoft Excel and Python. Mean maximum temperature rose gradually across the period, from 37.4 °C in 2012 to a peak of 38.6 °C in 2025, representing an average annual increase of approximately 0.039 °C. Annual rainfall fluctuated between 1,151.8 mm and 2,156.6 mm, with a mean of 1,561.3 mm and a coefficient of variation of approximately 18%, reflecting a regression slope of 12.17 mm per year that was not statistically significant ($p = 0.230$). Rainfall onset ranged from 4 May to 1 June, with a statistically significant delay of 1.057 days per year ($p = 0.030$), amounting to a cumulative delay of about 16 days over the study period. Cessation dates ranged from day 285 to day 318 of the year, with a weak, non-significant trend toward earlier cessation, while the length of the growing season declined gradually from a maximum of 194 days in 2018 to a minimum of 150 days in 2023. Early season dry spells showed only a marginal increase, whereas late season dry spells rose markedly, by approximately 0.874 days per year, corresponding to a cumulative increase of about 14 days, signalling intensifying moisture stress during the reproductive and grain filling stages of major crops. The findings demonstrate that the principal climatic challenge confronting Kaduna State is not a change in total rainfall volume but increasing intra-seasonal variability, delayed onset, a shortening growing season and intensifying late season dry spells. The study recommends strengthened seasonal forecasting, the promotion of early and medium maturing crop varieties, soil moisture conservation practices and climate informed agricultural advisory services to support adaptation in the Guinea savanna zone of Nigeria.

Keywords: climate variability; rainfall; temperature; growing season; dry spells; Kaduna State

1 Introduction

Climate change and climate variability have become critical global concerns, with recent decades witnessing marked alterations in temperature and rainfall patterns affecting environmental systems, health, ecosystems and food security (Le Treut et al., 2007). Agriculture is among the most climate sensitive sectors because of its dependence on well defined seasonal rainfall and temperature regimes (Obot and Onyeukwu, 2010). Anthropogenic activities, including population growth, deforestation and fossil fuel combustion, have accelerated greenhouse gas emissions and disrupted climate systems, producing more frequent extreme weather, shifting rainfall regimes and increasing drought and flood risks (United Nations Development Programme, 2009).

In Sub-Saharan Africa, agriculture contributes approximately 15% of gross domestic product and supports over 70% of the population through rain fed smallholder farming (OECD and FAO, 2016), heightening vulnerability to rainfall variability. Nigeria reflects these trends, experiencing rising temperatures and altered rainfall patterns that undermine productivity (Building Nigeria's Response to Climate Change, 2011; Deressa et al., 2008). Kaduna State, in the northern Guinea savanna zone, is predominantly agrarian, cultivating maize, sorghum, millet, cowpea and rice, with limited coping capacity increasing susceptibility to climatic shocks (Apata et al., 2009).

Although several studies have examined climate change impacts on agriculture in Nigeria, sub-national empirical evidence on the inter-annual behaviour of climatic variables in Kaduna State remains limited. This study examines the inter-annual variability of rainfall, temperature, onset, cessation, length of the growing season, and early and late season dry spells over 2010 to 2025, providing an updated basis for climate informed agricultural planning, early warning systems and policy formulation in the state.

2 Study area

Kaduna State lies in northwestern Nigeria, between latitudes 8°49'30"N and 11°15'20"N, and longitudes 6°45'45"E and 8°26'15"E, bordering Niger State to the west, Zamfara, Katsina and Kano to the north, Bauchi and Plateau to the east, and the Federal Capital Territory and Nasarawa to the south. Its population was 6.1 million at the 2006 census, estimated at 8.9 million in 2020 at a growth rate of 3.18% (Kaduna State Government, 2018).

Agriculture is the primary livelihood and largest employer of labour in Kaduna State. Smallholder farmers dominate crop production, with the state ranking first nationally in maize and ginger, second in soybean, third in tomato, fourth in sorghum and tenth in cowpea production (NAERLS and Federal Ministry of Agriculture and Rural Development, 2019).

