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Seasonal rainfall variability across Nigeria's climatic zones and its relationship with national livestock production

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Abstract

Livestock production in Nigeria is threatened by climate change, as seasonal rainfall that sustains agricultural water supply varies substantially across space and time. This study evaluates seasonal rainfall variability and trends across Nigeria's Sahel, Savanna, and Rainforest climate zones, and separately examines the national-level relationship between seasonal rainfall and national livestock production. Observational rainfall data from the Climatic Research Unit (CRU) and national livestock production output from the Food and Agriculture Organization (FAO) were analyzed over 44 years (1979-2022). Raw cattle milk recorded the highest mean national production, 416,380.26 T, while sheep recorded the lowest, 98,598.79 T. Raw cattle milk, sheep, pig, goat, and chicken showed statistically significant positive trends from the modified Mann-Kendall (MMK) Z-test, which accounts for serial autocorrelation, while cattle did not. Seasonal rainfall variability was greatest in the Sahel, while increasing trends were observed at selected Sahel locations and declining trends across parts of the Savanna and Rainforest. Kendall's tau analysis showed a positive association between national seasonal rainfall and goat production ($\tau = 0.301$, $p = 0.004$), but the raw-series association is interpreted as descriptive because both rainfall and livestock series contain secular temporal structure. After detrending, the positive goat association was weaker ($\tau = 0.222$, $p = 0.034$) and did not meet the Bonferroni-adjusted significance threshold. These findings provide a national-scale description of rainfall-livestock association while distinguishing it from evidence of interannual or causal rainfall effects.

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Keywords: Nigeria, Livestock production, Seasonal rainfall, Climate variability, Kendall's tau

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1. Introduction

Climate change poses significant challenges to Nigeria's socio-economic development and environmental sustainability [1, 2], with documented health consequences for both humans and animals [3]. Nigeria's natural and agricultural ecosystems, including its freshwater and coastal resources, are highly vulnerable to climatic shifts [4]. The country's climatic zones range from tropical rainforest to savannah and semi-arid conditions, shaped largely by the seasonal migration of the intertropical Convergence Zone and the influence of the Atlantic Ocean [5]. Natural drivers such as solar radiation, ocean currents, and atmospheric circulation interact with anthropogenic pressures, including deforestation, urbanization, and industrialization, to intensify climate variability

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through rising greenhouse gas emissions [6]. The resulting irregular rainfall, prolonged dry spells, and extreme events such as floods, droughts, and heatwaves carry serious consequences for agriculture, water resources, public health, and national development more broadly [7].

These climatic shifts affect livestock production through several interacting pathways: plant growth, feed resource availability, and the physiological stress responses of animals themselves [8]. Rising temperatures and declining rainfall are of particular concern for pastoral and agro-pastoral communities that depend directly on natural resources for animal husbandry [9]. Elevated surface temperatures can favor some species while substantially reducing grassland productivity, thereby limiting grazing capacity and feed availability [10, 11]. As arid conditions expand, goats and sheep, which are more heat-tolerant than cattle and chickens, may become comparatively more dominant in affected areas [12].

Addressing this variability calls for a holistic strategy combining improved monitoring and early-warning systems with investment in sustainable farming, afforestation, and renewable energy. Local factors such as large water bodies, topography, and human land-use activity further shape Nigeria's rainfall regime, producing a bimodal pattern in the south and a unimodal pattern in the north [13, 14]. Much of this inter-annual variability is linked to sea surface temperature anomalies and the El Nino-Southern Oscillation [15].

Demand-side pressures compound these supply-side climatic risks. Rapid urbanization is shifting consumption patterns and increasing demand for livestock products [16], while rising incomes are driving further growth in livestock production systems, particularly across the developing world [17]. Climate change affects livestock productivity both directly, through heat stress, and indirectly, by altering water availability, forage quality, and disease pressure, with cascading effects on species diversity within production systems [18]. Because ecosystem and animal health are closely linked, climate change also influences the emergence and spread of livestock disease [19]: wind patterns affect vector distribution, while rainfall variability shapes the conditions under which pathogens survive and transmit [20].

