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An Evaluation of The Influence of Land Use and Parent Material on Soil Quality in Akwa Ibom State, Nigeria

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Abstract- This research examined how land use and parent material affect soil quality in Akwa Ibom State. Three types of parent materials coastal plain sand, sandstone/shale, and beach ridge sand along with three land use categories cultivated land, fallow land (unused for 3–5 years), and oil palm plantations were considered. For each parent material, composite soil samples were collected from a depth of 0–30 cm using a soil auger, and undisturbed core samples were taken to measure bulk density and saturated hydraulic conductivity. In total, 27 soil samples were analyzed in the laboratory. Findings indicated that soils developed on coastal plain sand had the highest levels of silt and clay content, organic matter, total nitrogen, available phosphorus, and exchangeable potassium. Sandstone/shale soils followed, while beach ridge sand had the lowest values across most parameters. Among the land use types, oil palm plantations showed superior soil properties, including greater silt and clay content, organic matter, and higher concentrations of exchangeable calcium and potassium. These were followed by fallow lands, with cultivated lands showing the poorest soil quality. The combined effect of parent material and land use showed that soils on coastal plain sand, regardless of the specific land use (cultivated, fallow, or oil palm), exhibited the highest overall soil quality. These soils demonstrated better water and nutrient retention, larger rooting volume, improved aeration, reduced erosion risk, higher cation exchange capacity, greater nutrient availability, and more active biological processes. Soils from sandstone/shale were moderately suitable, whereas beach ridge sand soils were the least favorable. The study recommends enhancing existing soil fertility management strategies, particularly the increased use of organic inputs like compost, manure, and household waste, while minimizing synthetic fertilizer use to sustainably improve soil health and productivity in the region.

Keywords: Land Use, Parent Material, Soil Quality, Akwa Ibom State

I. INTRODUCTION

Soil quality plays an essential role in both agricultural output and environmental sustainability, but it is not a fixed attribute. Instead, it changes over time, influenced by a range of natural processes and human interventions. In a country like Nigeria, where agriculture is a key part of the economy, understanding these influences is crucial for effective and sustainable land use. Soils are the backbone of terrestrial ecosystems, supporting plant growth, regulating water resources, and maintaining biodiversity. However, soil quality is dynamic and responds sensitively to environmental conditions and human land use practices. Of the many factors influencing soil health, parent material and land use are widely recognized as among the most impactful (Igwe, Nwokenkwu, & Ibezim, 2018).

Given the significance of agriculture in Nigeria's economy, assessing how these variables affect soil conditions is essential for sustainable farming and long-term food security. Akwa Ibom State, located in Southern Nigeria's humid tropical zone, offers a suitable setting for such research due to its wide-ranging land use practices and geological diversity. The soils in this region largely originate from Coastal Plain Sands and Sandstone formations. These parent materials tend to be coarse-textured, heavily leached, and inherently low in fertility (Kamalu & Ndeh, 2021). The humid climate further contributes to soil acidity and a lack of organic matter and essential nutrients (Ita Aki, Olim, Aberagi, & Umana, 2025).

Beyond natural limitations, human land use intensifies these issues. Different practices ranging from continuous farming and oil palm cultivation to fallow periods and urban development significantly influence soil properties. For example, ongoing cultivation has been linked to declining soil structure and losses in organic carbon, a key marker of soil health (Ogban & Utin, 2015). Research conducted in northern Akwa Ibom State by Ogban (2018) revealed that repeated cultivation reduces the soil's ability to absorb and retain water. Conversely, land used for oil palm or left under fallow tends to maintain better water infiltration, underscoring the direct impact of land management on soil physical properties. Soils formed from different parent materials in the region Coastal Plain Sands (CPS), Beach Ridge Sands (BRS), and Sandstone/Shale (SS) show notable differences in their physical characteristics. For instance, CPS soils generally exhibit higher saturated hydraulic conductivity than those derived from BRS and SS (Utin *et al*., 2021), highlighting how both geological origin and land use practices shape soil functionality.