Kaduna State lies within the northern Guinea savanna zone and experiences a tropical continental climate with distinct wet and dry seasons, governed by the seasonal movement of the Inter-Tropical Convergence Zone. The rainy season begins between April and May and lasts until October, peaking in July and August, with annual rainfall ranging from about 1,000 mm in the north to over 1,500 mm in the south. The dry season, November to March, is characterised by the Harmattan, a dry, dusty northeasterly wind from the Sahara. Temperatures are high year round, with the hottest months, March and April, often exceeding 35 °C, and the coolest period, December and January, falling below 15 °C; average annual temperatures range between 24 and 28 °C. The growing season varies from approximately 150 days in the north to over 180 days in the south, with rainfall variability, dry spells and occasional flooding presenting recurring challenges for rain fed crop production.

3 Methodology

3.1 Data sources

Secondary data comprising daily rainfall, and minimum and maximum temperature for the period 2010 to 2025 were obtained from the archives of the Nigerian Meteorological Agency. All datasets were reviewed for completeness and consistency before analysis to ensure the reliability of results.

3.2 Analysis of inter-annual variability

Daily rainfall and temperature records were aggregated into monthly and annual values using Instat, Microsoft Excel and Python. Monthly rainfall totals were computed by summing daily rainfall within each month, and annual rainfall totals were computed by summing the twelve monthly totals for each year. The standardised annual precipitation index was calculated as the deviation of annual rainfall from the long term mean, divided by the standard deviation of annual rainfall across the sixteen year record. Average annual maximum temperature was computed as the mean of daily maximum temperature values within each year, and a corresponding standardised temperature anomaly was derived using the same deviation approach applied to annual rainfall.

3.3 Onset, cessation and length of the growing season

Onset and cessation dates were determined using Instat software following the method originally proposed by [Walter \(1967\)](#) and modified by [Olaniran \(1983\)](#) for the West African monomodal rainfall regime. Onset was defined, for dates after 15 March, as a cumulative rainfall of at least 20 mm recorded over one to three consecutive days with no subsequent dry spell exceeding 20 days within the following 30 days, a modification suited to the erratic early rains characteristic of northern Nigeria. Cessation was determined using two complementary approaches following [Adefolalu \(1985\)](#): a reverse cumulative soil water balance method, in which cessation is identified as the day after 1 October on which a soil profile with 70 mm of available water holding capacity becomes fully depleted under an average evapotranspiration loss of 4 mm per day, and a rainfall threshold method, in which cessation is the last day after 1 August on which a cumulative rainfall of at least 20 mm has been recorded over any consecutive ten day period, followed by no further rainfall exceeding 10 mm within the subsequent 20 days. The length of the growing season was computed as the interval, in days, between the onset and cessation dates.

3.4 Dry spell analysis

A dry spell was operationally defined as a sequence of consecutive days with daily rainfall not exceeding 0.85 mm. Two dry spell indices were analysed using Instat Plus: the early season dry spell, defined as the longest dry spell within the first 50 days after onset, which is critical for crop establishment, and the late season dry spell, corresponding to the period between day 50 after onset and the average end of season date, which coincides with flowering, heading and grain filling stages of major crops.

3.5 Trend significance testing

The statistical significance of trends in each climatic variable was assessed using a parametric t-test, appropriate where the sample size is less than 30. The null hypothesis stated that the slope of the regression line fitted to the time series was equal to zero, against the alternative that the slope was significantly different from zero. The t-statistic was computed as the estimated slope divided by its standard error, and the associated p-value was obtained using the `scipy.stats` and `statsmodels` libraries in Python. A trend was considered statistically significant where the p-value was less than or equal to 0.05.

4 Results

4.1 Temperature variability

Mean maximum temperature in Kaduna State exhibited a gradual warming trend between 2010 and 2025. The lowest mean maximum temperature was recorded in 2012 at 37.4 °C, while the highest was recorded in 2025 at 38.6 °C. The fitted trend indicated an average annual increase of approximately 0.039 °C, equivalent to a cumulative increase of about 0.5 °C across the sixteen years, superimposed on strong inter-annual variability. This pattern is consistent with warming trends documented elsewhere in Kaduna State by [Aganbi et al. \(2021\)](#) and across the north-central geopolitical zone of Nigeria by [Aremu et al. \(2017\)](#), and aligns with regional projections by the [Intergovernmental Panel on Climate Change \(2021\)](#) of increasing temperatures across West Africa. The results are summarised in Table 1.