Species differ in their vulnerability to rainfall variability according to their adaptive physiology [21]. Livestock production is also closely connected to climate pressures through its dependence on water, forage, and other climate-sensitive resources. In Nigeria, where agriculture remains predominantly rain-fed, seasonal rainfall is an important climatic control on water resources and food production [23]. This rainfall is driven by the West African Monsoon, with onset in May and cessation in October [24].

Despite an expanding literature on Nigerian rainfall variability and on climate and livestock interactions separately, few studies have examined the two together using a methodologically consistent, multi-decadal framework that respects the spatial scale at which each dataset is actually resolved. Existing livestock-climate assessments for Nigeria (e.g., [25]) have tended to either aggregate rainfall to the national scale, discarding zonal detail, or to informally extend national livestock statistics across sub-national climate zones without corresponding spatial resolution in the livestock data itself. This study builds on that earlier national-scale work by resolving rainfall variability and trend at the zonal level while restricting the livestock correlation analysis strictly to the national scale at which FAO data are actually reported, thereby avoiding the ecological-inference problem that arises when spatially coarse and spatially fine data are combined.

This study therefore investigates seasonal rainfall variability and trend across Nigeria's Sahel, Savanna, and Rainforest climate zones, and separately examines the statistical relationship between national seasonal rainfall and national livestock production. The specific objectives are to (i) establish the status of national production for the selected livestock commodities, (ii) characterize the variability and trend of seasonal rainfall across Nigeria's climate zones, and (iii) evaluate the statistical relationship between national seasonal rainfall and national livestock production.

2. Study area

Nigeria is located between latitudes 4–14°N and longitudes 2–15°E on the western coast of Africa. It is bounded by Cameroon, the Niger Republic and the Republic of Benin in the east, north and west, respectively, while the southern part is bounded by the Gulf of Guinea [26]. It covers approximately 923,768 km^2 [27]. The country is administratively organized into 36 states and the Federal Capital Territory, grouped into six geopolitical zones: North-West, North-East, North-Central, South-West, South-South, and South-East. Its climate is governed jointly by localized convection and the West African Monsoon, producing a wet season from May to October and annual rainfall ranging from a minimum of 110 mm in the northern savanna to a maximum of 2,600 mm in the south [25].

For this study, Nigerian states were grouped into three broad climatic zones (Sahel, Savanna and Rainforest) using the study's adopted long-term rainfall and dominant-vegetation criteria. The resulting state grouping is shown in Figure 1.

3. Data acquisition

3.1. Rainfall

Seasonal (May-October) rainfall across Nigeria was obtained from the Climatic Research Unit (CRU) Time-Series (TS) version 4.07 [29], which provides monthly rainfall on a 0.5° × 0.5° land grid through December 2022. Monthly rainfall was summed over

