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Spatial Distribution and Variability of Selected Soil Chemical and Physical Properties in Zabarmari Floodplain of Jere Local Government Area, Borno State, Nigeria

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ABSTRACT

Understanding the spatial variability of soil properties is essential for sustainable land management, precision agriculture, and efficient utilization of agricultural inputs. This study assessed the spatial variability of selected soil chemical and physical properties in Zabarmari, Jere Local Government Area of Borno State, Nigeria. Thirty-one geo-referenced soil samples were collected from the 0-20 cm depth across cultivated fields in the study area. Laboratory analyses were conducted to determine soil pH, electrical conductivity (EC), organic carbon (OC), total nitrogen (TN), and particle size distribution. Descriptive statistics and Geographic Information System (GIS)-based interpolation techniques were employed to evaluate the spatial distribution of the measured properties. Soil pH ranged from 4.75 to 7.77, indicating strongly acidic to slightly alkaline conditions. Electrical conductivity varied between 0.12 and 2.26 dS m^{-1}, suggesting predominantly non-saline soils with localized salt accumulation. Organic carbon and total nitrogen ranged from 0.27-1.68% and 0.18-0.43%, respectively, indicating generally low fertility status. Particle size analysis revealed that clay content dominated the study area, ranging from 13.30 to 63.30%, while most soils were classified as clay, with a few locations identified as clay loam, silty clay, and sandy clay loam. Spatial distribution maps showed considerable heterogeneity in both chemical and physical properties across the landscape. The observed variability highlights the need for site-specific soil management practices, including balanced fertilizer application, organic matter incorporation, and appropriate irrigation management. The study demonstrates the usefulness of geospatial techniques in identifying soil fertility constraints and supporting sustainable agricultural production in the Sudan Savanna region of Nigeria.

Keywords: GIS, Spatial Variability, Soil Fertility, Soil Texture, Organic Carbon, Zabarmari

INTRODUCTION

Soil is a dynamic natural resource that provides the foundation for agricultural production and ecosystem sustainability. The capacity of soil to support plant growth depends largely on its physical, chemical, and biological properties, which often vary across landscapes due to differences in parent material, topography, climate, vegetation, and land management practices. Understanding the spatial variability of these properties is therefore essential for effective soil management, precision agriculture, and sustainable land-use planning (Mulla and McBratney, 2001).

Spatial variability refers to the variation in soil properties from one location to another within a field, farm, or landscape. Such variability influences nutrient availability, water retention, crop performance, and the effectiveness of management interventions. Traditionally, agricultural fields were treated as homogeneous units, with fertilizers and other inputs applied uniformly. However, research has shown that considerable differences in soil characteristics can occur over relatively short distances, making uniform management inefficient and often uneconomical (Cambardella et al., 1994; Onyechere et al., 2023).

The application of Geographic Information Systems (GIS) and geostatistical techniques has significantly improved the assessment and mapping of soil variability. These technologies enable the conversion of point-based soil observations into continuous spatial surfaces that can be used to identify management zones and guide site-specific interventions. Studies conducted in different parts of Nigeria have demonstrated the effectiveness of GIS-based approaches in evaluating soil fertility, monitoring degradation, and improving agricultural productivity (Onyechere et al., 2023).

In the Sudan Savanna region of northeastern Nigeria, agricultural production is frequently constrained by low soil fertility, erratic rainfall, nutrient depletion, and land degradation. Continuous cultivation, inadequate nutrient replenishment, and irrigation practices have contributed to increasing variability in soil properties, thereby affecting crop productivity and sustainability. Understanding the spatial distribution of key soil properties such as pH, electrical conductivity, organic carbon, total nitrogen, and soil texture is therefore critical for developing appropriate management strategies.

Zabarmari, located in Jere Local Government Area of Borno State, is an important agricultural community where farming serves as the primary livelihood of the inhabitants. Despite the importance of Zabarmari as a major agricultural production area within the Sudan Savanna region of northeastern Nigeria, information on the spatial distribution and variability of soil properties across its cultivated lands remains limited. Soil heterogeneity influences nutrient availability, water dynamics, crop productivity, and the efficiency of management practices. Consequently, the generation of reliable spatial information on soil chemical and physical properties is essential for developing site-specific soil management strategies, improving resource-use efficiency, and promoting sustainable agricultural production. This study therefore assessed the spatial variability and distribution of selected soil properties in Zabarmari using laboratory analyses and GIS-based spatial assessment techniques.