II. STATEMENT OF THE PROBLEM

In spite of soil quality being a critical determinant of agricultural productivity and environmental sustainability, soil quality in Akwa Ibom State is facing significant degradation due to a combination of natural and anthropogenic factors. The soils in Akwa Ibom State, largely originating from Coastal Plain Sands and Sandstone formations, are naturally low in essential nutrients, making them susceptible to degradation (Kamalu & Ndeh, 2021). This natural limitation is further intensified by current land use trends. The widespread transformation of native vegetation into farmland, residential zones, and oil palm plantations has contributed to the loss of soil organic carbon, increased soil compaction (as indicated by higher bulk density), and nutrient imbalances (Ogban & Utin, 2015). Although previous studies have explored how either parent material or land use independently affects soil properties, there remains a significant gap in understanding their combined impact on key soil quality indicators in this region.

This lack of integrated research presents a challenge for both farmers and policymakers, as it limits the ability to design effective, location-specific strategies for sustainable soil and land management in Akwa Ibom State. As such, the present study aims to generate vital scientific insights that can help guide efforts to maintain and improve soil productivity and health over the long term.

III. OBJECTIVES OF THE STUDY

The primary aim of this research is to assess how land use patterns and underlying parent materials affect soil quality in Akwa Ibom State. The study is guided by the following specific objectives:

1. To examine how different parent materials influence key soil quality indicators within the study area.
2. To analyze the impact of various land use types on soil quality parameters.
3. To evaluate the combined effects of land use and parent material on soil quality characteristics in the region.

Definition of Concept

Land Use

Land use describes how humans utilize land for various purposes, encompassing activities that often cause significant changes to the natural environment (Foley et al., 2005). Practices such as farming, urban development, forestry, and grazing affect soil characteristics by altering vegetation cover, introducing diverse management techniques, and causing both physical and chemical changes to the soil. For example, repeated plowing in agricultural fields can reduce soil organic carbon and degrade soil structure. Similarly, converting forest areas into urban landscapes frequently results in soil compaction and surface sealing, which impairs water infiltration and gas exchange (Amadi et al., 2018). The type and intensity of land use are critical in shaping the long-term sustainability and productivity of ecosystems.

Parent Material

Parent material refers to the geological foundation from which soil develops through weathering processes and biological activity. It provides the essential mineral content and largely determines the soil's physical and chemical traits, including texture, mineral composition, and nutrient availability (Kamalu & Ndeh, 2021). For example, soils formed from coarse materials like sandstone tend to have sandy textures and lower water retention, whereas soils originating from finer substrates like shale or basalt generally contain more clay and possess greater fertility (Liu et al., 2021). The characteristics of parent material serve as the initial framework for soil formation and can either support or limit the effectiveness of land management strategies.

Soil Quality

Soil quality is defined as the soil's ability to perform its functions within the context of an ecosystem and specific land use to sustain biological productivity, protect environmental health, and support the wellbeing of plants and animals (Doran & Parkin, 1994). It is a comprehensive concept that goes beyond nutrient content to include physical, chemical, and biological properties essential for a healthy ecosystem. Important indicators of soil quality include physical aspects such as bulk density and moisture retention, chemical factors like pH and organic carbon levels, and biological features including microbial activity and biodiversity. These indicators are dynamic and respond to changes in land use, while also being closely influenced by the soil's parent material. Enhancing or maintaining soil quality is key to sustainable land use, contributing to food security and climate change mitigation (Lal, 2015).

IV. MATERIAL AND METHODS

Study Area Location

The research was carried out in Akwa Ibom State, situated in southeastern Nigeria, between latitudes 4°30′ and 5°30′ North and longitudes 7°30′ and 8°20′ East (Udoh, Ogunkunle, Ibia, 2007). The geology of the region is mainly composed of coastal plain sands, beach ridge sands, sandstone/shale formations, and alluvial deposits. The climate is tropical, with annual rainfall ranging from approximately 3000 mm along the coast to about 2250 mm in the northern areas. Temperatures typically range between 27°C and 28°C yearly, with relative humidity levels of 75% to 80%. Originally covered by natural rainforest, much of the area has now been converted into secondary forests, dominated by oil palm and rubber plantations. Cultivation of various food crops such as maize, cassava, and yam, as well as tree crops like mango, citrus, and cashew, is common in the region.

Field Sampling

Soil samples were collected from three distinct parent material types: coastal plain sand, sandstone/shale, and beach ridge sand. Within each parent material category, three land use types were selected: cultivated land, fallow land aged 3 to 5 years, and oil palm plantations. For each combination of parent material and land use, six composite soil samples were collected from the 0–30 cm soil layer using a soil auger. Additionally, undisturbed core samples were taken to measure bulk density and saturated hydraulic conductivity. A total of 27 soil samples were transported to the laboratory for further analysis.