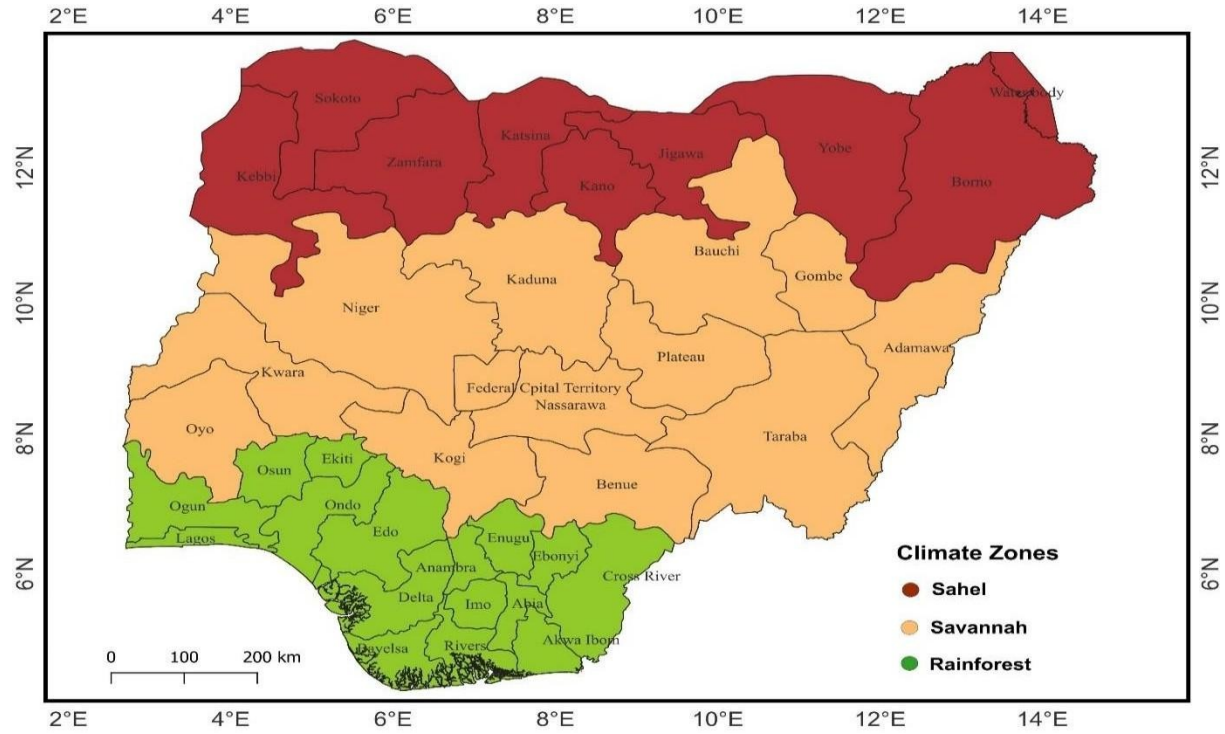


Figure 1: Map of Nigeria showing the study locations and the delineated climate zones (Sahel, Savanna, and Rainforest), following the agro-climatic classification of Ayanlade *et al.* [28].

May-October to form one seasonal total for each year from 1979 to 2022, giving 44 annual observations. For the spatial analysis, CRU grid cells whose centroids fell within each Nigerian state were used to generate state-level seasonal rainfall values; the corresponding state values were then assigned to the Sahel, Savanna, or Rainforest zones defined in Section 2 for zonal summaries. These state-level spatial values are presented in Section 5.2. The national seasonal series used in Section 5.3 was calculated separately by averaging the seasonal rainfall values across all CRU grid cells within Nigeria's land boundary. The dataset excludes oceanic grid cells; because Nigerian livestock and crop agriculture is land-based, this exclusion does not affect the present analysis.

3.2. Livestock production

Livestock production data were obtained from the Food and Agriculture Organization (FAO) FAOSTAT Production domain (QCL) for Nigeria for 1979-2022. Six national production series were selected: cattle meat, sheep meat, goat meat, pig meat, chicken meat, and raw cattle milk. The five meat commodities are reported by FAOSTAT as dressed carcass weight from total commercial and farm slaughter, excluding offal and slaughter fats, while raw cattle milk represents total whole fresh milk production without standardization for fat or protein content. All six series are expressed in metric tonnes (T). The data were used as reported at the national level, with no sub-national disaggregation, imputation, or unit conversion applied [30].