Table 1. Summary of temperature variability, Kaduna State, 2010–2025.

Parameter	Value
Lowest Mean Maximum Temperature	37.4 °C (2012)
Highest Mean Maximum Temperature	38.6 °C (2025)
Trend Slope	+0.039 °C per year
p-value	0.481
Remark	Not Statistically Significant

Source: authors' computation from Nigerian Meteorological Agency data.

4.2 Rainfall variability

Annual rainfall across the study period ranged from a minimum of approximately 1,151.8 mm to a maximum of 2,156.6 mm, recorded in 2022, with a mean annual rainfall of 1,561.3 mm. The coefficient of variation of approximately 18% indicates a moderately high level of year to year rainfall variability. The fitted regression equation, $y = 12.1691x + 1460.1691$, indicated a positive slope of 12.17 mm per year; however, the associated p-value of 0.230 shows that this trend was not statistically significant at the 5% level, indicating that observed rainfall changes were dominated by short term fluctuation rather than a sustained long term increase. This finding is consistent with [Aganbi et al. \(2021\)](#) and [Lawal et al. \(2024\)](#), who similarly reported high inter-annual rainfall variability in Kaduna State without evidence of a statistically significant trend. The results are summarised in Table 2.

Table 2. Summary of rainfall variability, Kaduna State, 2010–2025.

Parameter	Value
Minimum Annual Rainfall	1,151.8 mm
Maximum Annual Rainfall	2,156.6 mm (2022)
Mean Annual Rainfall	1,561.3 mm
Coefficient of Variation	18%
Trend Slope	+12.17 mm per year
p-value	0.230

Parameter	Value
Remark	Not Statistically Significant

Source: authors' computation from Nigerian Meteorological Agency data.

4.3 Rainfall onset

The earliest onset of the rainy season occurred on 4 May 2012, Julian day 124, while the latest onset was recorded on 1 June 2023, Julian day 152. The mean onset date was approximately day 137 of the year, corresponding to 17 May, with a coefficient of variation of about 6.8%, indicating relatively low year to year variability in the timing of onset. Trend analysis revealed a statistically significant delay of 1.057 days per year ($p = 0.030$), corresponding to a cumulative delay of approximately 16 days over the sixteen year period. Accurate onset prediction is critical for scheduling land preparation, crop selection and planting, and improper timing can lead to yield losses and threaten food security (Odekunle, 2004; Nicholson et al., 2000). The results are summarised in Table 3.

Table 3. Summary of rainfall onset, Kaduna State, 2010–2025.

Parameter	Value
Earliest Onset	4 May 2012 (Day 124)
Latest Onset	1 June 2023 (Day 152)
Mean Onset Date	Day 137 (17 May)
Coefficient of Variation	6.8%
Trend Slope	+1.057 days per year
p-value	0.030
Remark	Statistically Significant

Source: authors' computation from Nigerian Meteorological Agency data.

4.4 Rainfall cessation

Cessation dates ranged from day 285, the earliest, recorded in 2016, to day 318, the latest, recorded in 2018, corresponding to approximately 12 October and 14 November respectively. The fitted trend equation, $y = -0.128x + 302.272$, indicated a weak tendency toward earlier cessation of approximately 0.13 days per year, equivalent to about 1.3 days per decade; however, this trend was not statistically significant ($p = 0.711$). The pronounced inter-annual variability, including a 33 day swing between the earliest and latest cessation years within a two year span, is of greater agricultural significance than the weak directional trend, since it introduces substantial uncertainty into harvesting schedules and moisture availability during reproductive stages (Odekunle, 2004; Salack et al., 2015). The results are summarised in Table 4.

Table 4. Summary of rainfall cessation, Kaduna State, 2010–2025.

