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Assessment of Physicochemical Properties of Soils Underlain by Different Geological Formations in Enugu and Anambra States, Southeastern Nigeria

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Authors' contributions

This work was carried out in collaboration among all authors. Authors UCL and UCP conceptualized, designed the study, drafted the manuscript and coordinated revisions. Author OKS conducted field sampling and laboratory analyses. Authors UCL and ENE performed data analysis and interpretation. All authors read and approved the final manuscript.

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Abstract

Aims: To assess the influence of different geological formations on the physicochemical properties of soils in Enugu and Anambra States, southeastern Nigeria.
Study Design: A field-based comparative study employing laboratory analysis and statistical evaluation of soil physicochemical properties across multiple geological formations.

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Place of Study: The study was conducted in selected locations within Enugu and Anambra States, southeastern Nigeria.

Methodology: Soils developed over six geological formations, namely Nkporo Shale (NS), Ajali Sandstone (AS), False-Bedded Sandstone (FSS), Lignite-Claystone-Shale (LCS), Clayey Sand-Shale (CSS), and Alluvium (AL) were investigated.

Results: Soil texture varied significantly among the geological formations, ranging from sandy clay loam and loam in soils developed over sandstone and alluvial formations to clay loam in soils underlain by shale formations. Soils of the Nkporo Shale formation were strongly acidic (pH 4.7) and recorded the highest exchangeable Al^{3+} (2.54 cmol kg^{-1}) and exchangeable acidity (4.59 cmol kg^{-1}). In contrast, soils developed over alluvial deposits were near neutral (pH 6.3) with lower acidity (1.13 cmol kg^{-1}). Cation exchange capacity and available phosphorus differed significantly across formations, and positive correlations were observed between base cations and base saturation.

Conclusion: Underlying geological formations exert a strong control on soil physicochemical properties, fertility status, and acidity in the study area. Site-specific soil management practices tailored to individual geological formations are therefore recommended to enhance sustainable agricultural productivity.

Keywords: Geological formations; soil physicochemical properties; soil acidity; soil fertility; Southeastern Nigeria.

1. Introduction

Soil, as a dynamic natural body, supports plant growth, sustains ecosystems, and underlies agricultural productivity and environmental stability (Telo da Gama, 2023). Its formation and properties are influenced by several pedogenic factors including parent material, climate, topography, organisms, and time. Among these, the parent material has been widely recognized as the most dominant factor influencing soil morphology and its physical, chemical, and mineralogical characteristics (Wilson, 2019).

The formation and characteristics of soils are intricately linked to the nature of their underlying parent materials. Parent material, defined as the unconsolidated mineral or organic matter from which soils develop, plays a critical role in determining the texture, structure, and nutrient composition of soils (Brady & Weil, 2010). Differences in mineral composition, degree of weathering, and drainage conditions among parent materials result in diverse soil properties, influencing their fertility and agricultural potential (Schaefer et al., 2008). In tropical and subtropical regions, such as southeastern Nigeria, the dominant clay minerals are kaolinite, quartz, and various iron and aluminium oxides, which significantly influence soil structure, nutrient retention, and acidity (Nitzsche et al., 2008).

In this study, geological formations serve as the parent materials from which soils have developed. Enugu and Anambra States, located in southeastern Nigeria, are characterized by a complex geology that includes formations such as false-bedded sandstone, shale, and coastal plain sands. These geological variations have given rise to diverse soil types with distinct physicochemical characteristics, ranging from coarse-textured, low-nutrient soils derived from sandstone to finer-textured, more nutrient-rich soils derived from shale and other sedimentary rocks (Abam and Orji, 2019). The heterogeneity of these soils has significant implications for agricultural land use, soil fertility management, and environmental sustainability in the region. Understanding the influence of parent materials on soil properties is therefore fundamental to guiding land evaluation, optimizing crop production, and formulating site-specific soil management strategies in southeastern Nigeria.

