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# MORPHOLOGICAL AND PHYSICAL CHARACTERIZATION OF ZAGGA SOILS A SEMI-ARID LANDSCAPE IN NORTHWESTERN NIGERIA

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**ABSTRACT**

Soils of the Zagga District display strong variability in physical and morphological characteristics, which affect drainage, aeration, and agricultural productivity. Understanding these variations is critical for identifying constraints and recommending sustainable management practices. Soil profiles (ZG6–ZG13) were described morphologically and analyzed for particle size distribution, bulk density, particle density, porosity, gravimetric moisture content, and silt/clay ratio. Descriptive statistics and Pearson correlations were used to evaluate variability and interrelationships among properties. The soil composition was predominantly sand, with an average content of 59.5%, followed by silt at 18.1% and clay at 17.7%. Bulk density averaged 1.78 g $cm^{-3}$, with over half of the profiles exceeding the 1.6 g $cm^{-3}$ threshold for root restriction. Porosity averaged 23.7%, well below the 40–60% considered optimal. Morphological observations confirmed poor drainage in ZG6, ZG7, ZG9, ZG10, and ZG11, while ZG12 and ZG13 were better drained but limited by low water retention. The soils present contrasting limitations, with some profiles prone to waterlogging and others to drought. Site-specific management is essential, including drainage improvements in poorly drained soils and organic matter addition, mulching, and irrigation scheduling in sandy profiles, to enhance productivity and sustainability.

**Keywords**: Soil morphology, Texture, Bulk density, Northwestern Nigeria, Pedology

## INTRODUCTION

Soil morphology and physical properties form the foundational basis for understanding soil behavior, functionality, and land use potential, particularly in diverse and fragile ecosystems. Soil morphology refers to the observable characteristics of soils in the field, including horizonation, color, structure, texture, consistency, and root distribution (Buol *et al.,* 2011; Schoeneberger *et al.,* 2012). These features are indicative of the pedogenic processes that shape soil development over time and offer crucial clues to both current and past soil-forming environments (Phillips, 2017).

The study of soil morphology enables the identification of diagnostic horizons such as epipedons and endopedons, which are essential for soil classification and the inference of land capability (Mansyur *et al.,* 2019). Moreover, morphological indicators can provide insights into environmental change, degradation, or improvement, especially when combined with quantitative metrics or stratigraphic sequences (Phillips & Marion, 2020).

Complementary to morphology, the assessment of physical properties such as texture, bulk density, particle density, porosity, and moisture content is critical for understanding water movement, root penetration, and structural stability in soils (Brady & Weil, 2016; Hillel, 2008). These properties influence not only plant growth and microbial activity but also the soil's capacity to withstand compaction and erosion—key concerns in land management.

Totsche *et al.* (2018) emphasize that soil physical properties, when viewed in conjunction with morphological features, help predict hydraulic behavior and storage dynamics. For instance, high bulk density coupled with massive structure may indicate compaction or poor root aeration, while sandy textures with single-grain structures often reflect low water retention capacity. Gravimetric moisture content, as another example, can vary significantly across profiles due to differences in porosity.

A holistic approach that integrates field-based morphological descriptions with laboratory-determined physical characteristics can thus enhance our understanding of soil function and suitability for agriculture, forestry, or conservation (Esu, 2010; White, 2006). Soil morphology and physical properties are central to understanding land potential, particularly in semi-arid regions where soil constraints often limit productivity (Brady & Weil, 2016).

This study seeks to combine these two dimensions—morphological observation and physical characterization—to evaluate the spatial variability and pedological significance of soils in the semi-arid landscapes of Zagga District of Kebbi State, Nigeria.

## MATERIALS AND METHODS

### Study Area

The study was carried out in Zagga District, Bagudo Local Government Area of Kebbi State (Figure1). The study site is located in the southwest of Zagga town along Dakingari-Koko Road in Bagudo LGA of Kebbi State (Figure 1). It has a longitudinal extent of $4^0$ 00ˋ - $4^0$11ˊ32’’ E and latitudinal stretch of $11^0$ 27ˊ 20’’-$11^0$ 35ˊ 30’’N, lying parallel to the main road. The study area encompasses 12,857ha. For the purpose of this study, a portion measuring 170ha was allocated for the present study.

