

<https://doi.org/10.60787/johrms.vol1no3.95>

ONLINE ISSN: 3121-8806

Temporal Characteristics and Long-Term Trends of Harmattan Meteorological Variables in Gombe State, Northeastern Nigeria (1996–2025)

Jamilu, Dalibi Haruna, Department of Geography, Federal University of Kashere, Gombe State, Nigeria.

Email: jharunadalibi@yahoo.com

Abstract

The Harmattan season is a defining climatic phenomenon across northern Nigeria, influencing environmental quality, public health, transportation, and agricultural productivity. This study examined the temporal characteristics and long-term trends of Harmattan meteorological variables in Gombe State, Nigeria, using thirty years (1996–2025) of meteorological observations. We analysed five key variables, visibility, wind speed, relative humidity, maximum temperature, and minimum temperature, using descriptive statistics, seasonal analysis, and linear regression. Results revealed considerable interannual variability in all meteorological parameters. Mean visibility was 927.45 m, wind speed averaged 6.73 m s⁻¹, relative humidity averaged 21.81%, while mean maximum and minimum temperatures were 31.53°C and 16.69°C, respectively. Seasonal analysis indicated strengthening winds and declining humidity from November to February, with January representing the peak Harmattan period. Trend analysis showed increasing but statistically insignificant trends in visibility, wind speed, and temperatures ($p > 0.05$), whereas relative humidity exhibited a significant decreasing trend (slope = -0.31 ; $p = 0.0054$). The findings suggest that progressive atmospheric drying is the dominant long-term climatic signal affecting Harmattan conditions in Gombe State. At the same time, year-to-year variability continues to control dust transport and visibility. The study provides valuable evidence for climate adaptation planning and environmental management in the Sudano-Sahelian region.

Keywords: Harmattan, visibility, relative humidity, climate variability, Gombe State, dust transport, meteorology.

Introduction

The Harmattan is a distinctive seasonal meteorological phenomenon that dominates the climate of West Africa during the boreal winter, typically from November to February. It is characterized by dry, cool, and dust-laden north-easterly trade winds originating from the Sahara Desert. These winds transport large quantities of mineral dust across the Sahel and the Gulf of Guinea, producing marked reductions in atmospheric visibility, low relative humidity, substantial diurnal temperature variations, and deterioration in air quality. As one of the world's largest sources of atmospheric mineral dust, the Sahara Desert releases hundreds of millions of tonnes of dust annually, much of which is transported over West Africa before

dispersing across the Atlantic Ocean (Adebiyi et al., 2020; Engelstaedter et al., 2023). These dust outbreaks exert significant influences on regional weather, climate processes, environmental quality, ecosystem functioning, and human well-being.

Mineral dust is now recognized as an essential component of the Earth's climate system because of its interactions with atmospheric radiation, cloud microphysics, precipitation processes, and the global carbon and nutrient cycles. Atmospheric aerosols modify the Earth's radiation balance by scattering and absorbing incoming solar radiation, thereby influencing surface temperatures and regional circulation patterns. In West Africa, Harmattan dust plays an important role in regulating atmospheric stability, solar radiation reaching the Earth's surface, and cloud development, with consequent impacts on agriculture, hydrology, and ecosystem productivity (Kaskaoutis et al., 2022). Recent studies have further demonstrated that climatic variability, land degradation, vegetation dynamics, and changes in atmospheric circulation collectively influence the intensity and spatial distribution of Harmattan dust events across the Sahel (Knippertz & Todd, 2012).

Beyond its climatic significance, the Harmattan season has profound socio-economic and public health implications. Reduced visibility frequently disrupts road transportation and aviation operations, increasing the risk of accidents and travel delays. Fine particulate matter associated with Harmattan dust contributes to respiratory and cardiovascular diseases, particularly among children, the elderly, and individuals with pre-existing medical conditions. Previous studies have linked prolonged exposure to mineral dust with increased incidences of asthma, allergic reactions, bronchitis, conjunctivitis, and other respiratory illnesses throughout northern Nigeria and neighbouring Sahelian countries. Furthermore, the extremely low atmospheric humidity experienced during the Harmattan season enhances evapotranspiration, accelerates soil moisture depletion, and imposes additional stress on agricultural production systems that depend on limited dry-season water resources.