MATERIALS AND METHODS

Study Area

The study was conducted in Zabarmari, Jere Local Government Area of Borno State, Nigeria. The area lies between latitude 11°53'00"N and 11°54'30"N and longitude 13°08'00"E and 13°10'00"E within the Sudan Savanna ecological zone of northeastern Nigeria. The climate is characterized by a distinct wet and dry season, with annual rainfall ranging between 500 and 800 mm, occurring mainly from June to September. Mean annual temperatures range from 28°C to 35°C, with temperatures occasionally exceeding 40°C during the hot season. The soils are generally derived from alluvial and aeolian deposits and support the cultivation of maize, millet, rice, and vegetables. Agriculture remains the principal occupation of the inhabitants.

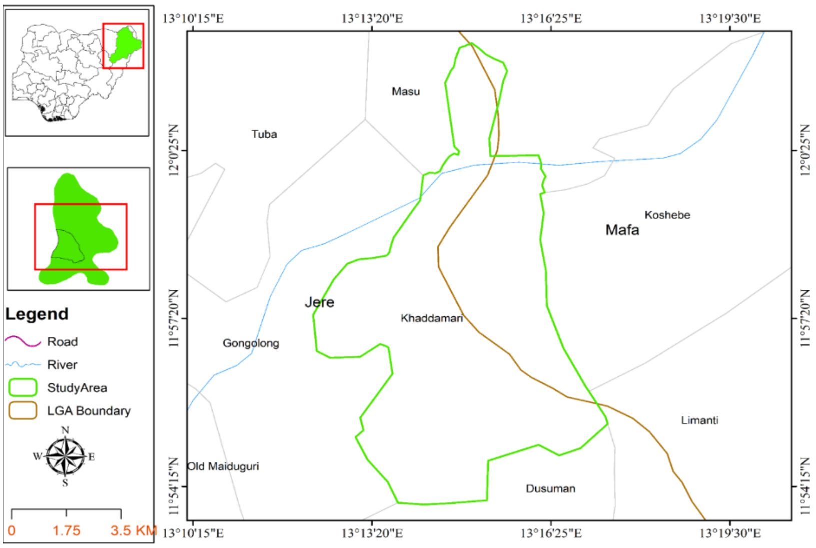

Figure 1: Location Map of the Study Area

Soil Sampling

Thirty-one (31) geo-referenced soil samples were collected from cultivated fields across Zabarmari to capture spatial variability within the study area. Sampling points were selected to represent variations in land use and field conditions. Soil samples were collected from the surface layer (0–20 cm) using a soil auger. Geographic coordinates of each sampling point were recorded using a Global Positioning System (GPS) receiver. Samples were air-dried, crushed gently, and passed through a 2-mm sieve prior to laboratory analysis.

Laboratory Analysis

Determination of Soil pH

Soil pH was determined using the glass electrode method in a soil-water suspension ratio of 1:2.5 following the procedure described by Thomas (1996). The pH values were measured using a calibrated digital pH meter.

Determination of Electrical Conductivity

Electrical conductivity (EC) was determined from a 1:2.5 soil-water extract using a conductivity meter following the method of Rhoades (1996). Results were expressed in dS m^{-1}.

Determination of Organic Carbon

Organic carbon was determined using the Walkley and Black wet oxidation method as described by Nelson and Sommers (1982). The procedure involved oxidation of organic matter using potassium dichromate and sulfuric acid, followed by titration of excess dichromate.

Determination of Total Nitrogen

Total nitrogen was determined using the Kjeldahl digestion method described by Bremner (1996). The method involved digestion, distillation, and titration procedures for estimating total nitrogen content in the soil samples.

Particle Size Analysis

Particle size distribution was determined using the hydrometer method according to Gee and Bauder (1986). The percentages of sand, silt, and clay were calculated and soil textural classes assigned using the USDA textural triangle.

