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Characterization and classification of some soils formed from coastal plain sands origin in Edo State, Nigeria

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Abstract

The aim of this research was to map and classify some soils of coastal plain sands origin in Edo State, Nigeria. The study covered two areas, including Site A (4 hectares) and Site B (12 hectares). The methodology used was a systematic soil survey using a rigid grid at detailed scales (1:5000 for Site A and 1:10,000 for Site B), with two mapping units delineated at each site. A representative pedon was excavated in each mapping unit, described, and sampled for analysis. Soil samples were analyzed using standard laboratory methods, and the data were processed with descriptive statistics. Soil classification followed USDA soil taxonomy, the World Reference Base for Soil Resources, and local systems. The morphological properties showed reddish soil colors when moist, with structures varying from single grain crumb to sub-angular blocky, and textures from sand to sandy clay loam. The content of sand, silt, and clay ranged from ≥742.0 to ≤886.00 g/kg, from ≥15.00 to ≤26.00 g/kg, and from ≥88.00 to ≤190.00 g/kg, respectively. Meanwhile, pH, organic carbon, cation exchange capacity, and base saturation ranged from ≥5.24 to ≤5.58, from ≥4.80 to ≤13.70, from ≥6.71 to ≤11.90 cmol/kg, and from ≥9.80 to ≤21.60 cmol/kg, consecutively. Pedons 2A and 2B were classified as Rhodic kandiudults by USDA, Rhodic Nudiargic Acrisols (Arenic, Vetic) by WRB, and locally as the Orlu series. Pedon 1A was classified as Typic Udipsamments by USDA, Eutric Rhodic Arenosols (Transportic) by WRB, and locally as the Ahiara series. Pedon 1B was classified as Typic Eutrudepts by USDA, Eutric Rhodic Cambisols (Arenic, Ochric) by WRB, and locally as the Kulfo series.

INTRODUCTION

Soil is a vital natural resource that supports plant growth, manages water supply, and enhances biodiversity and ecosystem services. Gaining insight into soil properties and classification is crucial for sustainable land use, agricultural productivity, and environmental protection (Seifu et al., 2023), especially in regions with diverse soil types and significant agricultural potential. Characterizing and classifying soil are essential factors in understanding soil property variability, which is the key for effective land management (Peter and Umweni, 2020). The soils in Edo state, including those from coastal plain sands, have yet to be thoroughly characterized and classified, making this study essential.

In addition to illustrating the spatial distribution of soil types, the processes of characterization and classification involve identifying and analyzing the different soil types present in a specific area, collecting information about their location, properties, characteristics and potential benefits, and documenting these data in maps and other records (Okunsebor and Umweni, 2021; Olaitan et al., 2022). This research concentrated on the characterization and classification of certain soils derived from coastal plain sands in Edo State. The soils in this region are shaped by the tropical climate and diverse geological formations,

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which present distinct characteristics that require thorough investigation.

Coastal plain sands, also known as coastal sediments, are prevalent along the Atlantic coast of West Africa, including southern Nigeria. These soils are predominantly composed of quartz and feldspar, with varying amount of clay, silt and organic matter (Adegoke et al., 2022). They are typically well drained, acidic, and low in nutrients, posing challenges for agricultural use (Nwakaudu et al., 2021). In Edo state, soils derived from coastal plain sands play a crucial role in supporting local agriculture, which is the main stay of the state's economy. However, there is paucity of detailed, region-specific data on these soils. This gap in knowledge hinders the development of tailored land management strategies and sustainable agricultural practices in the study area, as well as the entire state. Proper classification of soils in this region is necessary to predict soil behavior, guide land management decisions, and facilitate communication among soil scientists and land managers

Though earlier research has shed light on the general characteristics of coastal plain sands in Nigeria (Oko-oboh et al., 2016; Osinuga et al., 2020; Okunsebor and Umweni, 2021; Peter and Agbogun, 2022), these studies do not focus on specific regions. This study seeks to fill this gap by offering a thorough characterization and classification of the soils in the study area, thus providing a detailed identity for the soils at both local and global scales.

