

Appraisal of the Effects of Weather on Millet Yield in Northern Part of Gombe State, Nigeria

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Research Article

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Abstract

This study appraised the effects of weather elements on millet yield in the northern part of Gombe State using a ten-year dataset (2013–2022) obtained from relevant agricultural and meteorological agencies. The data included annual millet yield (kg/ha), total annual rainfall (mm), and average annual temperature (°C). Descriptive statistics, correlation analysis, trend analysis, and multiple regression techniques were employed to examine the relationship between weather variables and millet productivity. Results showed that millet yield ranged from about 620 kg/ha to 1,180 kg/ha, with a mean yield of approximately 890 kg/ha, indicating considerable inter-annual variability. Rainfall fluctuated between less than 700 mm and over 1,100 mm annually, while average temperature ranged from 26.1°C to 28.4°C, reflecting gradual warming over the study period. Trend analysis revealed a general decline in millet yield at an average rate of about 2.1% per annum. Correlation analysis indicated a moderate negative relationship between rainfall and millet yield ($r = -0.413$), suggesting that excessive or poorly distributed rainfall reduced productivity. Temperature also showed a weak negative relationship with millet yield ($r \approx -0.28$), implying that increasing heat stress adversely affected crop performance. Multiple regression analysis confirmed that weather variables jointly explained about 48% of the variation in millet yield. The study concluded that climate variability significantly constrains millet production in the study area. It recommended climate-smart agricultural practices, improved seasonal climate information, and the adoption of climate-resilient millet varieties to enhance productivity and food security.

1. Introduction

Climatic parameters such as rainfall, sunshine duration, temperature, relative humidity, and wind are major factors influencing cereal crop production worldwide (Environmental Protection Agency, 2022; Food and Agriculture Organization, 2022). Variations in these climatic elements, including extreme weather events, irregular rainfall patterns, and increasing greenhouse gas emissions, pose serious threats to global food security (Conrow, 2022). The growing frequency and intensity of climate extremes have increased uncertainties in agricultural production systems, particularly in developing regions that depend heavily on rain-fed agriculture (Srivastava et al., 2021). Studies have shown that climate change has already contributed to significant reductions in global food production, with adverse effects reported across Europe, Southern Africa, and Australia, while mixed outcomes have been observed in parts of Asia and the Americas (Ray, 2019). In Africa, crop yields are projected to decline by up to 50% by 2050 if effective adaptation measures are not implemented (Elum, 2017).

Climate change continues to alter global ecosystems and environmental conditions through rising temperatures and changing rainfall characteristics (Arora, 2020). Beyond increases in temperature, climate change significantly affects rainfall distribution, intensity, and duration, thereby influencing the length of growing seasons and crop productivity. These effects are particularly important in West Africa, where the majority of the population depends on rain-fed agriculture for food and income. Understanding the impacts of climate variability on rainfall patterns and agricultural productivity in the region is therefore essential for sustainable food production and economic stability. Global Climate Models

(GCMs) developed under different greenhouse gas emission scenarios by the Intergovernmental Panel on Climate Change (IPCC, 2007b) provide important tools for assessing future climate trends and their likely impacts on agriculture.

Rising temperatures, especially in tropical regions, can expose crops to severe heat stress, resulting in reduced growth and lower yields (Gray, 2021). Most countries in sub-Saharan Africa are predominantly agrarian, with rural populations relying heavily on agriculture as their primary source of livelihood (Essien, 2017). However, agricultural systems in the region remain highly vulnerable to climate variability because farming activities depend largely on natural rainfall rather than irrigation facilities. As a result, sub-Saharan Africa is considered one of the region's most vulnerable to climate change impacts due to widespread poverty, weak adaptive capacity, and dependence on climate-sensitive sectors (Conrow, 2022).

Agriculture is one of the most weather-dependent human activities, and fluctuations in climate conditions directly influence agricultural productivity. These impacts are more severe in developing tropical countries where poverty, inadequate infrastructure, and limited technological advancement increase vulnerability to climatic hazards (United Nations Development Programme [UNDP], 2004). In West Africa, rain-fed agriculture remains the dominant farming system, while effective mechanisms for mitigating climate-related risks are often lacking. Consequently, changes in rainfall patterns and temperature regimes have serious implications for food production, household income, and rural livelihoods.