Although several studies have examined the influence of parent materials on soil properties globally (Donatus et al., 2018; Ejikeme et al., 2021), there remains a scarcity of detailed, location-specific investigations in southeastern Nigeria, particularly within Enugu and Anambra States. Most existing works in the region have focused either on general soil characterization or on the effects of land use and vegetation on soil quality (Nnaji et al., 2023), with limited comparative assessment of how soils derived from different geological formations differ in their physicochemical attributes. Consequently, there is insufficient empirical data linking specific parent materials, such as false-bedded sandstone, shale, and coastal plain sand, to variations in key soil parameters such as pH, organic matter content, cation exchange capacity, and nutrient composition.

Furthermore, while earlier research (Ndukwu et al. 2015; Ahukaemere et al. 2016; Onwuka et al. 2016; Abam and Orji, 2019) has recognized that the mineralogical and geochemical composition of parent materials strongly determines soil fertility and agricultural suitability (Schaefer et al., 2008), such relationships have not been adequately quantified for the diverse geological settings of southeastern Nigeria. This gap in knowledge limits the ability of researchers, soil scientists, and land managers to make informed decisions on land use planning, soil conservation, and agricultural optimization within these states.

A comprehensive understanding of the relationship between parent material and soil physicochemical properties is fundamental for effective land management, agricultural planning, and environmental sustainability (Shen et al., 2001; Nkanga et al., 2025). In regions such as southeastern Nigeria, where agricultural productivity underpins rural livelihoods, variations in soil fertility resulting from differences in parent materials can directly impact crop yield, nutrient management practices, and land use efficiency. Assessing the influence of parent materials on soil properties will therefore provide critical information for soil fertility classification, crop suitability mapping, and the formulation of sustainable agricultural policies.

Moreover, the increasing pressure on land resources due to population growth, urbanization, and changing land use patterns necessitates a scientific basis for evaluating soil quality and its potential for various uses (Moore et al., 2022). By establishing the link between parent material and soil characteristics, this study will not only enhance understanding of soil variability in Enugu and Anambra States but also contribute to improved land evaluation and site-specific soil management strategies. The findings will serve as a valuable reference for policymakers, researchers, and agricultural practitioners in promoting sustainable land use and optimizing agricultural productivity in southeastern Nigeria. The primary objective of this study is to evaluate the physicochemical properties of soils underlain by various parent materials in Enugu and Anambra States, Southeastern Nigeria.