Laboratory Analysis

Upon arrival at the laboratory, the soil samples were air-dried and passed through a 2 mm sieve. A series of standard laboratory methods were then applied to determine various soil properties. Particle size distribution was analysed using the modified Bouyoucos hydrometer method (Gee & Or, 2002). Soil pH was measured with a pH meter in a 1:2.5 soil-to-water suspension (Udo et al., 2009). Organic carbon content was quantified following the procedure described by Nelson and Sommers (1996), while total nitrogen was determined using the conventional macro-Kjeldahl digestion and distillation technique (Bremner & Mulvaney, 1982). Available phosphorus was measured using the Bray-1 extraction method (Udo et al., 2009). Exchangeable cations were extracted with 1 M ammonium acetate (NH_4OAc) at pH 7.0. Calcium (Ca) and magnesium (Mg) concentrations were assessed by EDTA titration, while potassium (K) and sodium (Na) levels were measured via flame photometry (Udo et al., 1996). Exchangeable acidity was extracted with 1 M potassium chloride (KCl) and titrated with 0.01 N sodium hydroxide (NaOH). The effective cation exchange capacity (ECEC) was calculated as the sum of exchangeable bases ($Ca^{2+} + Mg^{2+} + K^+ + Na^+$) and exchangeable acidity ($Al^{3+} + H^+$). Base saturation was expressed as the percentage of total ECEC occupied by the bases Ca, Mg, K, and Na.

Influence of Parent Materials on Soil Quality Indicators in the Study Area

The evaluation of soil quality indicators across various parent materials within the study area, as summarized in Table 4.1, revealed notable differences in both texture and chemical composition. The soils predominantly ranged from loamy sand to sand, reflecting the geological makeup of Akwa Ibom State. Beach ridge sand soils exhibited the highest average sand content (95.0%), followed by sandstone/shale soils (89.2%), while coastal plain sand soils had a considerably lower sand fraction (74.2%). This observation is consistent with global findings that highlight parent rock type as a key factor influencing soil particle size distribution (Liu et al., 2021). The increased clay and silt contents in coastal plain sand soils suggest a greater capacity for

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retaining nutrients and moisture, which aligns with similar research conducted on soils of this nature in the region (Amadi et al., 2018).

Significant variations were also noted in physical soil properties. Bulk density values were higher in coastal plain sand and sandstone/shale soils (both at 1.6 g/cm³) compared to the beach ridge sand soils (1.0 g/cm³). Although these bulk density figures for the first two soil types were elevated, they remained below the typical limit (1.6 to 1.8 g/cm³) known to inhibit root penetration in sandy soils (D'Hose et al., 2020). The elevated bulk density is likely linked to the low organic matter and coarse texture, which reduce overall soil porosity. On the other hand, saturated hydraulic conductivity was greatest in the coarse-textured beach ridge sand soils, as expected due to their larger pore sizes that allow for rapid water movement (García-González et al., 2019).

Chemically, soils from all parent materials were slightly acidic, with pH values between 6.3 and 6.4, which is typical for tropical soils susceptible to nutrient leaching. Nevertheless, coastal plain sand soils had significantly higher average levels of organic matter (3.8%), total nitrogen (0.09%), and available phosphorus (30.4 mg/kg) than the other parent materials. This suggests that despite their relatively coarse texture, these soils may benefit from more effective nutrient cycling or greater organic matter input, as the biological and chemical processes can be influenced by the nature of the parent material (Kizilkaya & Dengiz, 2010). Additionally, the higher concentrations of exchangeable potassium and sodium in coastal plain sand soils further underscore their comparatively superior nutrient status.