In Nigeria, agriculture remains a critical sector of the economy, employing about 70% of the population at subsistence level despite the country's heavy reliance on oil revenues (Adhvaryu et al., 2019). Cereal crops constitute staple foods for many households in northern Nigeria, where millet is widely cultivated because of its adaptability to semi-arid conditions (Haruna & Tasi'u, 2017). However, agricultural productivity in the region is increasingly threatened by climate variability, including rising temperatures, erratic rainfall, floods, and droughts. These climatic challenges expose rural farmers to production and financial risks, thereby undermining food security and economic stability (Molden et al., 2020).

Furthermore, climate-related risks such as water shortages, flooding, heat waves, and the spread of vector-borne diseases continue to intensify across Africa (Ugochukwu et al., 2019). Therefore, understanding the relationship between weather elements and millet yield is essential for developing appropriate adaptation strategies aimed at improving agricultural productivity and enhancing food security in northern Gombe State. The aim of this study is to appraise the effects of weather on millet yield in the northern part of Gombe State, with a view to establishing a suitability index for profitable millet farming in the area. The specific objectives of the study are to: Examine the demographic characteristics of millet farmers in the study area, assess the prevailing weather conditions in the northern part of Gombe State, compare the prevailing weather characteristics with the climatic requirements for millet production and determine the effects of weather variables on millet yield in the study area.

2. Study Area and Methodology

The study was conducted in the northern part of Gombe State, located in northeastern Nigeria. The study area covers four Local Government Areas (LGAs): Dukku, Nafada, Kwami, and Funakaye. Geographically, Gombe State lies between latitudes 9°30'N and 12°30'N and longitudes 10°30'E and 11°45'E. The northern part of the state shares boundaries with Yobe State to the north and Borno State to the northeast.

The area is situated within the Sudan Savanna ecological zone, which is characterized by semi-arid climatic conditions suitable for dryland farming. Millet cultivation is widely practiced in the region because of the crop's adaptability to low rainfall conditions and relatively poor soils. The strategic location and environmental characteristics of northern Gombe State make it suitable for investigating the effects of weather variability on millet production.

Source: GIS Unit, Department of Geography and Environmental Management, GSU (2024).

Figure 1 Study area map showing the four selected Local Government Areas in northern Gombe State, Nigeria. Source: GIS Unit, Department of Geography and Environmental Management, Gombe State University (2024).

2.1 Climate, Rainfall, and Temperature

Northern Gombe State experiences a tropical continental climate characterized by distinct wet and dry seasons. The rainy season typically begins in May and ends in September, while the dry season extends from October to April. The Harmattan period, marked by dry and dusty northeastern winds, usually occurs between December and February (NiMet, 2022).

Annual rainfall ranges between 600 mm and 900 mm, decreasing northward and exhibiting considerable inter-annual variability (Nicholson, 2013). Rainfall distribution is often erratic, with delayed onset and early cessation of rains, thereby posing significant challenges to rain-fed agriculture. Such irregularities influence planting dates, crop establishment, and ultimately millet yield.

Temperature remains generally high throughout the year, with mean daily temperatures ranging from 26°C to 34°C. Peak temperatures exceeding 38°C are commonly recorded during the hot dry months of March and April (Abdullahi et al., 2020). Elevated temperatures increase evapotranspiration rates and soil moisture stress, thereby reducing millet productivity, particularly during critical growth stages (Azare et al., 2020; IPCC, 2021).

2.2 Relief and Drainage

The relief of northern Gombe State is predominantly low-lying and gently undulating, with elevations ranging between 300 and 600 meters above sea level. The terrain consists mainly of plains and shallow

valleys that support agricultural activities. However, the gentle slopes encourage surface runoff during intense rainfall events, contributing to soil erosion and nutrient depletion.

Drainage in the study area is largely seasonal and forms part of the Gongola River Basin. The area is characterized by ephemeral streams and tributaries, many of which dry up during the dry season. This seasonal nature of drainage limits irrigation opportunities and increases dependence on rainfall for agricultural production (FAO, 2022; Molden et al., 2020). Inadequate drainage infrastructure further heightens the vulnerability of farming systems to climate variability.

