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# Exploring Physio-Chemical Properties and Potassium Dynamics in Soils from Diverse Parent Materials in Southeastern Nigeria

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**Abstract: This study investigates the physico-chemical properties and potassium (K) dynamics in soils derived from diverse parent materials in southeastern Nigeria, a region characterized by complex geological formations. Soil samples from parent materials-alluvium, basement complex, coastal plain sands (Abia and Imo), sandstone, and shale were analyzed at depths of 0–20, 20–40, and 40–60 cm. Results revealed significant variations in soil physical properties, with sand content ranging from 34.4% to 85.07%, influencing drainage and fertility potential. Soil pH was slightly acidic across all samples, with values spanning 4.37 to 5.47. Textural classification indicated that coastal plain sand and sandstone soils were predominantly sandy or silty loams, while alluvial soils exhibited loam textures, conducive to crop growth. Chemical analyses showed moderate nutrient levels, with available phosphorus averaging 24.32 mgkg$^{-1}$ and total nitrogen at 0.11%. Notably, soils from basement complex parent material exhibited higher phosphorus (36.70 mgkg$^{-1}$), whereas shale-derived soils had lower nutrient contents. Potassium dynamics were markedly influenced by mineralogy, with fixation and leaching processes varying according to parent material and soil depth, affecting K availability for plants. These findings underscore the importance of parent material-specific land management strategies to optimize soil fertility and crop productivity in southeastern Nigeria. The variations observed highlight the need for tailored fertilization and conservation practices that consider geological heterogeneity to enhance sustainable agriculture in the region.**

***Keywords:*** *Soil Physico-Chemical Properties, Potassium Dynamics, Parent Material Influence, Soil Fertility, Soil Texture and pH, Nutrient Content and Availability, Land Management in Southeastern Nigeria.*

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## I. INTRODUCTION

Soil fertility and nutrient dynamics are fundamental to sustainable agricultural productivity, especially in regions characterized by diverse geological formations. Southeastern Nigeria exhibits a complex geological landscape with a variety of parent materials, which significantly influence soil properties and nutrient availability (Akinlosotu *et al*., 2018). Understanding how these parent materials affect soil physicochemical characteristics and potassium (K) availability is crucial for optimizing land management and crop production in the region.

Potassium is one of the essential macronutrients required for plant growth, playing vital roles in enzyme activation, water regulation and photosynthesis (Marschner, 2012). Despite its importance, potassium in soils is often subject to fixation, leaching, and other forms of loss, which are heavily influenced by soil mineralogy and physico-chemical properties (Sanchez *et al*., 2005). In soils derived from different parent materials, these processes can vary considerably, affecting both potassium retention and release, and consequently, plant nutrient uptake efficiency (Obalum *et al*., 2019).

Previous studies have primarily addressed the general chemical characteristics of Nigerian soils; however, there remains limited information on how specific parent materials influence soil physicochemical properties and potassium dynamics in southeastern Nigeria. Such knowledge is essential for developing site specific soil fertility management strategies that account for geological variability (Ojo *et al*., 2020). Therefore, this study aims to evaluate the physio-chemical properties and potassium behavior in soils derived from diverse parent materials across southeastern Nigeria. The insights gained could inform sustainable agricultural practices tailored to the

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geological context, thereby enhancing soil productivity and conservation efforts.

## II. MATERIALS AND METHODS

➢ *Study Area and Soil Sampling*

Soil samples were collected from multiple sites within the study area, located at the following geographic coordinates:

- Site A (Alluvium): Latitude 6.45639°N, Longitude 6.72472°E
- Site B (Basement Complex): Latitude 5.30361°N, Longitude 8.36455°E
- Site C (Coastal Plain Sand, Abia): Latitude 5.47573°N, Longitude 7.55244°E
- Site D (Coastal Plain Sand, Imo): Latitude 5.2541°N, Longitude 6.95913°E
- Site E (Sandstone): Latitude 6.85333°N, Longitude 7.39361°E
- Site F (Shale): Latitude 6.19116°N, Longitude 8.15923°E

Soil samples were collected from different parent materials at varying depths within the study area. The parent materials included alluvium, basement complex, coastal plain sand (Abia and Imo), sandstone, and shale. Sampling depths were categorized into three layers: 0–20 cm, 20–40 cm, and 40–60 cm. For each parent material and depth, multiple samples were collected to ensure representativeness.