Table 4.1 Influence of parent materials on soil quality indicators in the study area

Soil properties	Coastal plain sand	Sand Stone/shale	Beach ridge sand
Sand (%)	74.2a	89.27b	95.1b
Silt (%)	2.8a	2.0b	1.0c
Clay (%)	17.0a	8.8b	4.8c
Silt + Cay (%)	17.6	10.8b	5.0a
Texture	Loamy sand	Loamy sand	Sand
Bulk density (g/cm^3)	1.63a	1.57a	1.01b
Coarse sand (%)	51.2b	77.8c	25.1a
Porosity (%)	0.38b	0.41b	0.46b
Ks	0.04a	0.03a	0.11b
Ph	6.3a	6.4a	6.4a
Total N(%)	0.09a	0.07b	0.07b
Org. matter (%)	3.8a	2.8b	2.9b
Av. P (mg/kg)	30.4a	7.1b	8.6b
Exh. Ca (cmol/kg)	3.6a	4.4a	3.7a
Exh. Mg (cmol/kg)	1.3a	1.5a	1.3a
Exh. Na (cmol/kg)	0.06a	0.05b	0.05b
Exh. K (cmol/kg)	0.12a	0.07b	0.10c
ECEC (cmol/kg)	7.5a	5.9a	6.4a
Base saturation (%)	4.9a	5.9a	5.1a

Means with the same letter along the same row are not significant at 5% level.

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Influence of Land Use on Soil Quality Indicators in the Study Area

The effect of various land use types on soil quality indicators, as shown in Table 4.2, underscores the considerable influence of human activities on soil health. Soils under cultivation had a notably higher sand content (89.6%) and a lower clay content (7.2%) compared to those in oil palm plantations and fallow lands. This aligns with studies indicating that farming practices, especially tillage, can disrupt soil aggregates and cause the loss of finer soil particles (D'Hose et al., 2020). As a result, cultivated soils exhibited a significantly increased bulk density (1.6 g/cm^3), which is often a sign of soil compaction from the use of machinery and repeated tilling, negatively affecting root growth and water movement (García-González et al., 2019). In contrast, lower bulk density values were recorded in fallow lands (1.2 g/cm^3) and oil palm plantations (1.3 g/cm^3), where consistent vegetation cover and organic matter help maintain soil structure.

Regarding chemical characteristics, soil pH was found to be significantly higher in cultivated areas (5.8) compared to fallow lands and oil palm plantations, possibly due to the use of lime or fertilizers designed to increase pH and improve crop growth conditions. On the other hand, organic matter and total nitrogen were considerably lower in cultivated soils relative to fallow and oil palm plantation soils. This pattern is well documented, as intensive cultivation and soil disturbance speed up the breakdown and oxidation of organic matter, resulting in its rapid decline (Kizilkaya & Dengiz, 2010). The greater organic matter levels in oil palm plantations and fallow lands are attributed to ongoing leaf litter deposition and minimal soil disruption, which help preserve organic carbon by limiting microbial decomposition (Amadi et al., 2018).

Although available phosphorus levels did not vary significantly between land use types, exchangeable cations such as calcium and potassium were markedly higher in oil palm plantations. This is likely due to the continual addition of nutrient-rich organic residues from the trees, a process that does not occur in the more intensively managed cultivated lands (Ogban & Utin, 2015).

Table 4.2 Influence of land use on soil quality indicators in the study area

Soil properties	Cultivated Land	Fallow Land	Oil palm Plantation
Sand (%)	89.6a	89.4a	87.6b
Silt (%)	3.2a	1.8b	3.4a
Clay (%)	7.2a	8.8b	8.9b
Silt + Cay (%)	10.0a	9.3a	12.3b
Bulk density (g/cm^3)	1.6a	1.2b	1.3c
Ks (cm/hr)	0.0047ab	0.0059b	0.0043a
Ph	5.8a	5.5b	5.5b
EC	0.0a	0.03a	0.04a
Org. Matter (%)	3.7a	4.9b	4.5b
Total N (%)	0.09a	0.12b	0.13b
Av. P (mg/kg)	10.9a	12.7a	10.4a
Exh. Ca (cmol/kg)	2.7a	3.7b	4.8c
Exh. Mg (cmol/kg)	1.1a	1.1a	1.4a
Exh. Na (cmol/kg)	0.05a	0.05a	0.05a
Exh. K (cmol/kg)	0.06a	0.06a	0.07b
Exch. Acidity (cmol/kg)	1.2a	1.5a	1.9b
ECEC (cmol/kg)	5.0a	6.5a	8.2b
Base saturation (%)	77.2a	76.9b	76.8b

Means with the same letter along the same row are not significant at 5% level

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Influence of Parent Material and Land Use on Soil Quality Indicators in the Study Area
The combined impact of parent material and land use on soil quality indicators, as shown in Tables 4.3 and 4.4, reveals a complex interplay where the natural soil characteristics can be either maintained or diminished depending on specific human activities. Cultivated soils derived from coastal plain sand exhibited the lowest sand content and the highest clay fraction, which translates to superior water and nutrient retention and a reduced risk of erosion (Liu et al., 2021). This observation is significant because it demonstrates that even under intensive land use like cultivation, the inherently favorable properties of coastal plain sand contribute to better soil quality than cultivated soils formed from beach ridge sand.