4. Data analysis

Statistical analysis was conducted using Microsoft Excel for data organization and descriptive statistics, Python (SciPy and pyMannKendall) for statistical analysis, and QGIS 3.34.9-Prizren for spatial analysis and map production. Trend magnitude was estimated using ordinary least-squares (OLS) regression, while trend significance was assessed using the Hamed-Rao modified Mann-Kendall Z-test [31], which accounts for serial autocorrelation in the time series. Rainfall-livestock associations were quantified separately using Kendall's tau correlation coefficient implemented in SciPy. Confidence intervals for Kendall's tau were estimated using a moving-block bootstrap procedure implemented in Python, while spatial rainfall maps and climate-zone delineation were produced using QGIS 3.34.9-Prizren.

The coefficient of variation (CV) was calculated using Eq. (1):

$$\mathrm{CV}(\%) = \frac{\mathrm{SD}}{\mathrm{Mean}} \times 100, \tag{1}$$

where SD is the standard deviation and Mean is the arithmetic mean of the series, calculated separately for each climate zone (rainfall) and for each commodity (livestock production).

The linear trend was fitted using Eq. (2):

$$Y = a + bt + \varepsilon, \tag{2}$$

fitted by ordinary least squares, where Y is the seasonal rainfall or annual production value, t is year, b is the estimated trend (reported as mm yr^{-1} for rainfall and T yr^{-1} for livestock), and ε is the residual error. The OLS slope was used to quantify the magnitude of the linear trend, whereas statistical significance of monotonic trends was assessed using the modified Mann-Kendall (MMK) test which adjusts the variance of the Mann-Kendall statistic for serial autocorrelation. The variance of S was corrected for tied observations, and statistically significant autocorrelation in the detrended rank series was incorporated into the modified variance. The standardized Z statistic was then calculated from the modified variance and evaluated at the 95% confidence level ($|Z| \geq 1.96$).

Kendall's tau was used to quantify the rank-based association between the national seasonal rainfall series and each national livestock production series. The statistic was calculated with a tie-aware implementation so that tied observations are handled explicitly. This bivariate Kendall correlation is distinct from the one-sample Mann-Kendall trend test: Kendall's tau measures association between two series, whereas the modified Mann–Kendall Z-test is used separately to assess monotonic trend in a single series.

The national rainfall series and each livestock series contain 44 common annual observations (1979-2022). Raw-series Kendall's tau was retained as an overall descriptive association, but because both variables can contain secular trends, a detrended sensitivity analysis was also performed by removing the fitted linear temporal trend from each series before recalculating Kendall's tau.

Because six commodities were tested against the same rainfall series, a Bonferroni-adjusted threshold of $\alpha = 0.05/6 \approx 0.0083$ was used alongside the uncorrected p-values. This adjustment was applied to the raw-series Kendall associations and to the detrended sensitivity analysis.

5. Results and discussion

5.1. Status of livestock production in Nigeria

Figure 2 shows national production trends for the six selected livestock commodities from 1979 to 2022. Raw cattle milk recorded the highest mean national production (416,380.26 T), followed by cattle (310,030.20 T), chicken (198,098.94 T), goat (190,554.67 T), pig (173,396.78 T), and sheep (98,598.79 T). Pig production showed the strongest linear fit to time (R^2 = 0.981). Table 1 summarizes the statistics for each commodity; raw cattle milk, sheep, pig, goat, and chicken showed statistically significant positive trends based on the modified Mann-Kendall (MMK) Z-test, whereas cattle did not.

Residual lag-1 autocorrelation was positive in the national seasonal rainfall series (r_1 = 0.219) and in all six livestock production series (r_1 = 0.593-0.875). To account for this serial dependence in trend inference, the modified Mann-Kendall Z-test was applied to each annual series. The modified test retained significant positive trends for raw cattle milk, sheep, pig, goat, and chicken, while the cattle trend remained non-significant.

5.2. Seasonal rainfall variability and trend across Nigeria's climate zones

Figure 3 shows the climatology, variability, and trend of seasonal (May-October) rainfall from 1979 to 2022 across Nigeria's climate zones. Figure 3A (climatology) shows that the Sahel and parts of the Savanna, such as Bauchi, receive less than 800 mm of seasonal rainfall, the Savanna generally receives 800-1200 mm, and the Rainforest zone records the highest totals, frequently exceeding 1600 mm.