Data Analysis

Descriptive statistical analyses were performed to evaluate the variability of selected soil properties. Statistical parameters including minimum, maximum, mean, standard deviation (SD), and coefficient of variation (CV) were computed using Microsoft Excel and SPSS version 25. The degree of variability was classified according to Wilding (1985), where CV values less than 15% indicate low variability, 15–35% indicate moderate variability, 35–50% indicate high variability, and values greater than 50% indicate very high variability. Spatial distribution maps of soil pH, electrical conductivity, organic carbon, total nitrogen, C:N ratio, clay, sand, and silt contents were generated using the Inverse Distance Weighting (IDW) interpolation technique in ArcGIS 10.8. The IDW method was selected because of its simplicity and effectiveness for interpolating soil properties from relatively small datasets.

RESULTS AND DISCUSSION

Spatial Variability of Selected Soil Chemical Properties

The results of selected soil chemical properties are presented in Table 1. Considerable spatial variability was observed among the measured parameters, indicating heterogeneous soil conditions across the study area.

Table 1: Spatial Variability of Soil Chemical and Physical Properties in Zabarmari

S/N	Latitude	Longitude	pH (1:2.5)	EC (dS/m)	TN (%)	OC (%)	C:N
1	11.92976	13.242001	5.45	0.44	0.18	0.60	3.33
2	11.929156	13.241967	5.43	0.42	0.24	0.86	3.58
3	11.929176	13.242001	5.11	0.23	0.28	1.05	3.75
4	11.927483	13.240919	5.29	0.46	0.31	1.17	3.77
5	11.929248	13.242121	5.05	0.23	0.25	0.98	3.92
6	11.926811	13.239378	4.94	0.50	0.24	0.84	3.50
7	11.925372	13.241280	5.05	0.28	0.29	1.11	3.83
8	11.925923	13.243670	5.26	0.48	0.35	1.37	3.91
9	11.918714	13.248263	6.30	0.33	0.20	0.68	3.40
10	11.915841	13.246217	5.71	0.53	0.25	0.94	3.76
11	11.87415	13.31520	5.13	0.54	0.32	1.19	3.72
12	11.924549	13.315192	5.63	0.47	0.36	1.37	3.81
13	11.9257	13.2509	5.90	1.48	0.43	1.68	3.91
14	11.927	13.262	4.92	0.59	0.36	1.58	3.39
15	11.9218	13.2636	4.98	0.56	0.43	1.66	3.86
16	11.9223	13.2671	5.24	0.51	0.29	0.64	3.31
17	11.9296	13.2669	5.62	0.35	0.20	0.62	3.10
18	11.9296	13.2687	7.25	0.12	0.20	0.62	3.10
19	11.9295	13.2688	5.27	0.22	0.21	0.76	3.62
20	11.9281	13.2699	5.70	0.39	0.20	0.74	3.70
21	11.9273	13.2716	5.90	0.23	0.24	0.78	3.25
22	11.9253	13.2715	4.78	0.27	0.27	0.96	3.56
23	11.9234	13.27	5.40	0.45	0.20	0.70	3.50
24	11.9222	13.2678	6.27	1.01	0.24	0.99	4.13
25	11.9207	13.265	6.10	0.22	0.21	0.74	3.52
26	11.9204	13.2631	4.75	2.26	0.35	1.35	3.86
27	11.9189	13.2617	5.01	0.54	0.34	1.17	3.44
28	11.9787	13.2579	5.07	0.47	0.28	1.05	3.75
29	11.92	13.2585	5.17	0.25	0.42	1.64	3.90
30	11.9215	13.2594	5.60	0.38	0.27	0.92	3.41
31	11.7441	13.3134	7.77	0.20	0.20	0.27	2.70

Table 2: Descriptive Statistics of Selected Soil Chemical Properties in Zabarmari

Property	Minimum	Maximum	Mean	SD	CV (%)	Variability Class
pH	4.75	7.77	5.52	0.68	12.25	Low
EC (dS m^{-1})	0.12	2.26	0.5	0.42	83.77	Very High
Total N (%)	0.18	0.43	0.28	0.07	26.29	Moderate
Organic Carbon (%)	0.27	1.68	1	0.35	35.34	High
C:N Ratio	2.7	4.13	3.59	0.3	8.48	Low

Variability Classification: CV < 15% = Low; 15–35% = Moderate; 35–50% = High; >50% = Very High (Wilding, 1985).