Northern Nigeria experiences some of the most intense Harmattan conditions in West Africa because of its proximity to the major Saharan dust source regions. Gombe State, situated within the Sudan Savanna ecological zone, experiences a well-defined Harmattan season characterized by persistent dust haze, reduced atmospheric moisture, moderate wind speeds, and pronounced diurnal temperature fluctuations. These meteorological conditions influence agriculture, water resources, transportation, energy demand, and public health within the state. Despite the socio-economic importance of Harmattan weather, relatively few long-term investigations have examined the temporal behaviour of key meteorological variables at the state level in northeastern Nigeria. Most previous studies have relied on regional dust transport, satellite-derived aerosol observations, or short-term climatic variability, with limited emphasis on long-term ground-based meteorological records that are essential for detecting local climatic trends.

Understanding long-term changes in Harmattan meteorological characteristics has become increasingly important under contemporary climate change. Although several studies suggest that dust emission and transport remain highly variable from year to year, recent evidence indicates progressive atmospheric warming and drying across much of the West African Sahel (Nicholson, 2021; Engelstaedter et al., 2023). These climatic changes may alter the frequency, intensity, and persistence of Harmattan dust events, with implications for environmental sustainability, ecosystem resilience, food security, transportation safety, and human health. Continuous assessment of long-term meteorological records therefore provides valuable information for evaluating climatic variability and supporting evidence-based adaptation and environmental management strategies.

The present study addresses this knowledge gap by analysing thirty years (1996–2025) of Harmattan meteorological observations in Gombe State, northeastern Nigeria. Specifically, the study

examines temporal variations in visibility, wind speed, relative humidity, maximum temperature, and minimum temperature during the Harmattan season using descriptive statistics, seasonal analysis, and linear regression techniques. By identifying long-term trends and seasonal characteristics of these key meteorological variables, the study contributes to a better understanding of the evolving nature of Harmattan conditions in the Sudan Savanna region. The findings provide important baseline information for climate monitoring, environmental planning, disaster risk reduction, public health preparedness, and sustainable development policies in northern Nigeria.

Materials and Methods

Study Area

The study was conducted in Gombe State, located in northeastern Nigeria within the Sudan Savanna ecological zone. Geographically, the state lies between approximately latitudes $9^{\circ}30'N$ and $12^{\circ}30'N$ and longitudes $8^{\circ}45'E$ and $11^{\circ}45'E$, occupying a land area of about 20,265 km² (Figure 1). Gombe State shares boundaries with Yobe State to the north, Borno and Adamawa States to the east, Taraba State to the south, and Bauchi State to the west. The state capital, Gombe, is located at approximately $10^{\circ}17'N$ and $11^{\circ}10'E$, where the Nigerian Meteorological Agency (NiMet) synoptic station used in this study is situated.