2. Materials and Methods

2.1 Description of the Study Area

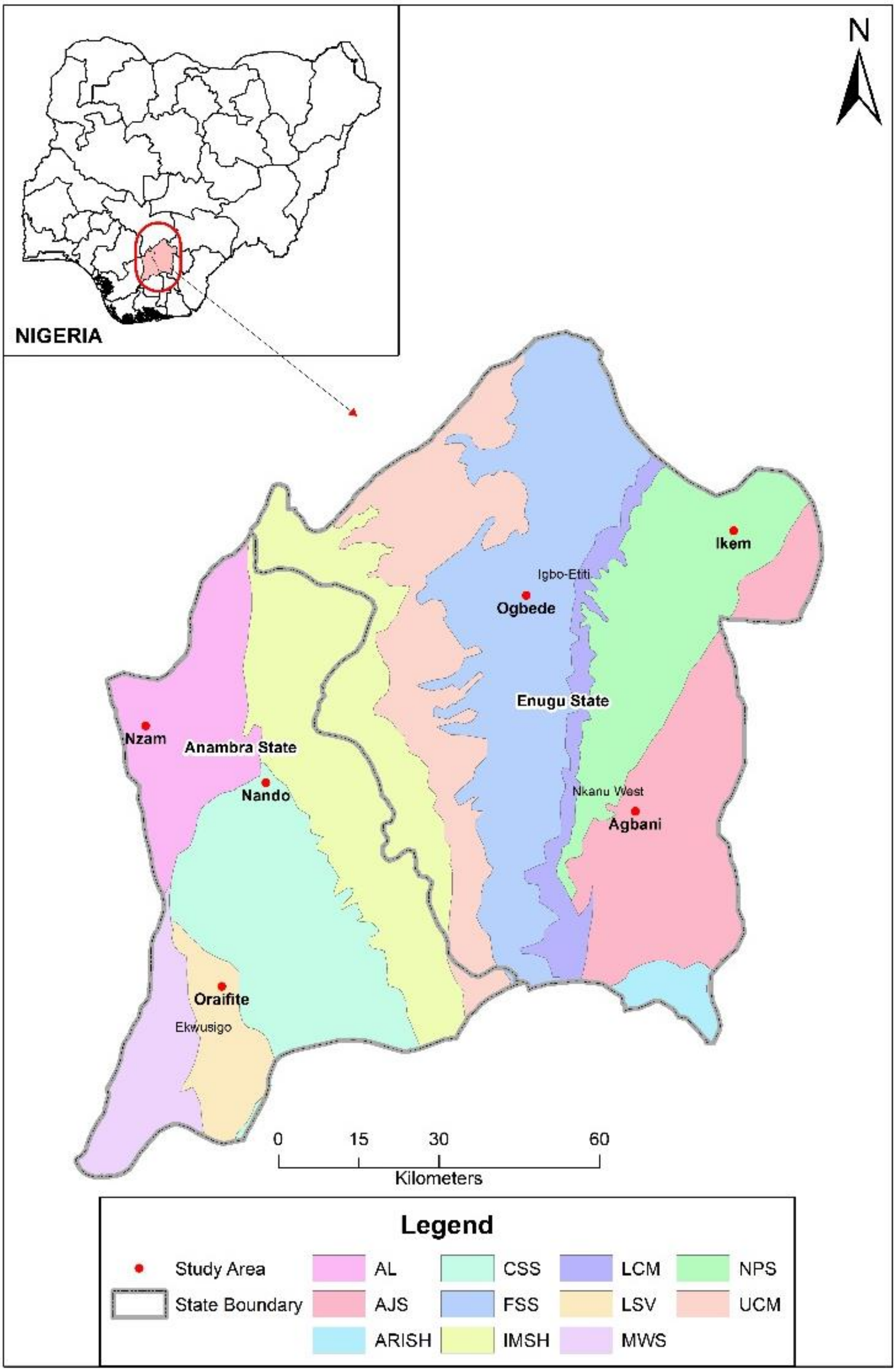
2.1.1 Location and Climate

This study was conducted on selected soils developed from various parent materials within Enugu and Anambra States, located in Southeastern Nigeria. Enugu State lies approximately between latitudes 06°44′83″N and longitudes 07°51′39″E, while Anambra State extends between 06°22′09″N and 06°93′70″E. Both states share similar climatic conditions typical of the tropical rainforest zone with a derived savanna influence.

The area experiences a humid tropical climate characterized by two distinct seasons: a wet season and a dry season. The wet season spans from March to November, with a pronounced rainfall peak between June and July. The dry season lasts from December to February. The mean annual rainfall is approximately 2,000 mm, and the average temperature ranges from 25°C to 32°C throughout the year (Anikwe, 2010). Relative humidity remains high, ranging from 70% to 90% during most months (Obasi et al., 2015). These climatic conditions promote intense weathering and leaching processes, which influence the physicochemical characteristics of soils developed over different parent materials in the study area.

2.1.2 Geology and Soil

The geology of Enugu and Anambra States is predominantly sedimentary, comprising diverse formations that significantly influence the nature and properties of the soils developed from them. The major geological formations within the study area include false-bedded sandstone, shale, and coastal plain sand, each contributing distinct mineralogical and physicochemical characteristics to the soils. The soils of Enugu State are derived from varied geological formations such as false-bedded sandstone, shale, alluvial deposits, and volcanic ash, while those of Anambra State are formed mainly from Cretaceous and Tertiary sedimentary formations, including the Mamu Formation, Imo Shale, and Nanka Sandstone.