Figure 3B (standard deviation) shows substantial spatial variability in seasonal rainfall, with higher standard-deviation values in much of the Sahel and moderate values across the Savanna and Rainforest. Because Figure 3B represents the standard deviation of seasonal rainfall totals, its unit is millimetres (mm), not mm yr^{-1}.

Figure 3C shows predominantly increasing rainfall trends across parts of the Sahel, with statistically significant trends indicated at selected locations, while declining trends occur across parts of the Savanna and Rainforest; Figure 3D presents the spatial coefficient of variation (CV) of seasonal rainfall.

The spatial pattern in Figure 3C indicates increasing rainfall trends across parts of the Sahel and declining trends across parts of the Savanna and Rainforest. Given the spatial heterogeneity shown by the state-level map, these results are interpreted as regional patterns within the study period rather than as evidence of a uniform rainfall trend across each climatic zone.

5.3. Relationship between national seasonal rainfall and national livestock production

Because FAO livestock production statistics for Nigeria are reported only at the national scale, the correlation analysis in this study is restricted to the national level: national seasonal rainfall (averaged across all CRU grid cells within Nigeria's land boundary) against each commodity's national annual production series, 1979-2022 (44 observations). These national-level correlations are descriptive and should not be interpreted as zone-specific relationships.

Table 2 reports the raw-series national associations.

Table 3 presents the detrended sensitivity analysis.