2.3 Soil Characteristics and Vegetation

The soils of northern Gombe State are predominantly sandy loam to loamy sand, derived mainly from sedimentary parent materials. These soils are generally low in organic matter and essential nutrients such as nitrogen and phosphorus, resulting in low natural fertility (Ali & Olayinka, 2020). Their light texture also makes them highly susceptible to erosion by wind and water.

Despite these limitations, the soils are moderately suitable for millet cultivation because of their friability and ease of tillage. However, continuous cultivation, bush burning, and overgrazing have contributed to soil degradation and declining productivity. The interaction between poor soil fertility and climatic stress constitutes a major constraint to millet production in the study area (FAO, 2021; Bello et al., 2018).

The study area falls within the Sudan Savanna vegetation zone, characterized by short grasses and scattered drought-resistant tree species such as *Acacia spp.*, *Parkia biglobosa*, and *Balanites aegyptiaca* (Aliyu et al., 2019). Vegetation density varies seasonally, becoming more pronounced during the rainy season and sparse during the dry season.

Human activities, including agricultural expansion, fuelwood extraction, and overgrazing, have significantly degraded vegetation cover in the area. This degradation exposes soils to wind erosion, accelerates moisture loss, and intensifies the adverse effects of climate variability on millet cultivation (Abdu et al., 2020).

2.4 Agriculture

Agriculture is the dominant economic activity in northern Gombe State, with the majority of the population engaged in subsistence farming. Farming activities are predominantly rain-fed, and major crops cultivated include millet, sorghum, maize, cowpea, and groundnut. Millet remains the most widely cultivated cereal because of its drought tolerance and adaptability to semi-arid conditions (GSADP, 2011).

Agricultural productivity in the area is constrained by erratic rainfall, rising temperatures, declining soil fertility, and limited access to improved farm inputs and extension services. These challenges contribute to fluctuating millet yields and increased food insecurity among rural households (Azare et al., 2020; Jalloh et al., 2019).

2.5 Population Characteristics

Northern Gombe State is predominantly rural, with settlements consisting mainly of dispersed villages and small towns. The majority of the population depends on agriculture as the primary source of livelihood. Rapid population growth has intensified pressure on available land resources, leading to land fragmentation and shortened fallow periods (Umar et al., 2021).

The population structure is largely youthful, providing labor for agricultural activities. However, high poverty levels and low literacy rates limit the adoption of improved farming technologies and climate-smart agricultural practices (Adamu et al., 2017).

2.6 Economic Activities

The economy of northern Gombe State is predominantly agrarian and supported by crop farming, livestock rearing, petty trading, and small-scale agro-processing activities. Livestock production, particularly cattle, sheep, and goats, complements crop farming and serves as an important coping mechanism during periods of crop failure.

Despite the economic significance of agriculture, the sector remains highly vulnerable to climate variability. Poor infrastructure, limited access to credit facilities, and weak market linkages further constrain economic development in the area. Consequently, fluctuations in weather conditions directly affect household income, food availability, and rural livelihoods (FAO, 2021; Essien, 2017).

3.0 Methodology

This study adopted a quantitative research design to examine the effects of weather variables on millet yield in northern Gombe State. The design was considered appropriate because it enables statistical analysis of relationships between climatic variables and crop productivity using correlation and regression techniques. The study utilized both primary and secondary data collected from agricultural and meteorological sources covering the period 2013–2022.

3.1 Reconnaissance Survey

A reconnaissance survey was conducted to obtain preliminary information on the effects of weather elements on millet production in the study area. The survey involved visits to selected millet-producing communities within Dukku, Kwami, Nafada, and Funakaye LGAs.

The exercise focused on:

Observing the growth stages of millet crops, identifying evidence of weather-related stress such as drought and flooding, interacting with local farmers to understand their perceptions of weather variability and its effects on millet yield, and obtaining preliminary information on rainfall and temperature records from meteorological stations.

3.2 Types of Data

The study utilized the following categories of data:

1. Socio-economic and demographic characteristics of respondents, including gender, age, and farm size/location.
2. Weather data for northern Gombe State, including:
 - Average annual temperature obtained from the Dadinkowa Meteorological Station;
 - Annual rainfall records covering the period 2013–2022.
1. Millet production data obtained from the Gombe State Ministry of Agriculture for the period 2013–2022.
2. Historical millet yield data (kg/hectare) used to examine the effects of weather variables on millet productivity.