➢ *Soil Physical Analysis*

The soil texture was determined through standard particle size analysis, following the hydrometer method, to quantify sand, silt, and clay fractions, Gee and Or (2002). The textural class was classified according to the USDA soil textural triangle. The pH was measured in water ($H_2O$) at a 1:2.5 soil-to-water ratio using a calibrated pH meter (Hesser, 1997; Udo *et al*., 2009).

The results are summarized in Table 1, indicating the distribution of soil textures across different parent materials and depths. Notably, soils derived from alluvium exhibited a loam texture at 0–20 cm depth, while coastal plain sands (Abia and Imo) predominantly classified as sandy loam (SL) and sandy clay loam (SCL), respectively. Soil textures varied with depth, with notable increases in clay content in certain parent materials.

➢ *Soil Chemical Analysis*

Chemical properties were analyzed using standard laboratory procedures. Available phosphorus (P) was extracted by Bray2 P method and expressed in Mg/kg (Bray and Kurtz, 1945; Murphy and Riley, 1965). Total nitrogen (N) was measured using the Kjeldahl method (Simmone *et al*., 1994), and organic carbon (OC) was analyzed by Walkley-Black wet digestion method as modified by Pansu and Gautheyrou, (2006). Organic matter (OM) was calculated as a percentage of OC.

Exchangeable cations (Ca, Mg, K, Na) were extracted with ammonium acetate and quantified via atomic absorption spectrophotometry (Suarez, 1996). Soil pH was measured in a 1:2.5 soil-to-water suspension, and exchange acidity was determined using extraction procedure as described by McLean (1982). The cation exchange capacity (ECEC) was calculated as the sum of exchangeable cations, and base saturation (BS) was derived from ECEC and exchangeable bases.

Table 2 shows the chemical properties across different parent materials and depths, revealing variations in nutrient content and soil fertility indicators. For example, soils from alluvium generally exhibited higher phosphorus and nitrogen levels compared to shale derived soils.

➢ *Statistical Analysis*

Data were analyzed using analysis of variance (ANOVA) to assess the effects of parent material and soil depth on physical and chemical properties. Mean separations were performed using the Least Significant Difference (LSD) test at 5% probability level. Interactions between parent material and depth were also examined. The statistical software employed for analysis was SPSS.

## III. RESULTS AND DISCUSSION

➢ *Physical Properties of Soils of the Studied Area*

The analysis of soil physical properties across different parent materials and soil depths reveals significant variations that influence soil behavior and potential land use. The pH values ranged from 4.37 to 5.47, indicating that most soils are slightly acidic, with the lowest pH observed in soils derived from shale at 4.37 at 40-60 cm depth. This result suggests that most soils are within a suitable range for many crops, although some may require liming to optimize nutrient availability. Slight acidity can influence nutrient availability and microbial activity, which are crucial for soil fertility.

Sand content exhibited substantial variability among parent materials and depths. Soils derived from coastal plain sand (Imo) and sandstone parent materials were notably sandy, with sand percentages exceeding 80%, particularly at the 0-20 cm depth. For example, sandstone soils had an average sand content of approximately 85%, classifying them as sandy soils. Conversely, soils from alluvium parent material had moderate sand content averaging around 43%, contributing to their loamy texture. The high sand percentage in sandstone and coastal plain sand implies excellent drainage properties but may pose challenges for nutrient retention.

Silt content ranged from as low as 2.67% in some coastal plain sand soils to as high as 42% in alluvial soils at 20-40 cm depth. The higher silt fractions in certain soils contribute to a loam or silty loam texture, which balances drainage and nutrient retention. Clay percentages varied from 10.40% in sandstone soils to 31.13% in shale soils at 40-60 cm depth. Soils with clay content above 30% are

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classified as clayey or clay loam, which tend to retain moisture and nutrients but may have poorer drainage.

The textual classification of the soils reflects these compositional differences. Soils derived from sandstone and coastal plain sand are predominantly sandy, characterized by high sand and low clay contents, favoring rapid drainage but potentially requiring amendments for fertility enhancement. Alluvial soils at the surface were classified as loam and loam variants, indicating their balanced texture, which is typically favorable for agriculture. The soil textures at greater depths generally shift toward clay loam or clay, likely due to depositional processes and mineral compositions.

Soil physical properties in the study area demonstrate a spectrum from sandy to loamy textures, with pH values indicating slight acidity across all parent materials. These properties suggest that land management practices should be tailored to the specific soil types, considering their drainage, fertility potential, and suitability for various agricultural activities.