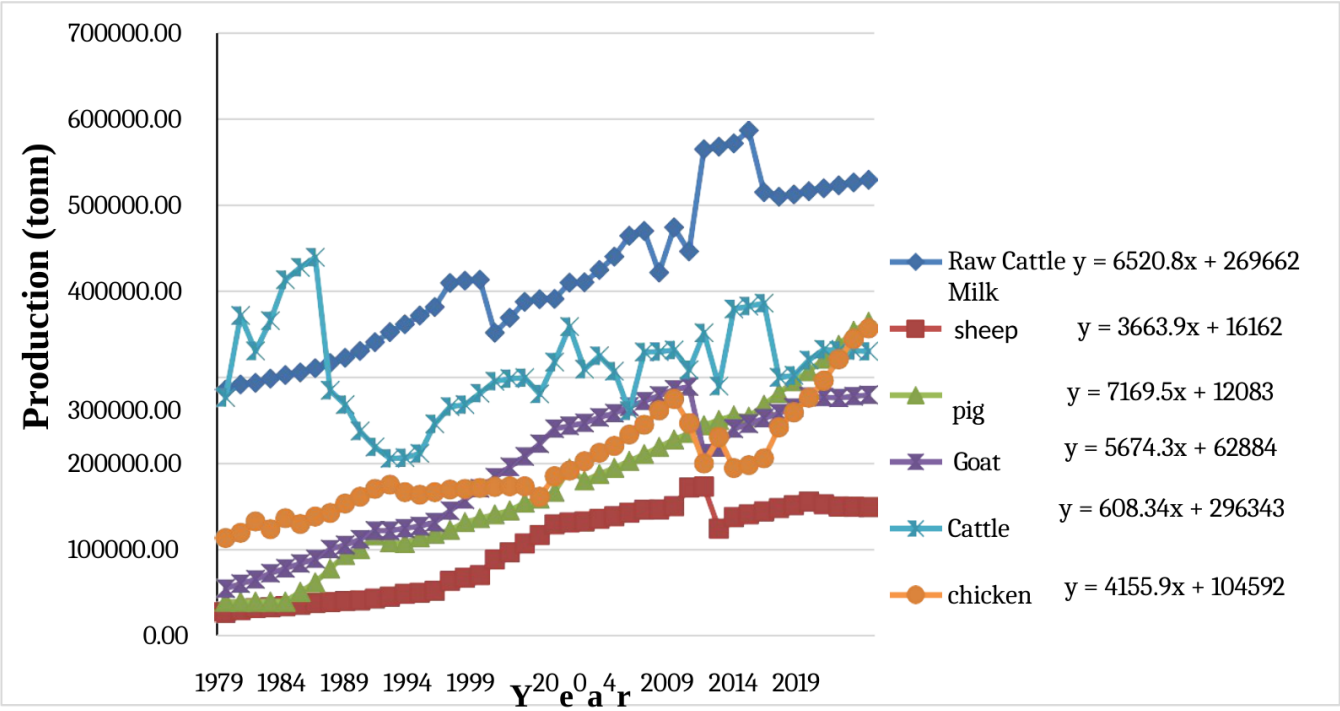


Figure 2: Nigeria livestock production (1979–2022).

Table 1: Statistical summary of selected livestock production from 1979 to 2022.

Livestock production	Mean (T)	Standard deviation (T)	CV (%)	Trend (T yr^{-1})	R^2
Raw cattle milk	416,380.26	89,017.43	21.38	6,520.8*	0.885
Sheep	98,598.79	50,250.76	50.96	3,663.9*	0.877
Pig	173,396.78	92,991.78	53.63	7,169.5*	0.981
Goat	190,554.67	77,901.35	40.88	5,674.3*	0.875
Cattle	310,030.20	55,607.21	17.94	608.34	0.020
Chicken	198,098.94	59,478.89	30.02	4,155.9*	0.806

* Indicates a statistically significant trend at the 95% confidence level based on the Hamed–Rao modified Mann–Kendall (MMK) Z-test.

Table 2: Kendall's tau correlation between national seasonal rainfall and national livestock production, 1979–2022.

Livestock commodity	Kendall's τ	p-value	95% bootstrap CI for τ	Significant at $\alpha = 0.0083$
Cattle	−0.256	0.014	−0.457 to 0.055	No
Sheep	+0.233	0.026	−0.082 to 0.484	No
Goat	+0.301	0.004	0.032 to 0.518	Yes
Raw cattle milk	+0.161	0.124	−0.252 to 0.444	No
Pig	+0.240	0.022	−0.110 to 0.481	No
Chicken	+0.269	0.010	−0.015 to 0.486	No

Goat retained a positive association after detrending, although the association did not meet the Bonferroni-adjusted significance threshold. The remaining positive raw-series associations weakened substantially after detrending, while cattle became more negative ($\tau = -0.345$, p = 0.001). These results indicate that secular temporal structure contributes materially to several of the raw-series associations and caution against interpreting the raw Kendall coefficients as interannual rainfall-driven effects.

Table 2 reports the raw-series Kendall's tau associations together with 95% moving-block bootstrap confidence intervals. Goat production shows the strongest positive raw-series association ($\tau = 0.301$, p = 0.004), but its bootstrap interval is relatively broad. The other raw-series confidence intervals include zero. Because the raw series contain strong secular trends, these associations should