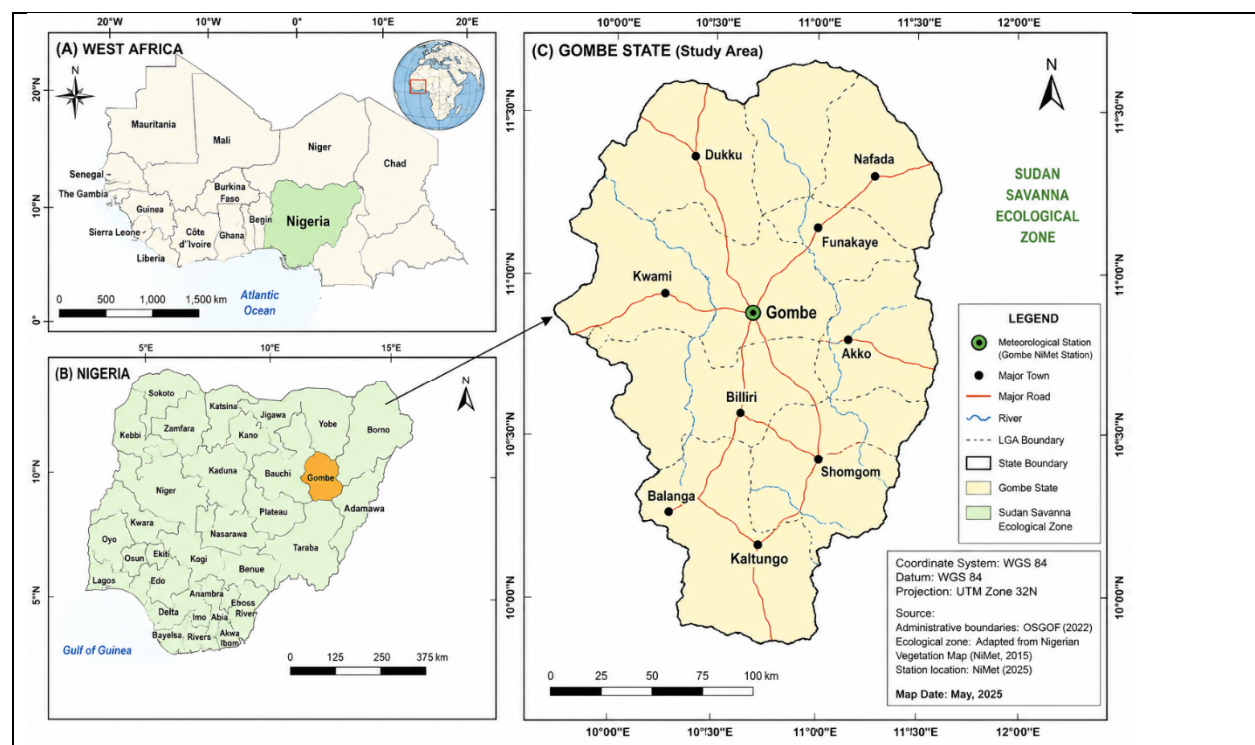


Figure 1: Study Area

Gombe State experiences a tropical savanna climate (Köppen Aw) characterized by two distinct seasons: a rainy season extending from May to October and a dry season from November to April. The Harmattan season occurs between November and February, when cool, dry, dust-laden north-easterly trade

winds originating from the Sahara Desert dominate the regional circulation. These winds are associated with reduced atmospheric visibility, low relative humidity, increased atmospheric aerosol loading, and marked diurnal temperature variations. Annual rainfall generally ranges between 850 and 1,200 mm, while mean annual temperatures vary from 25°C to 38°C, reflecting the semi-arid climatic conditions of northeastern Nigeria. (Benjamin et al., 2024)

The vegetation is predominantly Sudan Savanna, consisting of short grasses interspersed with drought-tolerant tree species such as *Acacia* spp., *Parkia biglobosa*, *Adansonia digitata*, and *Azadirachta indica*. However, extensive cultivation, grazing, fuelwood extraction, and urban expansion have considerably modified the natural vegetation cover. During the Harmattan season, sparse vegetation and exposed dry soils enhance wind erosion and facilitate the suspension and long-range transport of mineral dust, thereby contributing to persistent dust haze and poor air quality. These environmental conditions make the state particularly susceptible to the impacts of Harmattan dust events. (Habila et al., 2025)

The geographical location of Gombe State within the Sudano-Sahelian transition zone and its proximity to major Saharan dust source regions make it an ideal location for investigating the temporal variability and long-term trends of Harmattan meteorological characteristics. Long-term observations of visibility, wind speed, relative humidity, and temperature are essential for understanding regional climate variability and supporting climate adaptation, environmental management, and disaster-risk reduction strategies in northeastern Nigeria

Data Collection

The study utilized thirty years (1996–2025) of Harmattan meteorological data obtained from Gombe State meteorological records. The analysis focused on five key meteorological variables that characterize Harmattan conditions:

1. Visibility (m)
2. Wind speed (m s^{-1})
3. Relative humidity (%)
4. Maximum temperature (°C)
5. Minimum temperature (°C)

Only observations recorded during the Harmattan months (November–February) were extracted and used for the analysis to ensure that the results reflected the meteorological characteristics of the Harmattan season.

Data Analysis

The meteorological data were organized into annual and monthly datasets and analyzed using descriptive and inferential statistical techniques.

Descriptive Statistics

Descriptive statistics were computed to summarize the temporal characteristics of each meteorological variable over the study period. Mean, minimum, and maximum values were calculated to assess annual variability and identify the range of meteorological conditions experienced during the Harmattan season.

Seasonal Analysis

Seasonal variability was evaluated by computing monthly mean values for the Harmattan months (November, December, January, and February). This analysis enabled the identification of seasonal changes in visibility, wind speed, relative humidity, and temperature as the Harmattan progressed from onset to cessation. Line graphs were used to illustrate monthly patterns and facilitate comparison among the meteorological variables.

Trend Analysis

Linear regression analysis was employed to determine the direction and magnitude of long-term changes in the selected meteorological variables between 1996 and 2025. Regression slopes were used to indicate increasing or decreasing trends, while statistical significance was evaluated at the 95% confidence level ($p < 0.05$). A statistically significant positive slope indicated an increasing trend over time, whereas a significant negative slope indicated a decreasing trend.