MATERIALS AND METHODS

The research was carried out in Iguzama Community, located in the Ovia North East Local Government Area of Edo State, Nigeria. As depicted in Figures 1 and 2, the study area includes two sites: Site A, covering 4 hectares (Figure 1), is situated

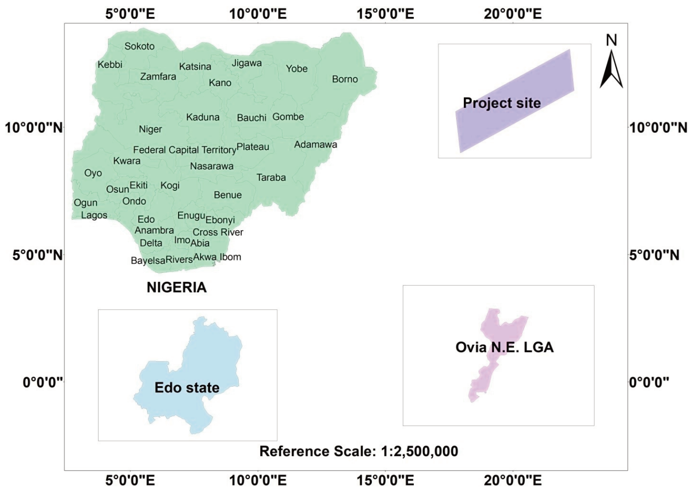

Figure 1. Map of site A

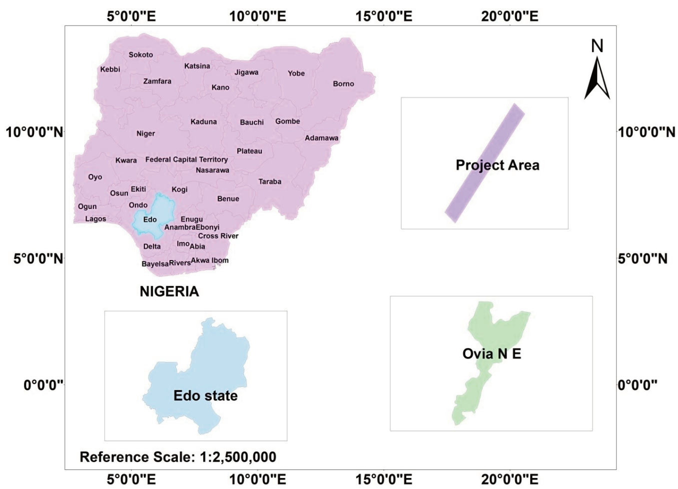

Figure 2. Map of site B

between Latitudes 6°24'40" N and 6°24'45" N and Longitudes 5°28'25" E and 5°28'35" E. Site B spans 12 hectares (Figure 3) and is located between Latitudes 6°24'30" N and 6°25'0" N and Longitudes 5°28'30" E and 5°29'0" E. The area is characterized by a tropical climate, with an annual average rainfall of 1900 mm, mean annual temperatures ranging from 23°C to 37°C, and mean annual relative humidity ranging from 89% in the morning (10:00 am) to 75% in the evening (4:00 pm), based on data collected over 18 years (NIFOR, 2018).

The soils originated from coastal plain sand, which is derived from sedimentary rock that has experienced extensive weathering due to heavy rainfall and high temperatures (Nigeria Geological Survey Agency, 2008). The terrain is a terrace, with slopes ranging from 2.59% to 6.09% in Site A and 0.2% to 5.9% in Site B.

Field studies

Soil survey was conducted on site A (4ha) and site B (12 ha) using the rigid grid systematic survey method at a detailed scale, resulting in two observation points per hectare in site A and one observation point per hectare in site B, according to guideline of Dent and Young (1981). Traverses were cut at intervals of 100m apart; along the traverses, observation points (50 m apart for site A and 100 m apart for site B) were located using a GPS (global position system), in which Site A had eight observation points (Figure 3), while Site B had twelve (Figure 4). Soil samples were examined at depth intervals of 30 cm, 60 cm, 90 cm and 120 cm using a soil auger. The morphological properties, which include texture by feel, color with the aid of Munsell soil color chart (Munsell, 1994), vegetation, and slope position, were studied on the

Figure 3. Google imagery of site A showing auger points

Figure 4. Google imagery of site B showing auger points

field and recorded on their respective proforma sheet. Mapping units were delineated based on similarities in properties and characteristics; two mapping units were delineated in each study site. Pedons measuring 2 m x 2 m x 2 m in dimension were sunk at representative points in each mapping unit and described appropriately according to the guidelines of FAO (2006). The observed horizons were sampled from below to the top, collected in polythene bags and labeled properly for laboratory analysis.