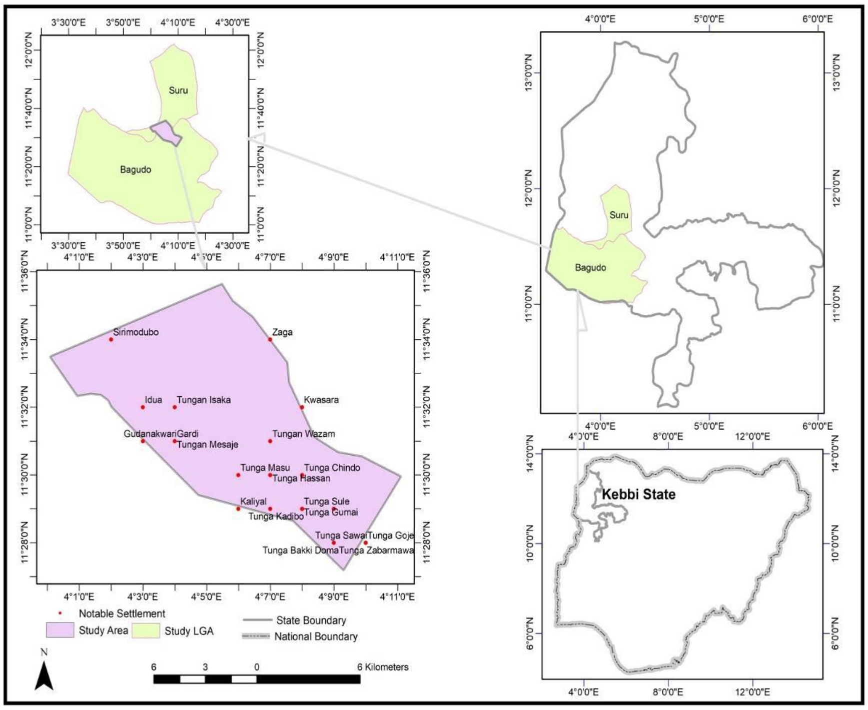


Figure 1: Map of Nigeria Showing the Study Area

Climate of Kebbi state is hot, semi-arid tropical (AW) in Koppen's classification (Wali *et al.,* 2016), characterized by a long dry season lasting between months of October and May with a short but intensive wet season between the months of May and October. Annual rainfall is variable and declining, being 600mm to 875mm and on average 650mm during the period 1997 to 2014 (Usman *et al.,* 2016)**.** Mean maximum temperature is about 45°C (highest in April to June) while mean minimum temperature is about 16°C (lowest in December and January) (Gada, 2014). The natural vegetation of the state consists of Northern Guinea Savannah in the south and south-east and Sudan Savannah in the north (Olayide *et al.,* 2023). Trees like *Adansonia digitata, Piliostigma reticulatum, Faidherbia albida* and *Tamarindus indica* dominate the area while shrubs like *Guiara senegalensis* abound. The geology of Kebbi State is dominated by two formations of the Precambrian Basement Complex in the south and south east and young sedimentary rocks in the north. The Basement Complex region is composed of very old volcanic and metamorphic rocks such as granites, schists, gneisses, quartzites and migmatites.

**Field Work**

A semi-detailed soil survey was conducted at a scale of 1:25,000 following procedures described by Kairis *et al.* (2020) to identify the different pedons. Pegging was carried out at intervals on a fixed grid pattern. Auger borings were also made to examine and describe the soils consistently at 250 meters interval along each traverse. Observations relating to morphological properties of the soils, physiographic position, topography, colour, textural differentiation were used to establish soil boundaries.

Morphological properties, including soil colour (using the Munsell Soil Colour Chart), texture and consistency, effective soil depth, surface stoniness, mottling, structure, cementation, rock fragments, and slope were all recorded in a soil profile description sheet. The profiles were then described according to FAO (2006) manual, while samples from each genetic horizon were collected for laboratory analyses.

Horizons were named using standard horizon nomenclature and their thickness were measured and recorded. Samples for bulk density were also collected with core sampler (5cm diameter) from the various genetic horizons. The samples were taken to the laboratory for processing and analyses.