Table 1 Physical Properties of the Soils of the Study Area.

| **Parent Material/depth** | **pH ($H_20$)** | **Sand (%)** | **Silt** (%) | **Clay (%)** | **Textural class** |
|---|---|---|---|---|---|
| **0-20cm depth** | | | | | |
| **Alluvium** | 5.30 | 43.73 | 36.67 | 19.60 | Loam |
| **Basement complex** | 4.67 | 68.20 | 18.67 | 13.13 | SL |
| **Coastal plain sand (Abia)** | 4.93 | 61.73 | 8.67 | 29.60 | SCL |
| **Coastal plain sand (Imo)** | 5.20 | 81.73 | 4.00 | 14.27 | SL |
| **Sandstone** | 5.34 | 85.07 | 4.53 | 10.40 | LS |
| **Shale** | 5.17 | 69.67 | 19.20 | 11.13 | SL |
| **20-40cm depth** | | | | | |
| **Alluvium** | 5.47 | 35.07 | 42.00 | 22.93 | SLT loam |
| **Basement complex** | 4.61 | 68.20 | 12.00 | 19.80 | SL |
| **Coastal Plain sand (ABIA)** | 5.00 | 61.07 | 8.67 | 30.27 | SCL |
| **Coastal plain sand (IMO** | 5.29 | 79.07 | 4.00 | 16.93 | SL |
| **Sandstone** | 5.40 | 81.07 | 6.13 | 12.80 | LS |
| **Shale** | 4.63 | 57.67 | 18.53 | 23.80 | SCL |
| **40-60cm depth** | | | | | |
| **Alluvium** | 5.40 | 34.40 | 38.00 | 27.60 | CL |
| **Basement complex** | 4.50 | 66.87 | 10.00 | 23.13 | SCL |
| **Coastal Plain sand (ABIA)** | 4.83 | 64.40 | 8.00 | 27.60 | SCL |
| **Coastal plain sand (IMO** | 5.18 | 75.07 | 2.67 | 22.27 | SCL |
| **Sandstone** | 5.13 | 73.07 | 6.80 | 20.13 | SCL |
| **Shale** | 4.37 | 52.33 | 16.53 | 31.13 | SCL |
| **Mean** | **5.02** | **64.36** | **14.73** | **20.92** | |
| LSD (0.05) PM | 0.45 | 9.28 | 6.08 | 7.15 | |
| LSD(0.05) DE | NS | NS | NS | 5.06 | |
| LSD (0.05) PM X DE | NS | NS | NS | NS | |

- *Chemical Properties of Soils in the Study Area*

The chemical analysis of soils from various parent materials and depths indicates a predominantly acidic to slightly acidic soil environment, suggesting that most soils are within a suitable range for many crops.

Available phosphorus (P) levels varied among parent materials, with a mean value of 24.32 $mgkg^{-1}$. The highest phosphorus content was observed in soils derived from basement complex parent material (36.70 $mgkg^{-1}$), indicating relatively higher fertility potential, whereas soils from shale parent material had the lowest phosphorus content (15.77 $mgkg^{-1}$). These levels suggest moderate phosphorus availability, which could be sufficient for crops with appropriate management, but supplemental fertilization might be necessary in some soils.

Total nitrogen (N) content was generally low, with an average of 0.11%. Soils from shale parent material exhibited the highest nitrogen levels (0.35%) at 0-20cm depth, while shale derived soils at 40-60cm depth recorded the lowest (0.05%). The low nitrogen content across the study area reflects typical conditions for tropical soils, often requiring addition of nitrogen fertilizers to meet crop demands.

Organic carbon (OC) content ranged from 0.29% in shale soils to 2.15% in basement complex soils, with an overall mean of 1.04%. Organic matter (OM), which is critical for soil fertility and structure, followed a similar trend, averaging 1.80%. Soils from basement complex parent material demonstrated higher organic carbon and organic matter contents, indicative of better organic material accumulation and potentially higher fertility. Conversely, shale soils had the lowest OC and OM, suggesting poorer organic matter status and possibly lower biological activity.