3.2.1 Sources of Data

Both primary and secondary data sources were utilized in this study.

3.2.2 Primary Data

Primary data were collected through field surveys, direct observations, structured questionnaires, interviews, and focus group discussions with millet farmers across the study area. These instruments provided information on farmers' perceptions of weather patterns, planting periods, yield trends, and challenges affecting millet production.

3.2.3 Secondary Data

Secondary data included historical records of rainfall and temperature obtained from the Nigerian Meteorological Agency (NiMet), Dadinkowa Station, as well as millet yield data collected from the Gombe State Ministry of Agriculture and agricultural extension offices covering the period 2013–2022.

3.3 Method of Data Collection

Questionnaires were administered to respondents through face-to-face interaction to ensure clarity and a high response rate. Respondents completed and returned the questionnaires immediately after administration. This approach enhanced the reliability and completeness of the data collected.

The questionnaire titled *“Appraisal of the Effects of Weather on Millet Yield in Northern Part of Gombe State, Nigeria”* was designed to obtain relevant information relating to farming practices, weather variability, and millet production. Additional data were collected from meteorological agencies, agricultural extension services, and relevant government institutions.

3.3.1 Data Collection Instruments

The following instruments were used for data collection:

- **Questionnaire:** Structured questionnaires were used to collect quantitative data on farming practices, crop yield, and farmers' perceptions of weather effects.
- **Interview Guide:** Interview schedules were used to obtain qualitative information from agricultural officers, extension workers, and experienced farmers.
- **Climate Data Sheets:** Standardized forms were used to compile meteorological data on rainfall and temperature.

3.3.2 Population of the Study

The study population consisted of millet farmers residing and actively engaged in farming within the four selected LGAs of northern Gombe State: Dukku, Kwami, Nafada, and Funakaye. These farmers constituted the target population for assessing the effects of weather variability on millet yield.

3.3.3 Sample Size and Sampling Technique

A purposive sampling technique was adopted to select the study area and relevant respondents based on their involvement in millet production. Historical datasets covering multiple years were also purposively selected to facilitate trend analysis.

The sample size was determined using Yamane's (1967) formula:

$$N$$

$$1 + N(e)$$

N= Total Population

e= Error margin (in this case 5%)

1 = constant

Where:

- n = Sample size
- N = Total population
- e = Margin of error (0.05)

The total target population was 6,679 millet farmers across the four LGAs. Based on the formula, a sample size of 378 respondents was considered adequate for the study. The distribution of the target population and respondents across the four selected LGAs is presented in Table 1.

Table 1
Sample size distribution across the selected Local
Government Areas

Zone	LGAs	Population	Respondents
Gombe North	Kwami	2,122	120
	Funakaye	2,005	113
	Dukku	1,551	88
	Nafada	1,001	57
Total		6,679	378

Source: Field Survey (2025).

3.4 Method of Data Analysis

Both descriptive and inferential statistical techniques were employed in analyzing the data. Statistical analyses were carried out using SPSS and Microsoft Excel. The analytical techniques used for each objective are summarized as follows:

1. **Socio-economic Characteristics of Respondents:** Frequencies and percentages were used to analyze demographic and socio-economic variables. Results were presented using tables.
2. **Evaluation of Existing Weather Elements:** Descriptive statistics were used to summarize rainfall and temperature patterns in the study area.
3. **Comparison of Weather Characteristics with Millet Requirements:** Percentages analysis was used to compare historical weather data with established climatic requirements for millet production.
4. **Effects of Weather Variables on Millet Yield:** percentage and tables analysis was employed to determine the extent to which rainfall and temperature influenced millet yield in northern Gombe State.

4. Results and Discussion

4.1 Demographic Characteristics of Respondents

The demographic characteristics of millet farmers in the study area provide important insights into the socio-economic conditions influencing agricultural production and adaptation to climate variability. The findings indicate that most respondents were within the active and productive age categories. Farmers aged 31–40 years constituted 24.5% of the respondents, while those aged 21–30 years accounted for 18%. Farmers aged 41 years and above represented the largest proportion, accounting for 46.5%, indicating the dominance of experienced and mature individuals in millet cultivation.