To delineate the soils into mapping units, soil a combination of observable and measurable soil characteristics were used. They include soil texture, soil structure, soil colour (using soil colour chats), soil depth, soil drainage class, parent material, topography, rock fragment content and presence of diagnostic horizons.

A modal profile pit was excavated in each identified soil mapping unit to a depth of 2m (unless where water table or an impermeable layer is reached) and documented. Data on geographic coordinates and altitude were also recorded at each profile point.

**Laboratory Analyses**

Physical properties of the soils were determined using the following laboratory standard procedures:

***Particle Size Analysis***

Particle size distribution was determined using the principles of Boyoucous Hydrometer method (Gee & Or, 2002). Sand, silt and clay were determined by dispersing the soil samples in 5% Calgon (sodium hexametaphosphate) solution. The dispersed samples were shaken on a reciprocating shaker after which particle size distribution was determined with the aid of Bouyoucos hydrometer. Textural classes were extrapolated using the USDA textural triangle.

***Bulk Density (ρb)***

ρb was determined on the undisturbed core samples from each horizon using core samplers (metal rings). The samples were oven dried constantly at 105°C for 48 hrs. Mass of the oven dried soil was divided by total soil volume to obtain the bulk density **(**Blake, 1965**).**

$$\rho b = \frac{\text{Mass of oven dried soil}}{\text{Total soil Volume}}$$

Where:
ρb= Bulk density

***Particle Density (ρs)***
ρs was determined after the expulsion of entrapped air in soil using pycnometer method as described by Blake and Hartge (1986).

***Total porosity (TP)***
TP was derived from the relationship between particle density and bulk density using the formula of Vomocil (1965).
TP = 1- [ρb/ρs] x 100.
Where:
TP = Total porosity
ρs = particle density and
ρb = bulk density.

***Gravimetric Moisture Content (GMC)***
GMC content was determined by gravimetric method. Fresh weight of soil sample was measured with an electronic balance and thereafter placed in an oven to dry at controlled temperature of 105$^{o}$C for about 48 hours. Loss in weight was the amount of water in the soil, and expressed in percentage.

***Silt Clay Ratio***
The ratio is expressed as: $Silt - Clay\ Ratio = \frac{Clay(\%)}{Silt\ (\%)}$

**Data Analysis**
Descriptive statistics including mean, standard deviation, and correlations were computed.

**RESULTS AND DISCUSSION**
The entire study area was divided into eight mapping units labelled ZG6, ZG7, ZG8, ZG9, ZG10, ZG11, ZG12, and ZG13, this is because 1 to 5 were previously studied and documented by another researcher as part of an earlier phase of the study. By continuing the numbering sequence from 6 onward, this presentation avoids duplication of and ensures a clear distinction between the two sets of data.
Visual Soil Assessment (VSA) was used to evaluate the parent material, topography, soil drainage status and vegetation. This type of assessment is considered important in assessing surface soil properties, which are capable of changing as a result of diverse land use practices (Soil Survey Staff, 2010). The parent material was generally alluvial and is considered good for a wide range of agricultural activities by FAO (2006). Topography was generally flat, with elevation ranging from 145 to 159m above sea level (asl). Nature of the topography makes it visible from 1m to 100m according to USDA-NRCS (2020) guidelines. The flat relief also shows little or no impact of surface erosion. The soils were imperfectly to poorly drained and the lower slopes were characterized with redoximorphic features such as gleization with minimum horizon development. According to Ditzler *et al.* (2017) soil depth categorization, pedons 7, 9, 10 and 11 were deep (90-150cm), pedon 8 was moderately deep (50-90cm) and pedons 6, 12 and 13 were very deep (more than 150cm) in soil depth class classification. Rooting depth of the soil determines the quantities of plant nutrients and water available to plant roots (Talha *et al.,* 2022). Plant root growth, nutrient, and water availability were not affected by depth of pedons at the research site. Idoga *et al.* (2007) attributed extent of soil depth to parent material, erosion and shape of area. All the pedons were free of hard pans, gravels and stones as gravel concentrations were below the 25% critical value of gravel concentration for arable crops as proposed by Orimoloye & Oluwatosin (2019).