Laboratory analysis

The soil samples from each horizon were air-dried and passed through a 2mm sieve. The sieved samples were analyzed for some physical and chemical properties as shown in Table 1.

Statistical analysis

The data collected were statistically analyzed using Genstat (version 8.1). The variability of soil properties across different horizons within the pedons was assessed using the coefficient of variation (CV). The coefficient of variation was categorized following the method outlined by Wilding et al. (1994), where a CV of less than 15% indicates low variation (LV), a CV between 15% and 35% indicates moderate variation (MV), and a CV greater than 35% indicates high variation (HV).

Soil map

A soil map was generated for Site A at a scale of 1:500 and for Site B at a scale of 1:1,500 using data from both field and laboratory analyses.

Soil classification

Data obtained from the field and laboratory analyses were used to classify the soils in the appropriate local series using Moss (1957) as updated by Ogunkunle (1983). The local classification was correlated with the USDA Soil Taxonomy (Soil Survey Staff, 2014) and World Reference Base for soil Resources (IUSS, 2015).

RESULTS AND DISCUSSION

Table 2 presents key morphological properties of the study area's soils (Sites A and B). Overall, the soils were deep, well-drained, and without any sign of flooding. The soil color ranged from dark reddish brown (2.5YR3/3) to red (2.5YR4/6, 2.5YR4/8) in pedon 1A; dusky red (2.5YR5/2), dark red (2.5YR3/6) to red (2.5YR4/6, 2.5YR4/8) in pedon 2A; very dusky red (2.5YR2.5/2), dark reddish brown (2.5YR3/4) to red (2.5YR4/6, 2.5YR4/6) in pedon 1B; and dusky red (2.5YR3/2) to red (2.5YR4/6, 2.5YR4/8) in pedon 2B (Munsell, 1994). The dominance of red color (2.5YR) in the area likely indicates good drainage conditions

Table 1. Laboratory analysis

Soil property	Method of determination
Particle size distribution	Hydrometer method (Gee and Or, 2002); after the removal of organic matter content with hydrogen peroxide and dispersion with sodium hexametaphosphate (IITA, 1979)
Available P	Bray-1 method (Olsen and Sommers, 1982)
pH	Glass electrode pH meter in soil: soil and water at ratio 1:1 (Maclean, 1982)
Exchangeable bases (Na, K, Ca and Mg)	Extraction with neutral normal ammonium acetate (NH4OAC at pH 7.0)
Na and K	Flame photometer
Ca and Mg	Atomic absorption spectro photometer (Thomas, 1982)
Total N	Macro Kjedhal method (Bremner, 1996)
Exchangeable acidity	titration method (Anderson and Ingram, 1993)
Organic carbon	Wet oxidation method (Page, 1982)
Effective cation exchange capacity (ECEC)	Summation of Exchangeable Bases and Exchangeable Acidity (Tan, 1996)
Base saturation	The sum of Exchangeable Bases (Na, K, Ca and Mg) by the ECEC and multiplying the quotient by 100

Table 2. Soil morphological properties of the study area

Pedon	Horizon Desig.	Depth (cm)	Colour (moist)	Texture	Roots abundance	Structure	Boundary form
Site A							
1A	Ap	0–13	2.5YR3/3	Sand	Fine many	Very fine single grain crumb	Smooth-clear
	AB	13–33	2.5YR4/8	Loamy sand	Medium many	Fine/medium sub-angular blocky	Smooth-diffuse
	BA	33–69	2.5YR4/6	Sandy loam	Coarse very few	Medium sub-angular blocky	Smooth-diffuse
	B1	69–121	2.5YR4/6	Sandy clay loam	Fine very few	Medium sub-angular blocky	Smooth-clear
	B2	121–180	2.5YR4/6	Sandy clay loam	Fine very few	Medium sub-angular blocky	-
2A	Ap	0–15	2.5YR3/2	Sand	Fine many	Fine single grain crumb	Smooth-clear
	Bt1	15–39	2.5YR3/6	Sandy loam	Fine/medium many	Fine sub-angular blocky	Smooth-diffuse
	Bt2	39–76	2.5YR4/6	Sandy clay loam	Coarse few	Fine sub-angular blocky	Smooth-diffuse
	Bt3	76–127	2.5YR4/8	Sandy clay	Medium very few	Medium sub-angular blocky	Smooth-diffuse
	Bt4	127–169	2.5YR4/8	Sandy clay	-	Medium sub-angular blocky	-
Site B							
1B	Ap	0–11	2.5YR2.5/2	Sand	Medium many	Fine single grain crumb	Smooth-clear
	Bw1	11–27	2.5YR3/4	Loamy sand	Medium many	Fine sub-angular blocky	Smooth-diffuse
	Bw2	27–59	2.5YR4/6	Loamy sand	Medium few	Medium sub-angular blocky	Smooth-diffuse
	Bw3	59–101	2.5YR4/6	Sandy clay loam	Medium very few	Medium sub-angular blocky	Smooth-diffuse
	Bw4	101–175	2.5YR4/8	Sandy clay loam	-	Medium sub-angular blocky	-
2B	Ap	0–17	2.5YR3/2	Loamy sand	Medium many	Very fine single grain crumb	Smooth-clear
	Bt1	17–34	2.5YR4/8	Sandy clay loam	Medium many	Fine sub-angular blocky	Smooth-diffuse
	Bt2	34–78	2.5YR4/6	Sandy clay loam	Medium few	Medium sub-angular blocky	Smooth-diffuse
	Bt3	78–116	2.5YR4/6	Sandy clay loam	Fine few	Medium sub-angular blocky	Smooth-diffuse
	Bt4	116–183	2.5YR4/6	Sandy clay	Fine very few	Medium sub-angular blocky	-