ALV = Alluvium, AJS = Shale and limestone, ARISH = Shale and limestone, CSS = Siltstone and Sandstone, FSS = False-bedded sandstone, IMSH = Imo Shale, LCM = Lower coal measure, LSV = clay sandstone lignite and shale, MWS = sand gravel and clay, NPS = Nkporo shale, UCM = Upper coal measure

Fig. 1. Geology map of the study area

Source: Nigeria Geological Survey Agency

These formations have produced soils that are generally classified as Ultisols, characterized by being deep, porous, and strongly leached, with low base saturation, acidic pH, and low organic matter content (Ezemonye & Emeribe, 2012; Ilori et al., 2016). The intense rainfall and high temperature of the region accelerate chemical weathering, leading to the dominance of kaolinitic clays and iron/aluminium oxides, typical of tropical soils. Consequently, the soils are often susceptible to erosion and nutrient depletion, particularly where vegetation cover is reduced. According to Akamigbo and Asadu (1983) and Umeugokwe et al. (2023), several soil orders occur in Southeastern Nigeria, including Ultisols, Inceptisols, Entisols, Oxisols, and Alfisols, reflecting the combined influence of geology, topography, and drainage.

2.1.3 Vegetation and Land Use

The vegetation of Enugu and Anambra States falls within the humid tropical rainforest zone, characterized by luxuriant growth and a high diversity of plant species. However, the original forest cover has been extensively modified due to anthropogenic activities, including farming, settlement expansion, and fuelwood extraction. The natural vegetation is now predominantly secondary forest, interspersed with derived savanna and patches of bush regrowth (Nwankwoala et al., 2022). Typical tree species include *Elaeis guineensis* (oil palm), *Albizia zygia*, *Daniellia oliveri*, and *Pentaclethra macrophylla*.

Land use within the study area is primarily agricultural, reflecting the high population density and dependence on subsistence farming. Primary land use types include cultivated land, fallow land, plantations (notably oil palm and rubber), and settlement areas. Continuous cultivation on fragile soils derived from sandstone and shale formations has led to declining soil fertility and increased susceptibility to erosion, particularly on sloping terrain (Ezemonye & Emeribe, 2012). In contrast, areas under plantation or forest cover tend to exhibit better soil structure, higher organic matter content, and reduced erosion risks due to canopy protection and litter accumulation (Ufot et al., 2016).

2.2 Site Selection and Field Work

With the aid of the geologic map of Enugu and Anambra States (Fig. 1), six sampling locations were purposively selected to represent the dominant parent materials within the study area. The selected sites included Ikem (Nkporo Shale - NPS), Agbani (Ajali Sandstone - AJS), and Ogbede (False-Bedded Sandstone - FBS) in Enugu State; as well as Oraifite (Lignite, Claystone and Shale - LCS), Nando (Clayey Sand and Shale - CSS), and Nzam (Alluvium - ALV) in Anambra State.

At each location, random soil samples were collected in triplicate to ensure representative coverage of the study area, giving a total of 18 soil samples from the six locations. The samples were placed in clean, properly labeled polyethylene bags and transported to the laboratory for analysis. Geographical coordinates of all sampling sites were recorded using a handheld Global Positioning System (GPS) device for accurate spatial referencing.

2.3 Laboratory Analysis

The collected soil samples were air-dried at room temperature, gently crushed to break up large clods, and passed through a 2 mm sieve to obtain fine earth fractions for laboratory analyses. All analyses were conducted at the Department of Soil Science Laboratory, University of Nigeria, Nsukka, following standard procedures for determining soil physical and chemical properties.