**Soil Texture, Colour, and Drainage**
Soil texture was highly variable, with sand ranging from 16.9% to 91.0% (mean 59.5%, CV = 47%), clay from 3.0% to 59.0% (mean 17.7%, CV = 98%), and silt from 5.0% to 59.0% (mean 18.1%, CV = 80%). Clay generally increased with depth in profiles such as ZG6 and ZG7, reflecting eluviation–illuviation processes consistent with argillic horizon formation (Obi et al., 2009; Yakubu & Ojanuga, 2009). In contrast, ZG12 and ZG13 were dominated by loamy sands, reflecting weak textural differentiation and low water-holding capacity. Morphological evidence (Table 1) of fluctuating water tables was apparent in ZG6, ZG7, ZG9, ZG10, and ZG11, where grey and mottled colours confirmed hydromorphic conditions (Esu, 2010; Adesemuyi et al., 2019; Barczok et al., 2023). Conversely, brighter colours and deeper rooting zones in ZG12 and ZG13 indicated better drainage and aeration.

**Soil Structure and Consistency**
Soil structures ranged from fine subangular blocky in surface horizons to coarse blocky in subsurface layers, reflecting aggregation and clay migration (Harsh & Kumar, 2022). Platy structures in ZG8 and ZG9 suggested compaction and restricted infiltration (Esu & Ojanuga, 1985). Soil consistency increased with depth, shifting from sticky to very sticky, which could hinder root penetration. The observed decrease in root density with depth corroborates earlier findings that compact subsoils limit biological activity and root exploration (Hassan et al., 2015).

**Bulk Density, Porosity, and Moisture**
Table 2 displays a summary of the physical properties of the soils. Bulk density ranged from 1.71 to 1.86 g cm$^{-3}$ (mean 1.78 ± 0.05), with more than half of the profiles exceeding the 1.6 g cm$^{-3}$ threshold for root restriction (Hazelton & Murphy, 2007). Total porosity averaged 23.7% (SD = 3.4), well below the optimal 40–60% for crop production (Eyee et al., 2022).
Gravimetric moisture content was highly variable, ranging from 16.9% to 26.5% (mean 21.6%, CV = 18%). Loamy sands (ZG8, ZG9, ZG12, ZG13) retained moisture near wilting point, indicating drought susceptibility (FAO, 2004). In contrast, ZG10 and ZG11 exhibited higher moisture contents, but periodic saturation may reduce aeration and root activity (Glinski & Lipiec, 1990). The strong negative correlation between porosity and moisture (r = –0.73) reflects rapid drainage in macroporous sandy soils, confirming that water retention depends more on drainage status than on clay alone.
Statistical analysis revealed that bulk density and porosity were moderately positively correlated (r = 0.56), reflecting the dominance of coarse particle packing in sandy soils. Moisture content correlated strongly and negatively with porosity (r = –0.73), showing that sandy soils with higher macroporosity drained rapidly and retained little available water. Clay content showed only a weak negative correlation with moisture (r = –0.22), indicating that drainage rather than clay alone determined water availability.

**Table 1: Summary of Morphological Properties of Soils of Zagga District**

| Profile | Depth (cm) | Horizons Present | Dominant Colour (Dry/Moist) | Structure | Consistence (wet) | Roots | Pores | Boundary |
|---|---|---|---|---|---|---|---|---|
| **ZG6** | 0–170+ | Ap, AB, Bt1, Bt2, Bt3 | 10YR → 5YR hues; mottling common | f–m sbk, fabk | vs–ss | MR–NR | MP–VFP | CS → DS |
| **ZG7** | 0–107+ | Ap, Bw, Bt | 10YR hues, red mottles | sbk | vs–s | MR | MP–FP | GS → DS |
| **ZG8** | 0–74+ | Ap, Bt1, Bt2, Cg | 10YR–7.5YR hues; gleyic Cg | Platy/Prismatic | s–vs | MR–FR | FP–MP | GS |
| **ZG9** | 0–84 | Ap, AB, Bt, C1 | 10YR–7.5YR hues | Platy/sbk | s–vs | MR–FR | MP–FP | GS |
| **ZG10** | 0–100 | Ap, Bt, C1, C2 | 10YR–7.5YR hues, reddish | f–m sbk, abk, fabk | ss–vs | MR–FR | MP | GS |
| **ZG11** | 0–103+ | Ap, BC, C | 10YR–7.5YR hues | sbk, fsbk | s–vs | MR–FR | FP | GS |
| **ZG12** | 0–186 | Ap, Bt1, Bt2, Bt3, C | 10YR–2.5YR hues, red mottling | sbk, msbk | vs | MR–NR | MP–FP | GS → DS |
| **ZG13** | 0–200 | Ap, AB, Bw1, Bw2, C | 7.5YR–5YR hues | sbk, fabk | ss | MR–NR | MP | GS → DS |