Data Presentation

The analysed data were presented using tables, line graphs, and trend plots. Annual descriptive statistics were used to illustrate interannual variability, monthly averages were employed to describe seasonal characteristics, and regression plots were used to demonstrate long-term trends in the meteorological variables during the Harmattan season.

Results

Annual Variability of Harmattan Meteorological Variables

The annual descriptive statistics (Table 1) reveal substantial inter-annual variability in the meteorological characteristics of the Harmattan season in Gombe State between 1996 and 2025. Mean visibility was 927.45 m, with annual values ranging from 136.03 m to 2630.10 m, indicating considerable fluctuations in atmospheric clarity during the study period. Wind speed averaged 6.73 m s^{-1} , varying between 4.85 m s^{-1} and 8.20 m s^{-1} , reflecting the persistent influence of the north-easterly Harmattan winds. Relative humidity remained consistently low, averaging 21.81%, with values ranging from 12.00% to 46.00%. Maximum and minimum temperatures averaged 31.53°C and 16.69°C , respectively, while the mean diurnal temperature range was 14.84°C . Overall, the descriptive statistics indicate that declining atmospheric moisture represents the most consistent climatic feature of the Harmattan season, whereas visibility and wind speed exhibited marked year-to-year variability.

Table 1: Annual Descriptive Statistics of Harmattan Meteorological Variables in Gombe State (1996–2025)

Variable	Mean	Minimum	Maximum	Trend*
Visibility (m)	927.45	136.03	2630.10	Increasing
Wind Speed (m s^{-1})	6.73	4.85	8.20	Increasing
Relative Humidity (%)	21.81	12.00	46.00	Decreasing
Maximum Temperature ($^\circ\text{C}$)	31.53	28.50	34.50	Increasing
Minimum Temperature ($^\circ\text{C}$)	16.69	13.10	20.60	Increasing
Temperature Range ($^\circ\text{C}$)	14.84	10.50	19.70	Decreasing

Trend based on linear regression analysis.

Source: Computed from Gombe State Harmattan Meteorological Records (1996–2025).

Seasonal Characteristics of Harmattan Meteorological Variables

The seasonal analysis (Table 2 and Figure 2) demonstrated clear monthly variations in the selected meteorological variables during the Harmattan season. Visibility was lowest in November (618.26 m), increased markedly in December (936.96 m), remained relatively stable in January (932.36 m), and declined slightly in February (861.50 m). Wind speed increased progressively from 5.04 m s⁻¹ in November to 6.81 m s⁻¹ in February, indicating a gradual strengthening of the Harmattan circulation.

Relative humidity declined steadily throughout the season, decreasing from 29.03% in November to 20.17% in February, reflecting increasingly dry atmospheric conditions. Maximum temperature decreased from 34.23°C in November to 31.53°C in January before increasing to 34.33°C in February. Similarly, minimum temperature declined from 19.97°C in November to 16.63°C in January and subsequently increased to 19.53°C in February. These seasonal patterns indicate that January represents the period of strongest Harmattan influence, characterised by the lowest temperatures and persistently dry atmospheric conditions.

Table 2: Monthly Mean Meteorological Characteristics during the Harmattan Season in Gombe State (1996–2025)

Month	Visibility (m)	Wind Speed (m s ⁻¹)	Relative Humidity (%)	Maximum Temperature (°C)	Minimum Temperature (°C)
November	618.26	5.04	29.03	34.23	19.97
December	936.96	6.74	23.83	32.29	17.37
January	932.36	6.76	21.87	31.53	16.63
February	861.50	6.81	20.17	34.33	19.53

Source: Computed from Gombe State Harmattan Meteorological Records (1996–2025).