and the nature of the soil's parent material (Okunsebor and Umweni, 2021; Okunsebor et al., 2021). The Ap horizon exhibited a sandy texture, while the B horizon varied from loamy sand (pedons 1A and 2A) to sandy loam (pedons 2A and 1B) and sandy clay loam (pedons 2A and 2B). The prevalence of sand in the soil profiles may be due to the parent material (coastal plain sand), high leaching rates, and the slope position (Osujieke et al., 2018). Soil structure ranged from single-grain crumb in the Ap horizon to fine/medium sub-angular blocky in the B horizon. The predominance of sub-angular blocky structure may be linked to the high rate of argilluviation in the study area. Root abundance was high in the surface horizon but decreased from many to very few in the B horizon across all pedons. This variation in root abundance could indicate differences in microbial activity within the soil profiles. The boundary form ranged from smooth clear in the Ap horizon to smooth diffuse in the B horizon across all pedons.

Soil physical and chemical properties

The physical and chemical properties of the soils (Table 3) indicated that the pH values ranged from very strongly acidic (4.86) to slightly acidic (6.22) in pedon 1A; from strongly acidic (5.18−5.26) to slightly acidic (6.14−6.38) in pedons 2A and 1B; and from strongly acidic (5.26) to moderately acidic in pedon 2B, based on Chude et al. (2011) classifications. The average pH values were 5.24, 5.58, 5.53, and 5.40 for pedons 1A, 2A, 1B, and 2B, respectively. The acidity of these soils is likely due to the acidic parent material, the organic matter content, the local climate, and the slope position (Weil and Brady, 2017; Osujieke et al., 2018). Organic carbon showed considerable variability (≥59.70% to ≤110.10%) across all pedons, reflecting that acidic sands generally have low organic matter, with litter fall and increased soil biodiversity contributing to this variation. Total Nitrogen was low in all pedons according to Chude et al. (2011), with mean values of 0.66, 0.48, 0.40, and 0.58 g/kg for pedons 1A, 2A, 1B, and 2B, respectively, and a high variation (≥58.60% to ≤113.00%). This low nitrogen level is likely due to factors such as crop harvest and burning of bushes and residues, which increase nitrogen volatilization (Osujieke et al., 2018).

Available phosphorus levels varied across the pedons, with values ranging from 1.72 to 44.47 mg/kg in pedon 1A, 1.30 to 13.14 mg/kg in pedon 2A, 2.46 to 5.61 mg/kg in pedon 1B, and 1.72 to 6.48 mg/kg in pedon 2B. According to the ratings by Chude et al. (2011), Landon (1991), and FDALR (1985), these