**Table 2: Summary of Physical Properties of Soils of Zagga District**

| Profile | Sand % (mean) | Silt % (mean) | Clay % (mean) | Texture | Silt/Clay Ratio | Bulk Density ($g/cm^3$) | Particle Density ($g/cm^3$) | Total Porosity % | Gravimetric Moisture % |
|---|---|---|---|---|---|---|---|---|---|
| **ZG6** | 57.4 | 16.2 | 26.2 | Sandy loam | 0.7 | 1.86 | 2.03 | 28.1 | 17.5 |
| **ZG7** | 59.0 | 16.0 | 25.0 | Sandy loam | 0.7 | 1.74 | 2.13 | 21.8 | 16.9 |
| **ZG8** | 76.0 | 21.0 | 3.0 | Loamy sand | 4.0 | 1.83 | 2.21 | 28.7 | 14.9 |
| **ZG9** | 91.0 | 5.0 | 4.0 | Loamy sand / Sand | 3.5 | 1.79 | 2.05 | 24.2 | 16.9 |
| **ZG10** | 77.7 | 16.8 | 6.4 | Loamy sand / Sand | 4.8 | 1.71 | 2.03 | 21.2 | 26.5 |
| **ZG11** | 58.9 | 16.8 | 24.2 | Sandy loam | 0.8 | 1.76 | 2.07 | 21.3 | 25.9 |
| **ZG12** | 88.2 | 8.3 | 3.5 | Loamy sand / Sandy | 6.4 | 1.82 | 2.25 | 19.2 | 26.0 |
| **ZG13** | 85.5 | 6.3 | 8.3 | Loamy sand | 0.7 | 1.75 | 2.33 | 25.1 | 16.9 |

**Weathering Intensity**

The silt/clay ratio (0.7–6.4) differentiated soil maturity across profiles. Low values in ZG6, ZG7, and ZG13 suggested advanced weathering and greater pedological stability, while high values in ZG10 and ZG12 indicated weaker weathering and structural immaturity (Maniyunda et al., 2014; Ojetade et al., 2022). These differences further explain why ZG12 and ZG13, despite being better drained, are structurally weak and drought-prone.

**Land Use Implications**

The soils differ markedly in their land use potential. Poorly drained soils (ZG6, ZG7, ZG9, ZG10, and ZG11) are prone to waterlogging, compaction, and restricted rooting. Well-drained soils (ZG12, ZG13) show deeper rooting zones and better structure but suffer from low water-holding capacity due to their sandy texture. The combination of high bulk density (mean 1.78 g $cm^{-3}$), low porosity (mean 23.7%), and variable moisture (CV = 18%) underscores the need for targeted management.

The soils of Zagga District present contrasting physical limitations. Poorly drained soils (ZG6, ZG7, ZG9, ZG10, and ZG11) are vulnerable to waterlogging, compaction, and reduced aeration, while sandy soils (ZG12, ZG13) are drought-prone due to rapid drainage and low moisture storage. The combination of high bulk density (mean 1.78 g $cm^{-3}$), low porosity (mean 23.7%), and variable moisture (CV = 18%) underscores the need for targeted management or rather site- specific. In poorly drained soils, drainage interventions such as surface drains and ridging are required, while sandy profiles require organic matter incorporation, mulching, and regulated irrigation to enhance water retention (FAO, 2006; Esu, 2010).

## CONCLUSION

The soils of ZG6–ZG13 are characterized by high textural and structural variability, with bulk density, porosity, and moisture relations as the main constraints. Statistical evidence confirms that porosity does not equate to water availability in sandy soils, as macroporosity promotes rapid drainage (r = –0.73 with GMC). Effective management should therefore be site-specific: drainage improvements for hydromorphic soils, and organic matter addition, mulching, and controlled irrigation for sandy soils. These interventions are necessary to mitigate inherent limitations and sustain productivity.

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