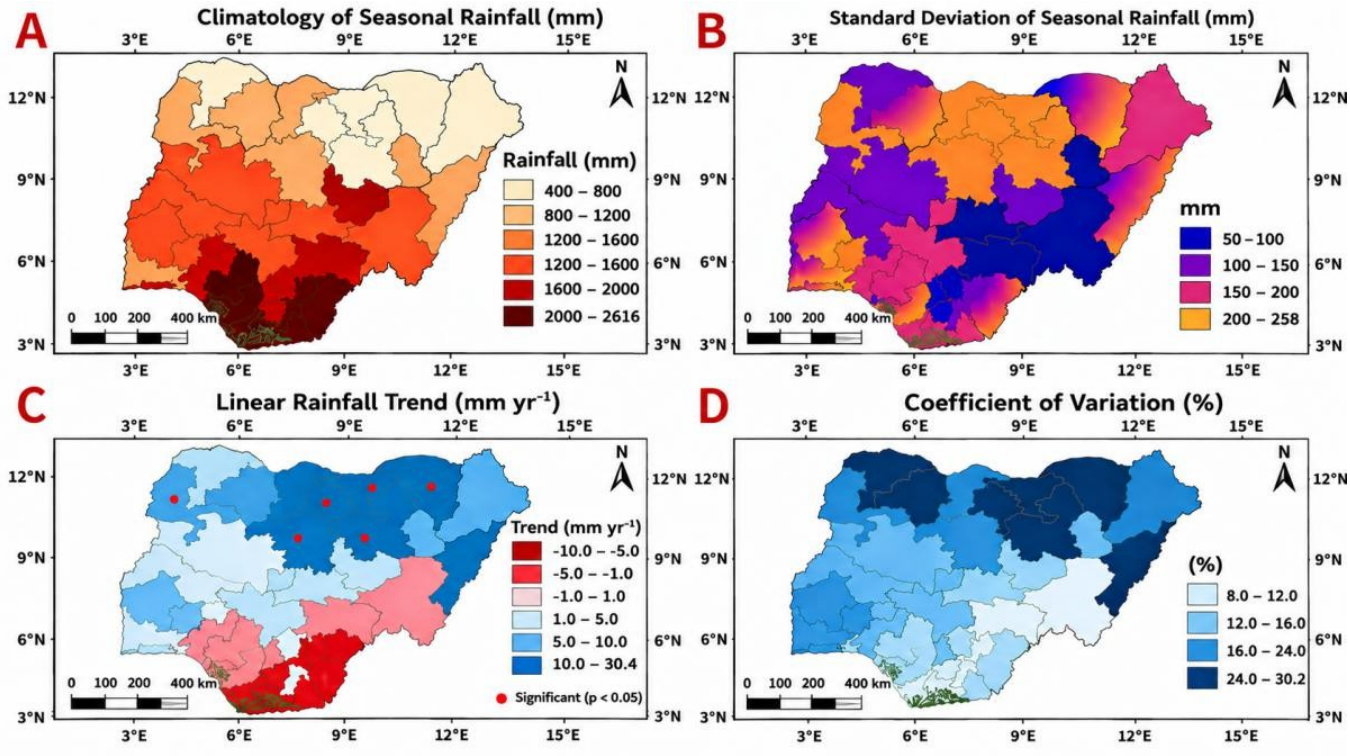


Figure 3: Trend and variability of seasonal rainfall across Nigeria's climate zones, 1979–2022: (A) climatology (mm), (B) standard deviation (mm), (C) linear trend (mm yr^{-1}), and (D) coefficient of variation (%).

Table 3: Detrended sensitivity analysis of national seasonal rainfall and national livestock production, 1979–2022.

Livestock commodity	Detrended Kendall's τ	p-value	95% bootstrap CI for τ	Significant at $\alpha = 0.0083$
Raw cattle milk	−0.175	0.093	−0.441 to 0.129	No
Sheep	+0.008	0.936	−0.194 to 0.203	No
Pig	−0.038	0.716	−0.206 to 0.171	No
Goat	+0.222	0.034	0.045 to 0.414	No
Cattle	−0.345	0.001	−0.508 to −0.114	Yes
Chicken	−0.036	0.731	−0.299 to 0.228	No

not be interpreted as direct interannual rainfall effects. In particular, the raw positive associations for sheep, pig, goat, and chicken are substantially weakened after detrending, while the negative association for cattle became stronger after detrending, changing from $\tau = -0.256$ in the raw series to $\tau = -0.345$ in the detrended analysis.

Table 4 summarizes the residual lag-1 autocorrelation and modified Mann-Kendall Z-test trend inference.