The findings also illustrate how land use can either mitigate or intensify the effects of parent material. For example, fallow land on coastal plain sand showed the highest organic matter content, reflecting this parent material's strong ability to recover when left undisturbed a result consistent with studies in tropical ecosystems (Ogban & Utin, 2015). In contrast, cultivated beach ridge sand soils contained the lowest organic matter and exchangeable calcium, indicating that the combination of a low-fertility parent material and intensive cultivation results in pronounced soil degradation.

In the case of oil palm plantations on coastal plain sand soils, the highest levels of exchangeable calcium were recorded, likely due to the continuous deposition of nutrient-rich organic material from the trees (Kamalu & Ndeh, 2021). This example demonstrates how appropriate land use practices can enhance the beneficial qualities of certain parent materials. Generally, the study highlights that while parent material establishes the initial soil properties, land use practices play a crucial role in either preserving or impairing soil quality. These results emphasize the need to align land management strategies with the specific characteristics of the parent material to promote sustainable soil use over the long term.

Table 4.3: Influence of Parent Material and Land use on Soil Physical indicators

Parent Material x Land use		Soil Quality Indicators Sand (%)	Silt (%)	Clay (%)	Silt + clay (%)	Bulk D. (g/c)m	Ks (cm/hr)
BRS	Cultivated	94.4	1.4	4.2	5.6	1.4	0.04
	Fallow land	92.4	1.4	6.2	7.6	1.1	0.06
	Oil palm plantation	87.7	3.4	8.9	12.3	1.1	0.05
CPS	Cultivated	83.1	4.1	12.9	16.3	1.7	0.05
	Fallow land	85.1	2.7	12.2	14.9	1.1	0.06
	Oil palm plantation	84.4	2.1	13.5	15.6	1.4	0.05
SSS	Cultivated	91.4	4.1	4.5	8.3	1.6	0.05
	Fallow land	90.7	1.4	7.9	5.7	1.5	0.04
	Oil palm plantation	90.7	4.7	4.5	8.9	1.2	0.05
	LSD (0.05)	0.016*	0.016*	0.009*	0.01*	0.77	0.77

*= Significant at 5% level, BD = Bulk density, Ks - Saturated hydraulic conductivity,
BRS = Beach Ridge Sand, CPS = Coastal Plain Sand, SSS = Sandstone/Shale

V. CONCLUSION AND RECOMMENDATIONS

This study's results showed that soil quality indicators in Akwa Ibom State varied notably depending on both the parent material and land use type. Among the different parent materials, soils originating from coastal plain sands displayed the best qualities, with higher proportions of silt and clay, increased organic matter, total nitrogen, available phosphorus, and exchangeable potassium. These were followed by soils from sandstone/shale, while soils from beach ridge sands had the lowest values. Similarly, land use significantly affected soil quality, with soils under oil palm plantations having the greatest silt and clay content, organic matter, and exchangeable calcium and potassium. Fallow lands ranked next, and cultivated lands consistently showed the poorest soil quality indicators.

The interaction between parent material and land use indicated that soils on coastal plain sands whether cultivated, fallow, or under oil palm plantations exhibited the most favorable physical and chemical properties. These soils had better water and nutrient retention, deeper rooting zones, enhanced aeration, lower erosion risk, greater cation exchange capacity, and increased biological activity. Sandstone/shale soils ranked next in quality, with beach ridge sands being the least productive. Overall, the study emphasizes the significant influence of both parent material and land use on soil quality and their combined effects on sustainable land management in the region. It is recommended that organic fertilizers be used more extensively, while reducing reliance on synthetic fertilizers, to improve soil health. Additionally, existing fertility management practices such as the use of household waste, manure, and compost should be strengthened and expanded to support ongoing agricultural productivity.

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