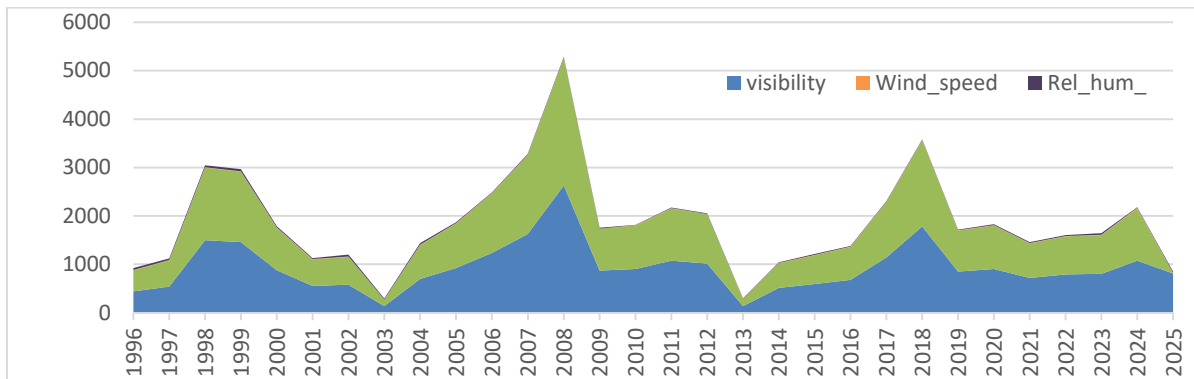


Figure 2: Monthly Variation of Visibility, Wind Speed and Relative Humidity during the Harmattan Season

Source: Computed from Gombe State Harmattan Meteorological Records (1996–2025).

Long-Term Trends in Harmattan Meteorological Variables

Linear regression analysis (Table 3) showed generally weak long-term trends in the meteorological variables over the 1996–2025 period. Visibility exhibited a slight increasing trend (slope = +0.03) but was not statistically significant ($p = 0.9583$). Wind speed also increased marginally (+0.01 m s⁻¹ year⁻¹), although the trend was similarly insignificant ($p = 0.4054$). Maximum and minimum temperatures displayed slight positive trends of +0.04°C year⁻¹ and +0.03°C year⁻¹, respectively, with both variables failing to attain statistical significance ($p > 0.05$).

In contrast, relative humidity exhibited a statistically significant decreasing trend (slope = -0.31; $p = 0.0054$), indicating a persistent decline in atmospheric moisture during the Harmattan season over the thirty-year study period. Among all variables investigated, relative humidity was the only parameter that demonstrated a significant long-term change, suggesting that progressive atmospheric drying constitutes the dominant climatic signal affecting Harmattan conditions in Gombe State.

Table 3: Long-Term Trends of Harmattan Meteorological Variables in Gombe State (1996–2025)

Variable	Trend	Slope	p-value
Visibility (m)	Increasing	+0.03	0.9583
Wind Speed (m s ⁻¹)	Increasing	+0.01	0.4054
Relative Humidity (%)	Decreasing	-0.31	0.0054*
Maximum Temperature (°C)	Increasing	+0.04	0.2813
Minimum Temperature (°C)	Increasing	+0.03	0.1845

Significant at $p < 0.05$.

Source: Computed from Gombe State Harmattan Meteorological Records (1996–2025).

Discussion

The present study provides new evidence on the temporal characteristics and long-term behavior of Harmattan meteorological variables in Gombe State over 30 years (1996–2025). The results demonstrate considerable inter-annual variability in visibility, wind speed, temperature, and relative humidity, indicating that Harmattan conditions are strongly influenced by short-term atmospheric processes operating at both regional and local scales. The substantial fluctuations observed in visibility are consistent with variations in Saharan dust emission, atmospheric circulation, vegetation cover, land surface characteristics, and antecedent moisture conditions, all of which regulate the transport and dispersion of mineral dust across the Sudano-Sahelian region.

Seasonal analysis revealed a progressive increase in wind speed from November to February, accompanied by a continuous decline in relative humidity. These patterns reflect the increasing dominance of dry continental air masses originating from the Sahara Desert as the Harmattan season progresses. However, despite the strengthening of Harmattan winds, visibility did not decline continuously throughout the season. Instead, atmospheric visibility improved after November before decreasing slightly in February,

suggesting that visibility is governed by the interaction of several meteorological and environmental processes rather than by wind speed alone. This observation confirms that dust transport is influenced not only by atmospheric circulation but also by factors such as land surface conditions, atmospheric stability, soil moisture, vegetation cover, and the availability of erodible materials.

The long-term trend analysis showed weak positive trends in visibility, wind speed, and air temperatures, although these changes were not statistically significant. In contrast, relative humidity exhibited a statistically significant decline throughout the study period, indicating progressively drier atmospheric conditions during the Harmattan season. This finding suggests that atmospheric drying represents the most pronounced climatic signal affecting Harmattan weather in Gombe State over the past three decades. Reduced atmospheric moisture enhances the suspension and persistence of mineral dust by limiting wet deposition processes and increasing atmospheric stability, thereby potentially intensifying the environmental and health impacts associated with Harmattan dust events.