The gender distribution revealed that 78% of the respondents were male, while 22% were female. This indicates that millet farming in northern Gombe State is predominantly male-dominated, although female participation remains significant. The relatively high involvement of women reflects their important role in household food production and rural livelihoods.

The geographical distribution of respondents ensured balanced representation across the four selected Local Government Areas. Nafada accounted for 32% of respondents, while Dukku and Kwami each accounted for 25%, and Funakaye accounted for 28%.

Regarding millet varieties cultivated, Pearl Millet was the dominant variety grown by 61% of respondents because of its drought tolerance and adaptability to semi-arid conditions. Finger Millet accounted for 28.75%, while other varieties constituted 10.75%.

Farming experience varied considerably among respondents. About 36.5% of the farmers had between 11 and 20 years of farming experience, while 24.5% had between 1 and 10 years of experience. Farmers with over 30 years of experience constituted 18.25%, reflecting the presence of highly experienced farmers with substantial indigenous knowledge of millet production and climate adaptation practices. The demographic characteristics of the respondents are summarized in Table 2.

Table 2

Demographic characteristics of respondents

Variable	Percentage (%)
Age 21–30 years	18.0
Age 31–40 years	24.5
Age 41 years and above	46.5
Male	78.0
Female	22.0
Pearl Millet	61.0
Finger Millet	28.75
Farming Experience (11–20 years)	36.5

Source: Field Survey (2025).

The predominance of older farmers suggests the possibility of reduced youth participation in agriculture, which may affect the long-term sustainability of millet farming in the region. Similarly, the high proportion of experienced farmers indicates strong local knowledge systems that can support adaptation to changing weather conditions. These findings are consistent with studies by Adger et al. (2015) and Reardon et al. (2019), which emphasize the importance of farmers’ demographic characteristics in shaping climate adaptation and agricultural productivity.

4.2 Evaluation of Existing Weather Elements

Farmers identified temperature fluctuations (84.9%) and rainfall variability (79.1%) as the most frequently changing weather elements affecting millet production in the study area. Wind patterns (63.7%), drought occurrence (53.3%), and humidity changes (46.5%) were also identified as significant climatic concerns.

An overwhelming majority of respondents (92.4%) reported that temperatures have consistently increased over time, while 74.7% indicated that rainfall has decreased. These findings suggest that the study area is experiencing increasing climatic stress characterized by rising temperatures and declining rainfall. The weather elements identified by respondents are summarized in Table 3.

Most respondents (65.8%) indicated that extreme weather events such as droughts, storms, and flooding occur occasionally, while 28.2% reported frequent occurrences. Despite these climatic challenges, 56.1% of respondents still considered the overall weather conditions favorable for millet cultivation, while 34.5% described them as very favorable.

Weather Variable	Percentage (%)
Temperature fluctuations	84.9
Rainfall variability	79.1
Wind pattern changes	63.7
Drought occurrence	53.3
Increasing temperature	92.4
Decreasing rainfall	74.7
Occasional extreme weather events	65.8

Source: Field Survey (2025).

The findings indicate that climate variability is becoming increasingly pronounced in northern Gombe State. Rising temperatures and irregular rainfall patterns have serious implications for millet productivity because the crop depends largely on favorable moisture conditions during germination and grain filling stages. Similar observations were reported by Harris et al. (2020) and IPCC (2021), who noted increasing temperature and rainfall variability across sub-Saharan Africa.

4.3 Comparison of Weather Characteristics with Millet Requirements

The findings reveal that current weather conditions only partially align with the climatic requirements for optimal millet production. About 50.4% of respondents reported that temperature conditions perfectly

match millet requirements, while 33.4% indicated partial suitability. However, 22.5% believed that current temperature conditions do not adequately support millet production.

Similarly, 43.9% of respondents stated that rainfall conditions perfectly match millet requirements, while 37.3% reported partial alignment. However, 25.1% believed rainfall conditions were unsuitable for optimal millet growth. Humidity conditions were also considered inadequate by 30.8% of respondents.

Most respondents (66.1%) acknowledged that seasonal weather fluctuations significantly affect millet cultivation, while 76.2% identified rainfall as the most critical climatic factor influencing millet growth. Furthermore, 67.4% indicated that they adjust their farming practices in response to changing weather conditions. A comparison of prevailing weather conditions with farmers’ perceptions of millet requirements is presented in Table 4.