2.3.1 Soil Physical Properties

The particle size distribution (PSD) of the <2 mm soil fraction was determined using the Bouyoucos hydrometer method (Van Reeuwijk, 1992), with sodium hydroxide as the dispersing agent. The resulting textural classes were identified using the USDA soil textural triangle.

2.3.2 Soil Chemical Properties

The soil pH was determined potentiometrically in a 1:2.5 soil-to-water and soil-to-1N KCl suspension using a glass electrode pH meter (McLean, 1982). Organic carbon (OC) was determined by the Walkley and Black dichromate oxidation method (Nelson & Sommers, 1996), while total nitrogen (TN) was analyzed using the macro-Kjeldahl digestion method (Bremner & Mulvaney, 1982). Available phosphorus (Av. P) was extracted using the Bray II method (Olsen & Sommers, 1982), and phosphorus concentration in the extract was measured colorimetrically. Exchangeable bases (Ca^{2+}, Mg^{2+}, K^+, and Na^+)

were extracted with 1N ammonium acetate (NH_4OAc) at pH 7.0. Potassium and sodium were determined by flame photometry, while calcium and magnesium were measured by atomic absorption spectrophotometry (AAS) (Thomas, 1982). Exchangeable acidity (EA) was determined by titration of 1N KCl extracts with 0.05N NaOH using phenolphthalein as indicator (Thomas, 1982). The cation exchange capacity (CEC) was determined using 1N NH_4OAc at pH 7.0 (Rhoades, 1982). The percentage base saturation (PBS) was calculated as:

$$\frac{\text{TEB}}{\text{CEC}} \times \frac{100}{1} \qquad (1);$$

where TEB represents total exchangeable bases.

2.4 Data Analysis

All data obtained from the laboratory analyses were subjected to analysis of variance (ANOVA) using GenStat for Windows 12th Edition (Payne, 2009) to assess the effects of parent materials on soil physicochemical properties. Differences between treatment means were separated using Fisher's Least Significant Difference (F-LSD) test at 5% probability level (Gomez & Gomez, 1984). The relationships among the soil physicochemical properties were evaluated using Pearson's correlation analysis. This analysis was used to determine the degree and direction of association between selected soil parameters across the different parent materials.

3. Results and Discussion

3.1 Main Effect of Geological Formations on Soil Physical Properties

The results of the particle size distribution (PSD) of soils developed over the six geological formations are presented in Table 1. The textural classes varied across the geological formations, ranging from sandy clay loam (AS and LCS) to clay loam (NS and AL), sandy clay (FSS), and loam (CSS). Among the locations, FSS recorded the highest clay content (380 g kg^{-1}), which is indicative of soils developed from fine-textured formations, likely shale or clay-rich sedimentary formations typical of parts of Enugu State. The high clay fraction in FSS-derived soils suggests reduced permeability and potentially higher nutrient retention capacity, characteristics typical of fine-textured soils developed from shale-influenced sandstone materials (Nnaji et al., 2023). Conversely, CSS soils, with a clay content of 160 g kg^{-1} and a relatively high silt content of 380 g kg^{-1}, were classified as loamy, suggesting derivation from alluvial deposits along the Anambra River basin. Such loamy to silty textures are typical of riverine deposits, as noted by Ukabiala et al. (2021), and are associated with better structure and moderate water-holding capacity. Soils developed over LCS and AS exhibited sandy clay loam textures, with LCS showing moderately high clay and silt fractions, reflecting a balanced mixture of fine and coarse materials. The dominance of coarse sand (460 g kg^{-1}) in AS soils is indicative of the arenaceous nature of the parent material, which produces coarser, well-drained soils. This agrees with Umeugokwe et al. (2023), who noted that false-bedded and Ajali sandstone formations in southeastern Nigeria typically yield sandy soils with low clay accumulation.