Parameter	Value
Earliest Cessation	Day 285 (12 October, 2016)
Latest Cessation	Day 318 (14 November, 2018)
Trend Slope	-0.128 days per year

Parameter	Value
p-value	0.711
Remark	Not Statistically Significant

Source: authors' computation from Nigerian Meteorological Agency data.

4.5 Length of the growing season

The length of the growing season ranged from 150 days in 2023 to 194 days in 2018. The fitted regression equation, $y = -0.315x + 174.110$, indicated a gradual decline of approximately 0.315 days per year, equivalent to a cumulative reduction of about five days over the study period; this trend was not statistically significant at the 5% level ($p = 0.585$). Even modest reductions of this kind can be agronomically important, since they shorten the time available for vegetative growth, flowering, grain filling and physiological maturity, particularly for crops with longer maturity requirements (Salack et al., 2015; Vrieling et al., 2013). The results are summarised in Table 5.

Table 5. Summary of length of the growing season, Kaduna State, 2010–2025.

Parameter	Value
Shortest Growing Season	150 days (2023)
Longest Growing Season	194 days (2018)
Trend Slope	-0.315 days per year
p-value	0.585
Remark	Not Statistically Significant

Source: authors' computation from Nigerian Meteorological Agency data.

4.6 Early and late season dry spells

The first dry spell, occurring shortly after onset, ranged from 3 to 9 consecutive dry days, with years such as 2014, 2015, 2024 and 2025 recording relatively long early season dry spells. The fitted trend, $y = 0.019x + 5.294$, indicated only a negligible increase of approximately 0.019 days per year, corresponding to a cumulative change of less than one third of a day over the study period, indicating that inter-annual variability rather than a sustained long term trend dominates early season dry spell behaviour (Odekunle, 2004; Sivakumar, 1992).

In contrast, the second dry spell, occurring toward the end of the rainy season, increased from relatively short durations of 3 to 6 days in several early years to exceptionally long dry periods exceeding 20 consecutive rainless days in 2015 and 2024. The fitted trend, $y = 0.874x + 4.199$, indicated an increase of approximately 0.874 days per year, corresponding to a cumulative increase of about 14 days over the study period, a magnitude substantially greater than that observed for the early season dry spell. Late season dry spells coincide with flowering, grain filling and physiological maturity, and moisture deficits during these stages can reduce grain weight, impair nutrient translocation and accelerate premature senescence (Gornall et al., 2010; Kabore et al., 2021). The dry spell results are summarised in Table 6.

Table 6. Summary of early and late season dry spells, Kaduna State, 2010–2025.

Parameter	DSP1 (Early)	DSP2 (Late)
Range (days)	3 to 9	3 to 6, up to over 20
Trend Slope (days/year)	+0.019	+0.874
Cumulative Change	< 0.3 days	≈14 days

Source: authors' computation from Nigerian Meteorological Agency data.

4.7 Summary of trend significance

Table 7 presents the onset, cessation and length of the growing season recorded for each year of the study period, while Table 8 summarises the statistical significance of trends in the principal climatic variables examined.

Table 7. Onset, cessation and length of the growing season in Kaduna State, 2010–2025.

Year	Onset	Cessation	Length of Growing Season (days)
2010	8 May	8 November	186
2011	5 May	30 October	180
2012	4 May	4 November	187
2013	27 May	21 October	151
2014	6 May	21 October	173
2015	28 May	26 October	157
2016	14 May	11 October	157
2017	15 May	13 October	158
2018	9 May	13 November	194
2019	26 May	10 November	177
2020	11 May	29 October	180
2021	19 May	14 October	159
2022	13 May	2 November	185
2023	1 June	16 October	150
2024	27 May	3 November	174
2025	22 May	26 October	177

Source: authors' computation from Nigerian Meteorological Agency data.

Table 8. Test of significance of trends in climatic parameters, Kaduna State, 2010–2025.