Table 3. Soil physical and chemical properties of the study area

Pedon ID	Horizon Design.	Horizon Depth	Ph	EC	Org. C	Org. matter	Total N.	Avail P	Ca	Mg	Na	K	H	Al	ECEC	CEC	ECEC-CLAY	BS	BS-CEC	SAND	SILT	CLAY	TC
		cm	H20	µS/cm	gkg⁻¹		gkg⁻¹	mgkg⁻¹	cmolkg⁻¹	cmolkg⁻¹	cmolkg⁻¹	cmolkg⁻¹	cmolkg⁻¹	cmolkg⁻¹	cmolkg⁻¹	cmolkg⁻¹	cmolkg⁻¹	cmolkg⁻¹	%	gkg⁻¹	gkg⁻¹	gkg⁻¹	
06.41313°N, 005.47692°E; 49 m ASL																							
1a	Ap	0-13	6.22	109.70	23.13	39.87	1.93	44.47	2.58	0.38	0.34	0.19	0.1	0.00	3.58	9.40	119.33	97.21	37.00	960.00	10.00	30.00	S
	AB	13-33	5.1	70.00	7.98	13.76	0.66	7.18	0.60	0.15	0.19	0.08	0.24	1.06	2.33	3.60	38.83	44.09	28.61	920.00	20.00	60.00	S
	BA	33-69	4.86	95.70	4.23	7.30	0.35	3.05	0.43	0.23	0.19	0.05	0.26	1.20	2.35	6.02	26.11	37.93	14.78	870.00	40.00	90.00	S
	B1	69-121	5.02	46.30	3.09	5.33	0.24	2.46	0.55	0.08	0.24	0.07	0.18	0.92	2.03	7.07	16.91	45.87	13.15	850.00	30.00	120.00	LS
	B2	121-180	5.02	65.10	1.30	2.25	0.10	1.72	0.55	0.08	0.29	0.17	0.16	0.82	2.06	7.45	14.71	52.52	14.49	830.00	30.00	140.00	LS
		Mean	5.24	77.36	7.90	13.70	0.66	11.80	0.94	0.18	0.25	0.11	0.19	0.80	2.47	6.71	43.00	56.00	21.6	886.00	26.00	88.00	
		CV	10.50	32.60	111.20	111.10	113.00	156.20	97.40	68.40	26.10	56.60	34.10	58.70	25.80	21.30	101.00	43.00	49.20	6.00	43.90	50.40	
		Ranking	LV	MV	HV	HV	HV	HV	HV	HV	MV	HV	MV	HV	MV	MV	HV	HV	HV	LV	HV	HV	
06.41168°N, 005.47450°E; 60 m ASL																							
2a	Ap	0-15	6.14	97.80	14.01	24.15	1.17	13.14	1.70	0.25	0.43	0.29	0.1	0.00	2.78	6.40	86.88	75.68	41.87	924.00	44.00	32.00	S
	Bt1	15-39	5.5	46.20	5.86	10.11	0.49	2.63	0.60	0.10	0.24	0.11	0.18	0.86	2.09	10.00	13.06	89.32	10.50	800.00	40.00	160.00	SL
	Bt2	39-76	5.34	34.80	3.58	6.18	0.30	1.30	0.50	0.10	0.14	0.02	0.18	1.00	1.94	10.74	10.21	84.22	7.08	790.00	20.00	190.00	SL
	Bt3	76-127	5.26	32.50	2.93	5.05	0.24	1.80	0.40	0.15	0.19	0.01	0.2	1.00	1.95	13.01	8.13	75.66	5.76	700.00	20.00	240.00	SCL
	Bt4	127-169	5.66	25.50	2.44	4.21	0.19	2.38	0.97	0.18	0.19	0.01	0.16	0.70	2.21	16.34	7.13	61.09	8.26	680.00	10.00	310.00	SCL
		Mean	5.58	47.00	5.80	9.90	0.48	4.20	0.83	0.16	0.24	0.09	0.16	0.71	2.19	11.30	25.00	77.20	14.7	787.00	26.80	186.00	
		CV	6.20	61.60	833.10	83.10	84.40	117.60	63.50	40.20	47.50	136.90	23.50	58.50	15.80	32.60	138.00	13.90	103.9	11.50	54.20	55.40	
		Ranking	LV	HV	HV	HV	HV	HV	HV	HV	HV	HV	MV	HV	MV	MV	HV	LV	HV	LV	HV	HV	
06.41097°N, 005.47964°E; 58 m ASL																							
1b	Ap	0-11	6.38	61.90	9.12	15.72	0.76	5.61	1.60	0.20	0.24	0.08	0.04	0.08	2.24	7.14	28.00	94.64	29.70	900.00	20.00	80.00	S
	Bw1	11-27	5.58	47.70	5.86	10.11	0.49	2.55	0.75	0.30	0.14	0.03	0.16	0.52	1.90	8.00	15.83	64.25	15.25	860.00	20.00	120.00	LS
	Bw2	27-59	5.26	41.20	4.15	7.16	0.35	3.05	0.46	0.19	0.19	0.02	0.19	1.10	2.16	8.43	15.43	40.14	10.32	850.00	20.00	140.00	LS
	Bw3	59-101	5.18	39.10	3.09	5.33	0.26	2.63	0.42	0.28	0.10	0.02	0.23	1.00	2.04	10.32	11.03	39.79	7.85	800.00	15.00	185.00	SL
	Bw4	101-175	5.26	33.80	1.71	2.95	0.15	2.46	0.50	0.25	0.19	0.01	0.16	1.12	2.23	10.09	11.74	42.71	9.42	800.00	10.00	190.00	SL
		Mean	5.53	44.70	4.80	8.30	0.40	3.26	0.75	0.24	0.17	0.03	0.16	0.76	2.11	8.80	16.40	56.00	14.5	842.00	15.00	143.00	
		CV	9.00	24.20	59.70	59.70	58.60	40.90	66.30	19.80	31.10	86.70	45.50	59.40	6.80	15.50	41.60	42.10	61.50	5.10	33.30	32.20	
		Ranking	LV	MV	HV	HV	HV	HV	HV	MV	MV	HV	HV	HV	LV	MV	HV		HV	LV	MV	MV	
06.41547°N, 005.48365°E; 96 m ASL																							
2b	Ap	0-17	5.82	63.20	19.22	33.13	1.64	6.48	1.50	0.50	0.24	0.12	0.08	0.10	2.54	10.13	36.28	92.92	23.30	900.00	30.00	70.00	S
	Bt1	17-34	5.26	36.50	5.70	9.83	0.47	2.71	0.46	0.19	0.10	0.02	0.22	0.98	1.96	8.47	15.08	38.87	8.97	850.00	20.00	130.00	SL
	Bt2	34-78	5.34	34.30	4.23	7.30	0.35	5.00	0.43	0.27	0.10	0.01	0.19	1.11	2.10	11.46	10.50	38.16	6.98	790.00	10.00	200.00	SCL
	Bt3	78-116	5.26	32.00	3.09	5.33	0.26	2.71	0.42	0.18	0.10	0.01	0.17	1.25	2.12	12.56	9.22	33.08	5.57	760.00	10.00	230.00	SCL
	Bt4	116-183	5.34	29.10	2.04	3.51	0.17	1.72	0.36	0.19	0.14	0.01	0.19	0.90	1.79	16.70	5.59	39.12	4.19	660.00	20.00	320.00	SCL
		Mean	5.40	39.00	6.90	11.80	0.58	3.72	0.63	0.27	0.14	0.03	0.17	0.87	2.10	11.90	15.30	48.00	9.80	792.00	18.00	190.00	
		CV	4.40	35.30	102.70	102.70	104.50	52.50	76.60	51.00	44.60	142.00	31.40	51.80	13.20	26.20	79.50	51.60	78.80	11.60	46.50	50.30	
		Ranking	LV	MV	HV	HV	HV	HV	HV	HV	HV	HV	MV	HV	LV	MV	HV		HV	LV	HV	HV	