3.2 Main Effect of Geological Formations on Soil Chemical Properties

The chemical properties of soils developed over the six geological formations are presented in Table 2. Statistical analysis revealed that the geological formations significantly influenced soil pH, Ca^{2+}, H^+, Al^{3+}, CEC, and Av. P. However, other parameters such as OC, TN, Mg^{2+}, Na^+, K^+, and BS did not differ significantly among the formations.

Soil pH varied considerably across the formations, ranging from 4.7 in NS to 6.3 in AL, indicating acidity levels from strongly acidic to near neutral. The low pH value 4.7 in NS reflects the inherently acidic nature of soils derived from shale and other fine-textured sedimentary rocks, which are typically rich in exchangeable acidity and aluminium. This agrees with Umeugokwe et al. (2023), who noted that shale-derived soils in southeastern Nigeria are dominated by aluminium and hydrogen ions due to the extensive leaching of basic cations. Conversely, the relatively higher pH (6.3) observed in AL soils corresponds to their depositional environment. Riverine and floodplain deposits are less leached and often enriched with weathered base cations from upstream materials, leading to improved base saturation and near-neutral pH values (Dickson et al., 2022).

The concentrations of Ca^{2+} and CEC followed a similar trend, with AL and CSS formations recording higher values compared to the NS and FSS. This pattern suggests that soils developed over depositional or mixed parent materials tend to retain more basic cations and exhibit better nutrient-holding capacity. The relatively low CEC in sandstone-derived soils (AS and FSS) can be attributed to their coarse texture and dominance of low-activity clay minerals such as kaolinite, which possess limited exchange sites (Kabala and Jedrzejewski, 2024).

The total exchangeable acidity reached 4.59 cmol kg^{-1} in the NS formation, with Al^{3+} alone accounting for 2.54 cmol kg^{-1}. In comparison, the AL soils recorded the lowest values of 1.13 cmol kg^{-1} for exchangeable acidity and 0.20 cmol kg^{-1} for aluminium. The high concentrations of Al^{3+} and H^+ observed in soils derived from NS and FSS indicate higher levels of soil acidity and potential aluminium toxicity. Such conditions are common in highly weathered tropical soils where extensive leaching removes base cations, leading to residual acidity (Onwuka et al., 2016; Regasa et al., 2025). In contrast, AL and LCS soils had comparatively lower exchangeable acidity, reflecting periodic sediment deposition and replenishment of base-forming cations.

The Av. P was significantly influenced by parent material, with higher values observed in AL and LCS formations. This can be attributed to the moderate pH levels in these soils, which enhance phosphorus availability by reducing its fixation by iron and aluminum oxides. On the other hand, NS and FSS soils recorded lower phosphorus values, likely due to the strong acidity and the presence of high Fe and Al oxides, which promote phosphorus immobilization (Asadu et al., 2001; Scherwietes et al., 2025).

3.3 Correlation among Physicochemical Properties

The correlation matrix (Table 3) revealed significant relationships among several soil physicochemical properties across the studied geological formations. Clay content exhibited a strong and negative correlation with FS (r = -0.73**), suggesting that as the proportion of clay increases, finer sand fractions decrease, a reflection of the textural differentiation inherent in soils derived from sedimentary parent materials of varying particle size distributions. Similarly, silt showed a significant negative relationship with CS (r = -0.84**), indicating contrasting depositional and weathering characteristics among the formations.

Soil reaction (pH) measured in both H_2O and KCl showed a highly significant positive correlation (r = 0.93**), implying that both measurements respond consistently to the same acid–base dynamics in the soils. The weak to moderate positive correlations between pH (H_2O) and CS (r = 0.38) may also reflect improved aeration and leaching in sandy-textured soils, which can influence proton exchange and acidity buffering.

The OC exhibited strong and significant positive correlations with total nitrogen (r = 0.58*), Na^+ (r = 0.97**), and K^+ (r = 0.87**), signifying that nutrient accumulation in these soils is closely tied to organic matter dynamics. The positive OC–TN relationship agrees with the findings of Nnaji et al. (2023), who emphasized that soil organic matter serves as a significant source of nitrogen and exchangeable cations in tropical soils with low mineral reserves.