Climatic Variable	p-value at 5%	Remark
Rainfall	0.230	Not Statistically Significant
Onset	0.030	Statistically Significant
Cessation	0.711	Not Statistically Significant
Length of Growing Season	0.585	Not Statistically Significant

Climatic Variable	p-value at 5%	Remark
Maximum Temperature	0.481	Not Statistically Significant

Source: authors' computation from Nigerian Meteorological Agency data.

Of the five variables tested, only rainfall onset showed a statistically significant trend, confirming that the dominant characteristic of the climate system in Kaduna State over the study period was pronounced inter-annual variability rather than a uniform long term directional shift, with the exception of the delay in onset timing.

5 Discussion

The findings indicate that Kaduna State is experiencing a climate system characterised by gradual warming, highly variable rainfall, delayed onset, variable cessation, a modest reduction in growing season length, and sharply increasing late season dry spells. The warming signal, averaging approximately 0.039 °C per year, is consistent with regional assessments by the [Intergovernmental Panel on Climate Change \(2021\)](#) and [Sawa and Adebayo \(2011\)](#) and [Ogunjobi et al. \(2018\)](#), who documented upward temperature trends across northern Nigeria. Rising temperatures increase evapotranspiration and soil moisture depletion, intensifying crop water stress in rain fed systems ([Lobell et al., 2011](#)).

The significant delay in rainfall onset is agriculturally important, since onset timing governs land preparation, crop selection and planting schedules ([Odekunle, 2004](#); [Walter, 1967](#)). A cumulative delay of 16 days increases the risk of mistimed planting, through premature sowing followed by seedling mortality or delayed sowing that shortens the growing period ([Dieng et al., 2018](#)). The weak but consistent decline in growing season length reinforces this concern, constraining time available for vegetative growth, flowering and grain filling, particularly for medium and long duration maize, rice and sorghum varieties.

The contrasting behaviour of early and late season dry spells is among the most significant findings of this study. While early season dry spells showed negligible long term change, late season dry spells increased by approximately 14 days, consistent with [Usman et al. \(2022\)](#) and the [Nigerian Meteorological Agency \(2024\)](#) in northern Nigeria, and [Salack et al. \(2016\)](#) across the Sahel. Because late season dry spells coincide with flowering, pollination and grain filling, their intensification poses a disproportionately severe threat to yield compared with early season deficits ([Sifer et al., 2016](#); [Kabore et al., 2021](#)).

Collectively, these findings suggest that the principal climatic challenge facing Kaduna State is not a change in total rainfall volume, since the rainfall trend was not significant, but increasing variability and uneven intra-seasonal distribution, manifested through delayed onset and intensifying terminal dry spells. This has direct implications for adaptation planning, since interventions focused solely on total rainfall would not address the intra-seasonal risks identified here.

6 Conclusion

This study has characterised the inter-annual variability of rainfall, temperature and agroclimatic indices in Kaduna State over 2010 to 2025. The results demonstrate a gradual warming trend, pronounced but non-significant inter-annual rainfall variability, a statistically significant delay in rainfall onset, a weak tendency toward earlier cessation, a modest decline in growing season length,

and marked intensification of late season dry spells. These findings confirm that the agroclimatic environment is shifting in ways that increase moisture stress risk during critical crop stages, even where total seasonal rainfall remains broadly stable, underscoring the importance of intra-seasonal rainfall characteristics over total rainfall alone in assessing climate risk to rain fed agriculture.

7 Recommendations

1. Seasonal climate forecasts and localised agro-advisory services should be strengthened and disseminated through extension services to support timely land preparation and planting decisions in response to the observed delay in rainfall onset.
2. Early and medium maturing crop varieties should be promoted to align crop cycles with the shortening length of the growing season and to reduce exposure to terminal dry spells during flowering and grain filling.
3. Soil moisture conservation practices, including mulching, tied ridging and minimum tillage, together with small scale irrigation and water harvesting infrastructure, should be expanded to buffer against the intensifying late season dry spells identified in this study.
4. Continuous, long term climate monitoring should be institutionalised in Kaduna State to track the evolution of onset, cessation, growing season length and dry spell characteristics, given the predominance of inter-annual variability over directional trends in most of the variables examined.

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