levels are classified in as very low to high in pedon 1A, very low to moderate in pedon 2A, and very low to low in both pedons 1B and 2B. The variation in available phosphorus was significant, ranging from 40.90% to 156.20%, likely due to factors such as soil erosion from surface runoff, removal of biomass during harvest, and phosphorus fixation. Acidic soils tend to fix phosphorus due to the formation of insoluble aluminum-phosphorus complexes (Okunsebor et al., 2024).

The results for exchangeable bases indicated that Calcium (Ca) was the most dominant basic cation in the soils of the study area. The Ca content ranged from 0.36 to 2.58 cmol/kg, while Magnesium (Mg), sodium (Na), and Potassium (K) content ranged from 0.08 to 0.50 cmol/kg, from 0.10 to 0.43 cmol/kg, and from 0.01 to 0.29 cmol/kg, respectively, across all the pedons. According to the ratings by Landon (1991) and Chude et al. (2011), the exchangeable bases were generally low in all pedons. The variation in Ca content was high (ranging from ≥63.50% to ≤97.40%), and the variation in K was also significant (ranging from ≥56% to ≤142%). For Mg, the variation was moderate in pedon 1B but high in the other pedons (ranging from ≥19.80% to ≤68.40%). Na showed moderate variation in pedons 1A and 1B but high variation in pedons 2A and 2B (ranging from ≥26.10% to ≤47.50%). The low levels of exchangeable bases in the area could be linked to the parent material of the soils (coastal plain sands). Additionally, the irregular trend of exchangeable bases with increasing depth might be due to the downward movement of materials within the soil profile.