Soil pH

Soil pH ranged from 4.75 to 7.77, indicating considerable variability in soil reaction across the study area. The spatial distribution of soil pH (Figure 2) revealed that most parts of the study area were moderately acidic, while a few locations exhibited near-neutral to slightly alkaline conditions. The predominance of acidic conditions may be attributed to continuous cultivation, leaching of basic cations, decomposition of organic residues, and nutrient removal through crop harvest. Similar pH ranges have been reported in cultivated floodplain and savanna soils of Nigeria, where soil reaction is influenced by parent material, management practices, and hydrological conditions (Nkanga et al., 2023; Onyechere et al., 2023). The occurrence of near-neutral to slightly alkaline conditions at some locations may reflect localized accumulation of exchangeable bases and differences in irrigation water quality. Soil pH is a major determinant of nutrient availability and crop productivity because it affects phosphorus solubility, micronutrient availability, and microbial activity (Brady and Weil, 2017).

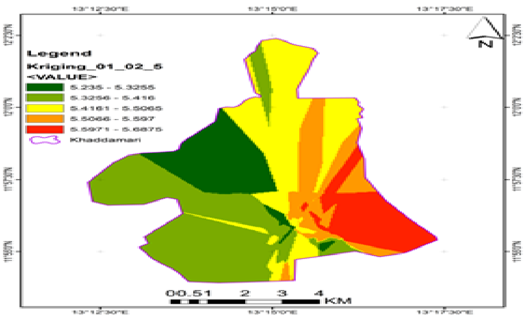

Figure 2: Spatial Distribution Map of Soil pH

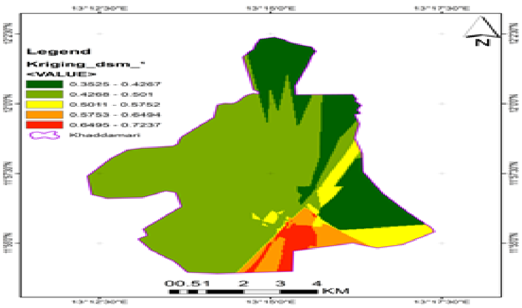

Figure 3: Spatial Distribution Map of Electrical Conductivity

Electrical Conductivity

Electrical conductivity exhibited substantial spatial variability, ranging from 0.12 to 2.26 dS m⁻¹. The spatial distribution map (Figure 3) showed that most sampling locations were within the non-saline range, although isolated areas recorded relatively higher EC values. These elevated values may be associated with irrigation-induced salt accumulation, restricted drainage conditions, and evapotranspiration effects commonly observed in semi-arid environments. Similar observations have been reported in irrigated agricultural lands where salinity distribution is often highly localized (Rhoades, 1996; Mwendwa et al., 2022). The high coefficient of variation recorded for EC further confirms the heterogeneous distribution of soluble salts within the landscape. Continuous monitoring of soil salinity is therefore necessary to sustain crop productivity and prevent long-term soil degradation.

Total Nitrogen

Total nitrogen content ranged from 0.18% to 0.43%, indicating generally low to moderate nitrogen status across the study area. The spatial distribution pattern presented in Figure 4 shows variations in nitrogen content among sampling locations, suggesting differences in nutrient management and organic matter accumulation across the landscape. The low nitrogen levels may be attributed to continuous cultivation, insufficient organic matter replenishment, rapid mineralization under high temperatures, and nutrient losses through leaching and volatilization. Similar findings have been reported for cultivated soils in the Sudan Savanna and other tropical agroecosystems where nitrogen deficiency remains a major limitation to crop production (Brady and Weil, 2017; Lal, 2020). These findings emphasize the need for integrated nutrient management strategies involving both organic and inorganic nutrient sources.