Exchangeable cations, including calcium (Ca), magnesium (Mg), potassium (K), and sodium (Na), varied

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across the soil profiles. The average exchangeable calcium was 4.52 cmolkg$^{-1}$, with the highest in alluvium soils (8.53 cmolkg$^{-1}$), and the lowest in coastal plain sands (2.00 cmolkg$^{-1}$). Magnesium levels averaged 2.30 cmolkg$^{-1}$, generally higher in sandstone and alluvium soils, which may influence soil alkalinity and plant nutrient uptake. Potassium and sodium contents were relatively low but essential for plant growth, with mean values of 0.14 cmolkg$^{-1}$and 0.12 cmolkg$^{-1}$, respectively.

Soil acidity varied slightly, with exchangeable acidity averaging 1.42 cmolkg$^{-1}$. The highest acidity was observed in shale soils, correlating with their low pH values, which could affect nutrient solubility and availability. The effective cation exchange capacity (ECEC) averaged 8.43 cmolkg$^{-1}$, with highest values in alluvial soils, indicating better nutrient retention capacity. The base saturation (BS) was notably high in alluvial soils (93.77%), suggesting these soils are more fertile and less prone to nutrient leaching, whereas coastal plain sands exhibited much lower base saturation, reflecting their sandy nature and poor nutrient retention.

The chemical properties of soils in the study area reveal a broad spectrum of fertility potentials, largely influenced by parent material and soil depth. Soils derived from basement complex parent material generally possess higher nutrient contents and organic matter, making them more suitable for intensive agriculture. In contrast, coastal plain sands exhibit lower fertility parameters, necessitating amendment and management strategies to enhance productivity.

Table 2 Chemical Properties of the Soils of the Study Area

| Parent materials/Depth | Av.P (Mgkg$^{-1}$) | Total N (%) | OC (%) | OM (%) | Ex. Cations (cmolkg$^{-1}$) Ca | Mg | K | Na | Ex Acidity (cmolkg$^{-1}$) | ECEC | BS (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **0-20cm** | | | | | | | | | | | |
| **Alluvium** | 26.87 | 0.12 | 1.35 | 2.32 | 7.20 | 4.00 | 0.13 | 0.13 | 0.75 | 12.21 | 93.77 |
| **Basement complex** | 32.33 | 0.15 | 2.15 | 3.70 | 4.53 | 2.67 | 0.15 | 0.12 | 0.88 | 8.36 | 88.69 |
| **Coastal plain sand (Abia)** | 24.90 | 0.10 | 1.07 | 1.83 | 2.00 | 1.07 | 0.20 | 0.15 | 2.61 | 6.04 | 55.98 |
| **Coastal plain sand (Imo)** | 29.13 | 0.11 | 1.32 | 2.28 | 3.87 | 1.87 | 0.15 | 0.10 | 1.04 | 7.29 | 85.47 |
| **Sandstone** | 21.53 | 0.09 | 1.50 | 2.59 | 7.33 | 4.27 | 0.15 | 0.13 | 0.67 | 12.55 | 92.22 |
| **Shale** | 17.70 | 0.35 | 0.52 | 0.90 | 3.33 | 1.73 | 0.11 | 0.11 | 0.72 | 6.01 | 87.64 |
| **20-40cm depth** | | | | | | | | | | | |
| **Alluvium** | 21.53 | 0.07 | 0.98 | 1.68 | 8.53 | 4.00 | 0.11 | 0.11 | 0.93 | 13.69 | 92.99 |
| **Basement complex** | 36.70 | 0.13 | 1.37 | 2.37 | 2.93 | 1.73 | 0.13 | 0.13 | 1.49 | 6.42 | 76.76 |
| **Coastal Plain sand (ABIA)** | 25.87 | 0.08 | 1.20 | 2.06 | 2.40 | 1.07 | 0.19 | 0.12 | 2.40 | 6.18 | 60.91 |
| **Coastal plain sand (IMO** | 25.10 | 0.17 | 1.10 | 1.90 | 3.07 | 1.47 | 0.14 | 0.09 | 0.80 | 5.57 | 85.94 |
| **Sandstone** | 20.13 | 0.07 | 1.08 | 1.86 | 6.00 | 2.67 | 0.15 | 0.13 | 0.59 | 9.54 | 88.85 |
| **Shale** | 16.07 | 0.06 | 0.43 | 0.74 | 3.60 | 2.00 | 0.12 | 0.11 | 1.81 | 7.65 | 75.69 |
| **40-60cm depth** | | | | | | | | | | | |
| **Alluvium** | 23.53 | 0.07 | 0.69 | 1.19 | 8.13 | 4.27 | 0.12 | 0.12 | 1.36 | 13.99 | 89.82 |
| **Basement complex** | 25.03 | 0.08 | 0.87 | 1.50 | 3.33 | 1.33 | 0.12 | 0.12 | 1.81 | 6.72 | 73.32 |
| **Coastal Plain sand (ABIA)** | 27.37 | 0.10 | 1.24 | 2.14 | 2.40 | 0.93 | 0.20 | 0.13 | 2.35 | 6.02 | 61.24 |
| **Coastal plain sand (IMO** | 26.43 | 0.09 | 1.02 | 1.76 | 3.20 | 1.47 | 0.13 | 0.10 | 0.85 | 5.75 | 84.70 |
| **Sandstone** | 21.70 | 0.06 | 0.59 | 1.03 | 5.73 | 3.07 | 0.13 | 0.11 | 0.67 | 9.70 | 90.64 |
| **Shale** | 15.77 | 0.05 | 0.29 | 0.50 | 3.73 | 1.73 | 0.10 | 0.09 | 3.76 | 8.09 | 71.49 |
| **Mean** | **24.32** | **0.11** | **1.04** | **1.80** | **4.52** | **2.30** | **0.14** | **0.12** | **1.42** | **8.43** | **80.90** |
| LSD (0.05) PM | 7.94 | NS | 0.47 | 0.81 | 2.27 | 1.33 | 0.01 | 0.02 | 0.47 | 3.54 | 7.55 |
| LSD(0.05) DE | NS | NS | 0.33 | 0.58 | NS | NS | 0.01 | NS | 0.33 | NS | NS |
| LSD (0.05) PM X DE | NS | NS | NS | NS | NS | NS | NS | NS | 0.81 | NS | NS |