Table 1. Mean effect of geological formations on the soil physical properties

Geology	Clay	Silt	FS	CS	Texture
	------------------------------g kg^{-1}------------------------------				
AJS	280	160	320	230	SCL
NPS	370	320	130	190	CL
FBS	380	110	110	410	SC
CSS	160	380	320	140	L
ALV	370	270	230	120	CL
LCS	250	130	200	460	SCL
F-LSD	3.61	2.97	2.81	3.19	

SCL = sandy clay loam, CL = clay loam, SC = sandy clay, L = loam, CL = clay loam, FS = fine sand, CS = coarse sand, AJS = Ajali Sandstone, NPS = Nkporo Shale, FBS = False-bedded Sandstone, CSS = Clayey Sand and Shale, ALV = Alluvium, LCS = Lignite, Claystone and Shale

Table 2. Mean effect of geological formations on the soil chemical properties

Geology	**pH**		**OC**	**TN**	**Ca^{2+}**	**Mg^{2+}**	**Na^{+}**	**K^{+}**	**H^{+}**	**AL^{3+}**	**CEC**	**Av. P**	**%BS**
	H_2O	**KCl**	**g kg^{-1}**		**----------------------------------cmol kg^{-1}----------------------------------**							**mg kg^{-1}**	
AJS	5.3	4.3	0.84	0.13	1.20	0.80	0.04	0.10	1.60	0.23	10.72	4.28	19.98
NPS	4.7	4.0	2.16	0.16	0.80	1.00	0.09	0.13	4.59	2.54	34.14	5.79	5.98
FBS	6.3	5.4	0.96	0.09	0.40	0.60	0.04	0.07	2.44	0.70	23.77	4.31	5.14
CSS	6.2	5.1	2.12	0.15	2.40	1.87	0.08	0.14	1.13	0.20	22.00	11.00	30.66
ALV	5.0	3.6	0.71	0.16	1.60	2.03	0.03	0.06	2.27	0.46	21.63	6.79	17.25
LCS	5.9	4.9	1.26	0.12	1.20	0.20	0.05	0.07	2.27	0.46	31.43	12.64	4.79
F-LSD	1.06	0.94	Ns	Ns	0.66	Ns	Ns	Ns	0.84	0.7	10.24	2.68	Ns

NS = not significant, OC = organic carbon, TN = total nitrogen, Ca^{2+} = exchangeable calcium, Mg^{2+} = exchangeable magnesium, Na^{+} = exchangeable sodium, K^{+} = exchangeable potassium, Al^{3+} = exchangeable aluminium, CEC = cation exchange capacity, Av. P = available phosphorus, BS = percentage base saturation, AJS = Ajali Sandstone, NPS = Nkporo Shale, FBS = False-bedded Sandstone, CSS = Clayey Sand and Shale, ALV = Alluvium, LCS = Lignite, Claystone and Shale

Table 3. Correlation between the physicochemical properties across the geological formations