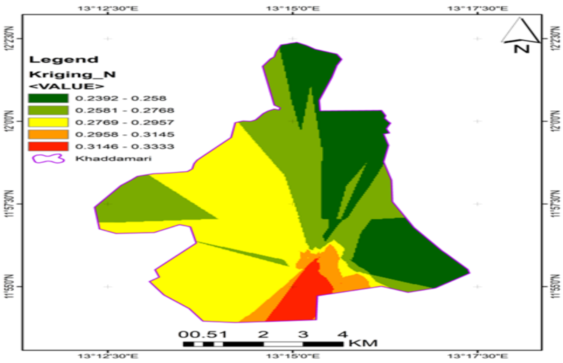

Figure 4: Spatial Distribution Map of Total Nitrogen

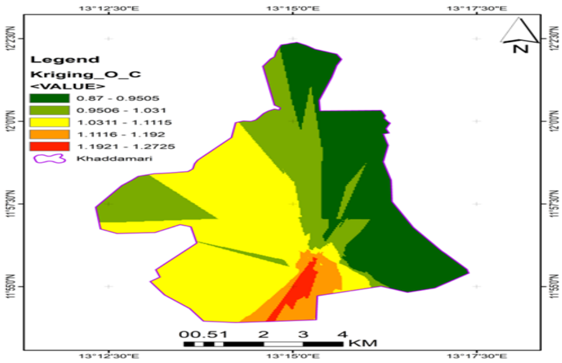

Figure 5: Spatial Distribution Map of Organic Carbon

Organic Carbon

Organic carbon content ranged from 0.27% to 1.68%, indicating considerable variability throughout the study area. The spatial distribution map (Figure 5) revealed distinct zones of low and relatively high organic carbon concentrations across the landscape. The generally low values reflect the effects of continuous cultivation, residue removal, low biomass return, and accelerated decomposition under the high-temperature conditions of the Sudan Savanna. Similar trends have been reported in cultivated tropical soils where organic matter depletion is associated with intensive land use and inadequate organic inputs (Lal, 2020; Nkanga et al., 2023). Variations in organic carbon among sampling locations may further be influenced by differences in sediment deposition, management practices, and crop residue incorporation. Since soil organic carbon plays a vital role in nutrient retention, aggregate stability, water-holding capacity, and microbial activity, its depletion may negatively affect long-term soil productivity (Brady and Weil, 2017; Lal, 2020).

Carbon-to-Nitrogen Ratio

The C:N ratio ranged from 2.70 to 4.13 and exhibited relatively low variability across the study area. The spatial distribution map (Figure 6) indicates a relatively uniform distribution of C:N ratio values throughout most parts of the study area. Such low values indicate rapid decomposition and mineralization of organic residues, which are characteristic of tropical and semi-arid environments where high temperatures promote microbial activity and organic matter turnover (Brady and Weil, 2017). The narrow range suggests relatively uniform decomposition processes despite variations in soil management practices. Although rapid mineralization may facilitate nutrient release in the short term, it may also contribute to declining organic matter reserves if not balanced with adequate organic inputs (Lal, 2020).

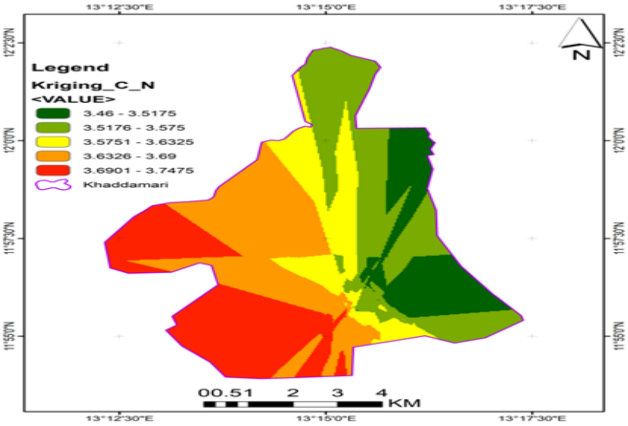

Figure 6: CN Ratio Map

Discussion of Chemical Properties

The observed variability in soil chemical properties indicates that soil fertility conditions are not uniform across Zabarmari. This spatial heterogeneity may be attributed to differences in depositional processes, land-use history, irrigation practices, organic matter management, cropping history, and micro-topographic variations across the floodplain landscape. Similar patterns of variability have been reported in agricultural soils of northern Nigeria and other semi-arid regions, where soil-forming factors and management practices strongly influence the distribution of soil fertility parameters (Nkanga et al., 2023). The predominance of floodplain deposits in the study area further contributes to soil variability through differential sediment deposition and redistribution processes (Buji et al., 2022). Floodplain soils are naturally heterogeneous, with their properties varying both horizontally across the landscape and vertically within soil profiles due to periodic flooding and sedimentation events (Mulla and McBratney, 2001; Brady and Weil, 2002).