Table 4
Comparison of weather conditions with millet requirements

Variable	Percentage (%)
Temperature matches millet needs perfectly	50.4
Rainfall matches millet needs perfectly	43.9
Seasonal fluctuations significantly affect millet	66.1
Rainfall identified as most critical factor	76.2
Farmers adjusting practices due to weather	67.4

Source: Field Survey (2025).

These findings suggest that while the climatic conditions of northern Gombe State remain generally suitable for millet cultivation, increasing weather variability poses serious production risks. Rainfall variability, in particular, remains the most critical challenge affecting millet productivity. The findings support earlier studies by Lobell et al. (2011) and Sharma et al. (2021), which identified rainfall distribution and temperature variability as major determinants of cereal crop performance in semi-arid environments.

4.4 Effects of Weather Elements on Millet Yield

The findings show that 45.4% of respondents experienced improvements in millet yield over recent years, while 36% reported stable yields and 24.5% observed declining productivity. Changes in rainfall patterns were identified as the major factor influencing millet yield by 70.2% of respondents, followed by temperature variations (43.4%), pest and disease outbreaks (36%), and soil quality decline (30.8%).

Rainfall was identified as a critical determinant of millet productivity. About 60% of respondents stated that adequate rainfall improved millet yield, while 54.6% reported that insufficient rainfall reduced yield. Additionally, 43.4% indicated that excessive rainfall negatively affected production.

Temperature also had significant effects on millet productivity. About 68.4% of respondents stated that high temperatures reduced millet yield, while 21.4% indicated that low temperatures also affected production. Extreme weather events were experienced by 79.9% of respondents and were reported to significantly affect agricultural productivity. The reported effects of weather elements on millet yield are summarized in Table 5.

Table 5
Effects of weather elements on millet yield

Variable	Percentage (%)
Yield improved	45.4
Yield decreased	24.5
Rainfall changes affect yield	70.2
High temperatures reduce yield	68.4
Extreme weather affects yield	79.9

Source: Field Survey (2025).

The results confirm that weather variability has substantial effects on millet productivity in the study area. Rainfall variability emerged as the most important factor influencing crop performance because millet production depends heavily on moisture availability during critical growth stages. High temperatures also contribute to heat stress, accelerated evapotranspiration, and reduced grain development. These findings are consistent with studies by Sultan et al. (2019) and Lobell et al. (2011).

4.5 Coping Strategies and Future Planning

Farmers in the study area employ various adaptation strategies to mitigate the adverse effects of climate variability. The most common strategy was adjustment of planting dates, adopted by 60% of respondents. Other adaptation measures included the use of drought-resistant seeds (54.6%), changing millet varieties (43.4%), and irrigation practices (36%).

Weather forecasting also played an important role in decision-making, with 43.4% of respondents regularly using weather information for farming activities. However, 19.3% reported never using weather forecasts due to limited access and inadequate awareness.

Improved drought-resistant millet varieties were identified as the most important intervention by 76.2% of respondents, followed by improved irrigation facilities (54.6%) and climate-smart agricultural training (38.1%). Furthermore, 70.2% of respondents expressed willingness to adopt new farming technologies, while 79.9% desired additional support for climate adaptation strategies.

The findings indicate that farmers are increasingly aware of climate variability and are willing to adopt adaptive practices. However, limited access to weather information, irrigation facilities, and improved

agricultural technologies constrains their adaptive capacity. These findings align with the observations of FAO (2023) and Hansen et al. (2020) regarding the importance of climate-smart agriculture in enhancing resilience among smallholder farmers.

Conclusion

The study concludes that weather variability significantly influences millet yield in the northern part of Gombe State. Fluctuations in rainfall and rising temperatures were identified as major factors affecting millet productivity, with excessive rainfall and high temperature conditions contributing to reduced yield performance. Although millet remains relatively adaptable to semi-arid conditions, increasing climatic instability continues to threaten sustainable production and food security in the area. The study therefore emphasizes the need for climate-smart agricultural practices, improved weather forecasting, and the adoption of drought-resistant millet varieties to enhance resilience and improve millet productivity among farmers in the study area.

Declarations

Competing Interests:

The authors declare that they have no competing interests.

Ethics Approval:

The authors confirm that the study was conducted in accordance with applicable ethical principles and that informed participation was obtained from respondents.