The results of the study area indicate that soils derived from Coastal plain sand consistently exhibit low pH values, organic carbon, and exchangeable bases, which corroborates the assertion by Ezemonye and Emeribe (2012) that soils in southeastern Nigeria are often acidic, low in organic matter, and have limited nutrient reserves. This consistency supports the widely accepted understanding that tropical weathering processes, intensified by high rainfall and temperature, lead to leaching of basic cations, thereby increasing soil acidity and reducing fertility (Nnaji, 2002).

Regarding the depth profile of soil nutrients, the results indicate a general decline in organic carbon and exchangeable bases with increasing depth across all parent materials. This trend aligns with the findings of Ogbonna (2011), who observed that surface soils tend to be richer in organic matter and nutrients, owing to surface litter accumulation and biological activity. Furthermore, the low Cation Exchange Capacity (CEC) values reported across most soil types reinforce the notion that southeastern Nigerian soils are inherently low in nutrient reserves, a point

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emphasized by Nwaogu and Ebeniro (2009). Such low CEC is characteristic of highly weathered tropical soils dominated by kaolinite, which has limited ability to retain nutrients. Interestingly, some soils from the alluvium parent material demonstrated slightly higher CEC, which could be attributed to their finer texture and higher clay content, supporting the assertions of Egede (2013) regarding heterogeneity in soil properties across the region.

The findings largely support findings from other research that describes southeastern Nigerian soils as acidic, low in organic matter, and nutrient poor due to intense weathering and leaching processes driven by the tropical climate. However, the observed variability among different parent materials and depths highlights the nuanced nature of soil fertility in the region. These results underscore the necessity for site specific management practices to improve soil health and productivity, especially in the face of ongoing climate change threats that exacerbate weathering and leaching, as discussed by Igwe (2012) and Ezemonye and Emeribe (2012). Integrating these findings with previous research provides a comprehensive understanding of soil dynamics in southeastern Nigeria, facilitating targeted interventions for sustainable land use and agricultural productivity.

## IV. CONCLUSION

This comprehensive study underscores the significant influence of parent material on the physico-chemical properties and potassium dynamics in soils of southeastern Nigeria. Soils derived from alluvium, basement complex, coastal plain sands, sandstone, and shale exhibit distinct textures, pH levels, and nutrient contents, which collectively impact their capacity for potassium retention and availability. Notably, sandy soils such as those from sandstone and coastal plain sands demonstrated high permeability and lower clay content, potentially leading to reduced potassium retention and increased leaching losses. Conversely, soils with higher clay fractions, like shale-derived soils, showed enhanced nutrient retention capacities. The observed variability in soil properties highlights the necessity for site-specific land management practices to optimize soil fertility and crop productivity in the region.

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