The low organic carbon and total nitrogen contents recorded in most pedons suggest declining soil fertility resulting from continuous cultivation, rapid mineralization under tropical conditions, and inadequate replenishment of organic matter. Similar findings have been reported for irrigated and floodplain soils in the Sudan Savanna region of Nigeria, where intensive agricultural activities often lead to nutrient depletion and reduced soil organic matter levels (Odunze et al., 2006; Chude et al., 2011). Since soil organic matter serves as a major reservoir of plant nutrients, its depletion can adversely affect nutrient availability, soil structure, and overall productivity (Brady and Weil, 2002).

The high variability observed in electrical conductivity indicates localized accumulation of soluble salts, which may be influenced by irrigation water quality, drainage conditions, evapotranspiration rates, and seasonal fluctuations in groundwater levels. Such spatial variation in salinity is common in irrigated floodplain environments where water movement and salt redistribution are uneven (Rhoades et al., 1999). In contrast, the relatively low variability of soil pH suggests that soil reaction remains comparatively stable across much of the study area despite differences in management practices and landscape position. Similar observations have been reported in floodplain soils where buffering effects associated with parent materials and sediment deposition tend to moderate pH fluctuations (Foth and Ellis, 1997).

The observed heterogeneity in soil pH, electrical conductivity, organic carbon, and total nitrogen has important implications for soil fertility management. Uniform fertilizer recommendations may not adequately address field-specific nutrient requirements and could result in inefficient use of agricultural inputs, increased production costs, and potential environmental risks associated with nutrient losses. Therefore, site-specific nutrient management strategies based on spatial soil information should be promoted to improve fertilizer-use efficiency, enhance crop productivity, and support sustainable land management practices (Mulla and Schepers, 1997; Robert, 2002).

Descriptive Statistics and Variability Assessment of Chemical Properties

The descriptive statistics of selected soil chemical properties are presented in Table 2. The results revealed varying degrees of spatial variability among the measured parameters. Soil pH had a mean value of 5.52 and exhibited low variability (CV = 12.25%), indicating relatively uniform soil reaction across the study area. The predominance of moderately acidic conditions suggests that soil acidity may influence nutrient availability and crop performance.

Electrical conductivity recorded the highest coefficient of variation (83.77%), indicating very high spatial variability. This result suggests uneven distribution of soluble salts within the study area, likely influenced by irrigation practices, fertilizer application, drainage conditions, and landscape position. Similar observations have been reported in irrigated agricultural lands where salinity distribution is highly localized (Mwendwa et al., 2022).

Total nitrogen showed moderate variability (CV = 26.29%), while organic carbon exhibited high variability (CV = 35.34%). The observed differences may be attributed to variations in organic matter inputs, residue management, cropping history, and microbial activity across the study area. Organic carbon is widely recognized as a sensitive indicator of soil quality and management effects (Lal, 2020).

The C:N ratio exhibited low variability (CV = 8.48%), suggesting relatively consistent organic matter decomposition rates throughout the study area. According to the variability classification proposed by Wilding (1985), pH and C:N ratio showed low variability, total nitrogen exhibited moderate variability, organic carbon showed high variability, while electrical conductivity demonstrated very high variability. These findings confirm the heterogeneous nature of the soils and support the need for site-specific soil fertility management practices

Discussion of Physical Properties

Spatial Variability of some Soil Physical Properties

The particle size distribution results revealed substantial variability in soil texture across the study area (Table 3). Clay content ranged from 13.30% to 63.30%, sand from 2.80% to 57.80%, and silt from 6.40% to 53.90%. Most soils were classified as Clay, while a few locations were classified as Clay Loam, Silty Clay, and Sandy Clay Loam.

Table 3: Particle Size Distribution and Textural Classification of Soils in Zabarmari