	Clay	**Silt**	**FS**	**CS**	**H_2O**	**KCl**	**OC**	**TN**	**Ca^{2+}**	**Mg^{2+}**	**Na^{+}**	**K^{+}**	**H^{+}**	**AL^{3+}**	**CEC**	**Av.P**
Silt	-0.29															
FS	-.73**	0.33														
CS	0.07	-.84**	-0.47													
H_2O	-0.37	-0.22	0.08	0.38												
KCl	-0.35	-0.26	-0.03	.48*	.93**											
OC	-0.25	.47*	0.03	-0.23	0.43	0.43										
TN	-0.02	.60**	0.28	-.61**	-0.1	-0.22	.58*									
Ca^{2+}	-.73**	.62**	.73**	-.53*	0.26	0.12	0.4	.47*								
Mg^{2+}	-0.1	.60**	0.36	-.69**	0.27	0.07	.59*	.69**	.66**							
Na^{+}	-0.19	0.45	0	-0.23	0.42	0.42	.97**	.58*	0.35	.56*						
K^{+}	-0.37	.48*	0.26	-0.34	0.34	0.34	.87**	.55*	.53*	.56*	.86**					
H^{+}	.61**	0.09	-.74**	0.02	-0.42	-0.32	0.24	0.18	-.47*	-0.15	0.29	0.16				
AL^{3+}	.48*	0.26	-.61**	-0.11	-0.39	-0.29	0.34	0.26	-0.41	-0.09	0.43	0.25	.91**			
CEC	0.22	0.09	-.63**	0.27	-0.32	-0.2	0.02	-0.16	-0.33	-0.43	0.04	-0.19	.60**	.57*		
Av.P	-.63**	0.22	0.27	0.15	0.43	0.36	.47*	0.22	.57*	0.24	0.4	0.29	-0.26	-0.24	0.21	
BS	-0.46	0.43	.64**	-.51*	.48*	0.33	.62**	.57*	.76**	.86**	.58*	.69**	-0.43	-0.33	-.65**	0.35

*** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed)*

FS = fine sand, CS = coarse sand, OC = organic carbon, TN = total nitrogen, Ca^{2+} = exchangeable calcium, Mg^{2+} = exchangeable magnesium, Na^{+} = exchangeable sodium, K^{+} = exchangeable potassium, Al^{3+} = exchangeable aluminium, CEC = cation exchange capacity, Av. P = available phosphorus, BS = percentage base saturation

Cation relationships revealed that Ca^{2+} and Mg^{2+} were strongly correlated (r = 0.66**), reflecting their common geochemical behavior and potential co-occurrence from the weathering of feldspar and carbonate minerals. Both cations also exhibited positive associations with BS (r = 0.76** and r = 0.86**, respectively), confirming that they are the dominant base-forming elements in these soils.

A strong positive correlation between H^+ and Al^{3+} (r = 0.91**) was recorded, signifying that exchangeable acidity is governed mainly by aluminium hydrolysis, a condition typical of strongly weathered soils derived from NS and FSS materials. Similarly, Al^{3+} was positively correlated with CEC (r = 0.57*), indicating that even though the soils are acidic, variable-charge minerals and organic colloids still contribute to cation retention.

The correlation between Av. P and Ca^{2+} (r = 0.57*) suggests that part of the phosphorus in these soils may exist as calcium-bound forms, especially in the less acidic, AL. Conversely, the negative association between Av. P and clay (r = -0.63**) implies phosphorus fixation by clay minerals and oxides in fine-textured soils, a process that limits P availability under acidic conditions.

4. Conclusions

This study confirmed that soil physicochemical properties in Enugu and Anambra States vary significantly with underlying geological formations. Soil derived from NS were strongly acidic with high exchangeable aluminium and clay content, while those formed from sandstone formations (AS and FSS) were coarse-textured, low in nutrient retention and CEC. In contrast, AL soils were near-neutral in pH, rich in silt, and higher base saturation. Soils from LCS and CSS exhibited intermediate characteristics, moderate acidity, and balanced nutrient content, suggesting better agricultural potential. The correlation results confirmed strong relationships among soil pH, exchangeable acidity, base cations, and CEC. In light of the findings, soils developed on NS, AS, and FSS require concerted management interventions, including liming to reduce acidity, incorporating organic matter to enhance structure and nutrient retention, and controlling erosion through mulching and cover cropping. Regular monitoring of soil chemical properties is further recommended to ensure balanced nutrient management and long-term agricultural sustainability across the diverse geological formations of Enugu and Anambra State.

Disclaimer (Artificial Intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

Competing Interests

Authors have declared that they have no known competing financial interests OR non-financial interests OR personal relationships that could have appeared to influence the work reported in this paper.

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