5.4. Limitations

This study's livestock correlation analysis (Section 5.3) is restricted to the national scale because FAOSTAT does not publish zone or state-disaggregated production statistics for Nigeria. Consequently, the results in Section 5.3 describe association at the national level only and cannot be used to infer how rainfall relates to livestock production within any individual climate zone or state. Readers should treat the zonal rainfall findings (Section 5.2) and the national livestock correlation findings (Section 5.3) as two separate lines of evidence rather than a single spatially resolved result.

The national livestock correlation analysis is also subject to omitted-variable bias: livestock output is jointly determined by market prices, herd demographics, veterinary service availability, feed imports, and farm management practices, none of which are controlled for here. In addition, serial dependence and common secular trends are present in the annual series. The moving-block bootstrap and detrended sensitivity analysis reduce, but do not eliminate, uncertainty associated with temporal dependence and shared time trends. The Kendall's tau correlations reported in Tables 2 and 3 should therefore be interpreted as descriptive, rank-based associations rather than evidence of a causal or dominant rainfall effect on production.

Table 4: Residual lag-1 autocorrelation and modified Mann–Kendall Z-test trend inference.

Series	Lag-1 residual autocorrelation (r_1)	Trend slope (unit/yr)	MMK Z (p-value)
National seasonal rainfall	0.219	2.20 mm yr^{-1}	2.215 (0.027)
Raw cattle milk	0.593	6,520.83 T yr^{-1}	6.566 (< 0.001)
Sheep	0.854	3,663.86 T yr^{-1}	4.819 (< 0.001)
Pig	0.836	7,169.52 T yr^{-1}	5.513 (< 0.001)
Goat	0.875	5,674.26 T yr^{-1}	4.238 (< 0.001)
Cattle	0.702	608.34 T yr^{-1}	1.602 (0.109)
Chicken	0.815	4,155.88 T yr^{-1}	6.969 (< 0.001)

Finally, this study is descriptive and diagnostic rather than predictive. It does not develop a forecasting or scenario-based model of future livestock production under projected rainfall change. Development of such a model, ideally using zone- or state-level livestock data if these become available, is identified as a priority for future research.

6. Conclusions

This study characterized seasonal (May-October) rainfall variability and trend across Nigeria's Sahel, Savanna, and Rainforest climate zones over 1979-2022, and separately examined the national-level statistical relationship between seasonal rainfall and national livestock production for six commodities. The rainfall maps show substantial spatial variability, with increasing trends at selected locations in the Sahel and declining trends across parts of the Savanna and Rainforest.

At the national scale, goat production had the largest positive raw-series Kendall association with seasonal rainfall (τ = 0.301, p = 0.004), but the association weakened after detrending (τ = 0.222, p = 0.034). Goat retained a positive association after detrending, although the association did not meet the Bonferroni-adjusted significance threshold. The other positive raw-series associations also weakened after detrending, illustrating the importance of accounting for shared temporal structure. Raw cattle milk recorded the highest mean national production, while pig production showed the strongest linear fit to time (R^2 = 0.981); all commodities except cattle had statistically significant positive linear trends using the modified Mann-Kendall Z-test.

The principal contribution of the study is therefore a scale-consistent description of Nigerian rainfall variability together with a cautious national-level assessment of rainfall-livestock association. Because the livestock data are national aggregates and the rainfall field is spatially heterogeneous, the correlation results should not be used to infer zone-specific livestock effects. Future work should combine spatially resolved livestock production data with the gridded rainfall series and explicitly model temporal dependence and other production drivers.

Data availability

The rainfall data used in this study were obtained from the Climatic Research Unit (CRU) Time-Series (TS) version 4.07 dataset, available through the UK Centre for Environmental Data Analysis (CEDA) at https://catalogue.ceda.ac.uk/uuid/5fda109ab71947b6b7724077bf7eb753. Livestock production data were obtained from the Food and Agriculture Organization of the United Nations (FAO) FAOSTAT Production domain (Crops and Livestock Products), available at https://www.fao.org/faostat/en/#data/QCL. Both datasets are publicly accessible. The data analysed in this study cover the period 1979-2022.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this manuscript.

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