S/N	Clay (%)	Sand (%)	Silt (%)	Textural Class
1	60.80	32.80	6.40	Clay
2	55.80	27.80	16.40	Clay
3	63.30	15.30	21.40	Clay
4	55.80	12.80	31.40	Clay
5	60.80	22.80	16.40	Clay
6	53.30	20.80	18.90	Clay
7	48.30	30.30	21.40	Clay
8	43.30	30.30	26.40	Clay
9	58.30	27.80	13.90	Clay
10	48.30	27.80	23.90	Clay
11	43.30	2.80	53.90	Silty Clay
12	45.80	22.80	31.40	Clay
13	28.30	57.80	13.90	Sandy Clay Loam
14	53.30	25.30	21.40	Clay
15	45.80	35.30	18.90	Clay
16	22.20	45.30	21.40	Sandy Clay Loam
17	30.80	37.80	31.40	Clay Loam
18	35.80	42.80	21.40	Clay Loam
19	33.30	52.80	13.90	Sandy Clay Loam
20	35.80	30.30	33.90	Clay Loam
21	35.80	35.30	28.90	Clay Loam
22	43.30	37.80	18.90	Clay
23	43.30	27.80	28.90	Clay
24	40.80	42.80	16.40	Clay
25	53.30	37.80	8.90	Clay
26	60.80	22.80	16.40	Clay
27	53.30	17.80	28.90	Clay
28	60.80	22.80	16.40	Clay
29	63.30	17.80	18.90	Clay
30	45.80	32.80	21.40	Clay
31	13.30	23.80	8.90	Sandy Clay Loam

Table 4: Descriptive Statistics of Selected Soil Physical Properties in Zabarmari

Property	Minimum (%)	Maximum (%)	Mean (%)	Standard Deviation	CV (%)	Variability Class
Clay	13.3	63.3	46.84	12.18	26	Moderate
Sand	2.8	57.8	29	12.26	42.28	High
Silt	6.4	53.9	22.39	10.31	46.05	High

Variability Classification: CV < 15% = Low; 15–35% = Moderate; 35–50% = High; >50% = Very High (Wilding, 1985)

The spatial distribution of clay content (Figure 7) showed that clay was the dominant particle-size fraction throughout most parts of the study area. Clay content ranged from 13.30% to 63.30%, indicating moderate variability. The predominance of clay-rich soils may be attributed to the depositional characteristics of the floodplain environment, where fine particles are transported and deposited during flooding events. Similar findings have been reported in floodplain soils of northern Nigeria (Buji et al., 2022). High clay content generally enhances nutrient retention and water-holding capacity but may also result in poor drainage and susceptibility to compaction under intensive cultivation (Brady and Weil, 2017). Similar observations have been reported in floodplain and irrigated soils of northern Nigeria where textural variability influences crop response and management requirements (Mwendwa et al., 2022; Khallah et al., 2025).

The spatial distribution map of sand content (Figure 8) revealed considerable variability across the study area. Sand content ranged from 2.80% to 57.80%, reflecting differences in depositional environments and sediment transport processes. Areas with higher sand content are likely to exhibit improved drainage and aeration but may also experience greater nutrient leaching and reduced water-holding capacity (Hillel, 2004). The high coefficient of variation recorded for sand confirms substantial spatial heterogeneity across the landscape.

The spatial distribution of silt content (Figure 9) showed substantial variability across the study area. Silt content ranged from 6.40% to 53.90%, indicating considerable differences in sediment deposition and redistribution processes within the floodplain environment. Areas with relatively high silt concentrations may possess improved moisture retention characteristics but may also be susceptible to surface crusting and structural instability under dry conditions (Hillel, 2004). Similar spatial variability in silt distribution has been reported in floodplain soils and alluvial landscapes of northern Nigeria (Khallah et al., 2025).

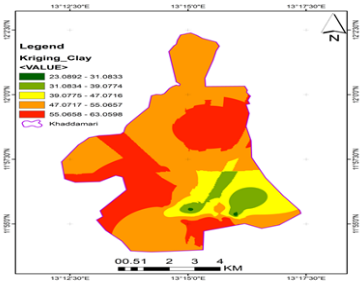

Figure 7: Clay Distribution Map

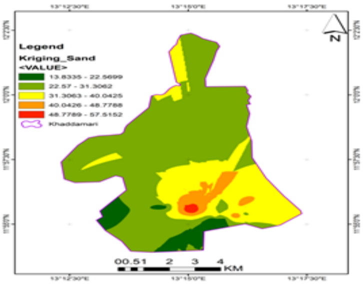

Figure 8: Sand Distribution Map

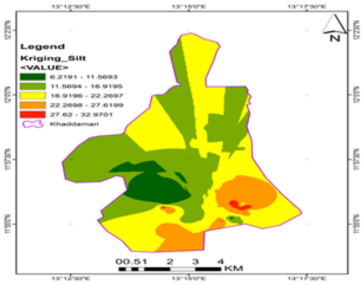

Figure 9: Silt Distribution Map

Descriptive Statistics and Variability Assessment of Soil Physical Properties

The descriptive statistics of the particle size fractions are presented in Table 4. Clay content ranged from 13.30% to 63.30%, with a mean value of 46.84%. The coefficient of variation (CV) of 26.00% indicates moderate spatial variability. The relatively high clay content across most sampling locations confirms the predominance of clayey soils within the study area. Clay particles play a significant role in nutrient retention, water-holding capacity, and cation exchange processes, making them important determinants of soil productivity (Brady and Weil, 2017).