The findings of this study are consistent with previous investigations conducted across the West African Sahel. Kaskaoutis et al. (2022) reported that inter-annual variability in atmospheric dust loading is primarily controlled by fluctuations in atmospheric circulation and dust source strength rather than by persistent long-term climatic trends. Similarly, Knippertz & Todd, (2012) concluded that seasonal variations in Harmattan dust transport are largely driven by regional meteorological conditions and moisture availability. Furthermore, Nicholson (2021) and Engelstaedter et al. (2023) observed that recent climatic changes across the Sahel are increasingly characterized by declining atmospheric moisture and gradual warming, while Harmattan wind circulation has remained relatively stable. The agreement between the present findings and these previous studies indicates that progressive atmospheric drying, rather than substantial changes in wind intensity, is emerging as the dominant feature of contemporary Harmattan climate variability in northern Nigeria.

Conclusion

This study assessed the temporal characteristics and long-term trends of Harmattan meteorological variables in Gombe State, northeastern Nigeria, using thirty years (1996–2025) of meteorological observations. The findings revealed substantial inter-annual variability in visibility, wind speed, temperature, and relative humidity, demonstrating that Harmattan conditions remain strongly influenced by short-term atmospheric processes. Seasonal analysis further showed progressive strengthening of Harmattan winds and declining atmospheric moisture from November to February, with January representing the period of strongest Harmattan influence.

Trend analysis indicated weak and statistically insignificant increases in visibility, wind speed, maximum temperature, and minimum temperature. In contrast, relative humidity exhibited a statistically significant declining trend, indicating progressively drier atmospheric conditions over the study period. These results suggest that atmospheric drying is the most pronounced long-term climatic signal affecting Harmattan conditions in Gombe State, whereas dust transport and atmospheric visibility continue to be governed largely by natural inter-annual variability.

The study provides important baseline information for understanding the evolving characteristics of the Harmattan season in the Sudan Savanna region of Nigeria. The findings have practical implications for climate monitoring, environmental management, public health, agriculture, and transportation, where Harmattan-related dust and atmospheric dryness continue to pose significant challenges. Continuous monitoring of Harmattan meteorological conditions, together with the integration of satellite observations

and atmospheric modelling, is recommended to improve the prediction of dust events and support evidence-based climate adaptation and environmental planning in northern Nigeria.

References

- Adebiyi, A. A., Kok, J. F., Stuut, J.-B. W., & Kahn, R. A. (2020). Climate controls on Saharan dust emission and transport to the tropical North Atlantic. *Nature Geoscience*, 13(8), 555–561. <https://doi.org/10.1038/s41561-020-0594-1>
- Engelstaedter, S., Washington, R., & Mahowald, N. (2023). Recent variability and climatic drivers of Saharan dust transport over West Africa. *Atmospheric Chemistry and Physics*, 23(4), 2475–2493. <https://doi.org/10.5194/acp-23-2475-2023>
- Kaskaoutis, D. G., Rashki, A., Houssos, E. E., Goto, D., Dumka, U. C., & Kosmopoulos, P. G. (2022). Atmospheric dust over the Sahara and West Africa: Sources, transport pathways, and environmental impacts. *Atmospheric Research*, 270, 106071. <https://doi.org/10.1016/j.atmosres.2022.106071>
- Knippertz, P., & Todd, M. C. (2012). Mineral dust aerosols over the Sahara: Meteorological controls on emission and transport and implications for modeling. *Reviews of Geophysics*, 50(1). <https://doi.org/10.1029/2011RG000362>
- Nicholson, S. E. (2021). *The climate of tropical Africa* (2nd ed.). Cambridge University Press. <https://doi.org/10.1017/9781108775392>
- Maina, B., Bulus, L., Kim, I., & Samuel, E. (2024). Assessment of the spatial distribution and socioeconomic impact of sachet water production in Gombe Metropolis, Nigeria. *Gombe Journal of Geography and Environmental Studies*, 4(2), 72–82.
- Habila, M. I., Dadan Garba, A., Daful, M. G., Helda, B. S., Lawal, N., Onwumere, G. B., Vincent, C. U., & Yabo, S. D. (2025). Spatial distribution of sachet water brands in Kaduna Metropolis, Kaduna State, Nigeria. *FUDMA Journal of Sciences*, 9(9), 180–183. <https://doi.org/10.33003/fjs-2025-0909-3690>