Funding:

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Author Contribution

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Figures

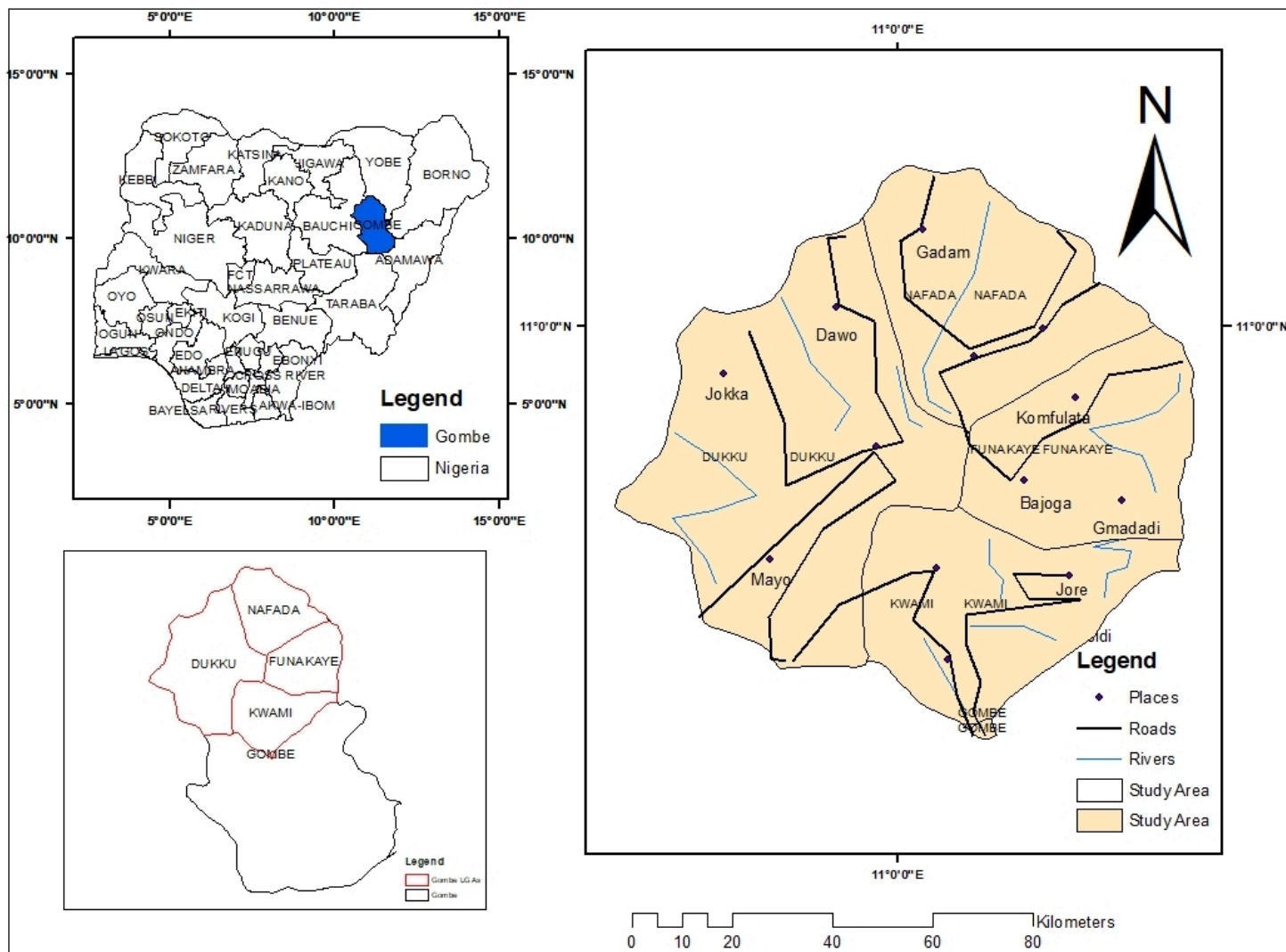


Figure 1

Source: GIS Unit, Department of Geography and Environmental Management, GSU (2024).

Fig. 1 Study area map showing the four selected Local Government Areas in northern Gombe State, Nigeria. Source: GIS Unit, Department of Geography and Environmental Management, Gombe State University (2024).