Sand content varied from 2.80% to 57.80%, with a mean value of 29.00% and a CV of 42.28%, indicating high spatial variability. The observed variability reflects differences in depositional environments, sediment transport processes, and management history across the floodplain. Areas with higher sand content are likely to exhibit improved drainage and aeration but may be more susceptible to nutrient leaching and moisture loss (Hillel, 2004).

Silt content ranged from 6.40% to 53.90%, with a mean value of 22.39%. The coefficient of variation of 46.05% indicates high variability across the study area. Variations in silt distribution may influence soil structure, aggregate stability, and water retention characteristics. High silt concentrations in some locations may enhance moisture retention but may also increase susceptibility to surface crusting under dry conditions (Onyechere et al., 2023). Based on the classification proposed by Wilding (1985), clay exhibited moderate variability, whereas sand and silt showed high variability.

The observed variability in particle size distribution is consistent with the geomorphic characteristics of floodplain environments, where sediment deposition and redistribution occur continuously over time. Areas receiving finer sediments tend to develop clay-rich soils, whereas zones influenced by higher-energy depositional processes may contain greater proportions of sand and silt. Similar spatial patterns have been reported in floodplain soils of the Sokoto-Rima Basin and other alluvial landscapes of northern Nigeria.

The predominance of clayey soils across the study area has important implications for agricultural management. While clay soils generally possess greater nutrient retention and water-holding capacity, they may also be prone to poor drainage, temporary waterlogging, and compaction under intensive cultivation. Conversely, sandy clay loam and clay loam soils may provide improved aeration and drainage but often require additional nutrient and moisture management. These findings highlight the importance of texture-specific management strategies for optimizing crop productivity and improving the sustainability of irrigated agriculture in Zabarmari.

CONCLUSION

This study revealed significant spatial differences in selected soil chemical and physical properties across cultivated lands of Zabarmari, Jere Local Government Area, Borno State. The use of GIS-based interpolation techniques successfully identified zones of variation in soil pH, electrical conductivity, organic carbon, total nitrogen, clay, sand, and silt contents. The observed heterogeneity demonstrates that soil fertility conditions are not uniform throughout the study area and therefore require location-specific management interventions. Soil pH ranged from strongly acidic to slightly alkaline conditions, while electrical conductivity values indicated predominantly non-saline soils with isolated areas showing moderate salt accumulation. Organic carbon and total nitrogen contents were generally low, suggesting declining soil fertility and insufficient organic matter replenishment. The low carbon-to-nitrogen ratios further indicated rapid decomposition and mineralization of organic residues.

The physical properties showed that the soils were predominantly clayey, with a few locations classified as clay loam, silty clay, and sandy clay loam. The dominance of clay suggests favorable nutrient retention and water-holding capacity but also indicates potential limitations related to drainage, aeration, and soil compaction.

The spatial distribution maps generated through GIS demonstrated clear patterns of variability in soil properties across the landscape. These findings emphasize the importance of adopting site-specific soil management strategies rather than uniform management practices. The study further highlights the usefulness of geospatial technologies in evaluating soil resources and supporting precision agriculture within the Sudan Savanna agro-ecological zone of Nigeria. Based on the findings, fertilizer application should be guided by site-specific soil fertility status, while regular incorporation of organic amendments, conservation practices, liming of acidic areas, and proper irrigation management should be encouraged to improve soil productivity and sustainability. Government agencies and extension services should promote precision agriculture approaches based on soil variability information to enhance resource-use efficiency and agricultural productivity. A limitation of this study is that it was restricted to surface soil samples (0–20 cm depth) collected from 31 sampling locations; therefore, future studies should incorporate greater sampling intensity, deeper soil profile investigations, additional fertility parameters, and advanced geostatistical analyses such as semivariogram modelling and spatial dependence assessment to improve prediction accuracy and support more comprehensive soil management decisions.

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