The results for exchangeable acidity (Table 2) indicated that hydrogen levels across all the pedons ranged from 0.04 to 0.26 cmol/kg, with moderate variation (23.50% to 34.10%) observed in pedons 1A, 2A, and 2B, and a higher variation of 45.05% in pedon 1B. Aluminum levels ranged from 0.00 to 1.2 cmol/kg across all pedons, with a high variation (51.89% to 59.40%) in each pedon.

The Cation Exchange Capacity (CEC) across all the pedons ranged from 3.60 to 16.70 cmol/kg. The variation was moderate, between 15.50% and 32.60%, across the pedons. The Effective Cation Exchange Capacity (ECEC) was between 1.39 and 3.58 cmol/kg in all the pedons, falling below the critical threshold of 12 cmol/kg, which is considered suitable for crop production (FAO, 2006; Ekong and Uduak, 2015). The ECEC showed low variability, ranging from 51.89% to 59.40%.

The sand fraction was the most abundant among the particle size components, with mean values of 886, 787, 842, and 792 g/kg, respectively, across all the pedons. The variation was minimal (between 5.10% and 11.60%), likely due to the uniformity of the parent material (coastal plain sand) in the study area (Osujieke et al., 2018; Okunsebor and Umweni, 2021). The silt fraction had mean values of 26, 26, 15, and 18 g/kg for all the pedons, with the low silt content indicating a high rate of eluviation in the area. Variation ranged from moderate (33.30% in pedon 1B) to high (43.90% to 54.20% in pedons 1A, 1B, and 2B). The clay fraction had mean values ranging from 88.00 to 190.00 g/kg. Clay content increased with depth, indicating the presence of argillic or Cambic horizons in some pedons. The higher clay content in subsurface soils suggests active pedogenesis and argilluviation in the study area. The variation in clay content ranged from moderate (32.20% in pedon 1B) to high (50.30% to 55.40%).

Soil classification

Soil classification was conducted using the methods of Moss (1957), later updated by Ogunkunle (1983) for local or series classification, along with the USDA soil taxonomy and the World Reference Base for Soil Resources classification systems. The soils were labeled as 1A, 2A, 1B, and 2B. The study area generally exhibits an udic moisture regime and an isohyperthermic soil temperature regime. Pedons 2A and 2B were classified as Ultisols due to the presence of an argillic horizon and a base saturation value below 35% at the relevant depth. Pedon 1B was identified as an Inceptisol because of the presence of a cambic horizon. However, Pedon 1 lacked any genetic horizon or significant morphological features aside from color, leading to its classification as an Entisol.

At the sub-order level, pedons 2A and 2B were classified as Udults due to the presence of an udic moisture regime. They were identified as Kandiudults at the great group level because both pedons contained a kandic horizon at the required depth. At the subgroup level, they were classified as Rhodic Kandiudults because they exhibited a hue of 2.5YR. At the family level, pedons 2A and 2B were classified as Sandy Kaolinitic Isohyperthermic Rhodic Kandiudults, based on the area's sandy surface texture, isohyperthermic temperature regime, and kaolinitic mineral class (USDA soil taxonomy, 2014; Okunsebor and Umweni, 2021; Ogunkunle, 1983). Locally, they were identified as belonging to the Orlu series. Pedon 2A was designated as the normal phase of the Orlu series because it exhibited a sandy loam (SL) texture at 30–60 cm depth and a sandy clay loam (SCL) texture at 90–120 cm depth. In contrast, Pedon 2B was classified as the clayey phase of the Orlu series due to its sandy clay loam texture at both 30–60 cm and 90–120 cm depths. The Orlu series generally has an acidic nature, with sandy loam to sandy clay loam texture, sub-angular blocky structure, and low organic matter content (Igwe and Obalum, 2020; Nwosu and Okeke, 2023). They were correlated as Rhodic Nudiargic Acrisols (Loamic, Vetic) in the WRB classification system (IUSS, 2015).

Pedon 1A was identified as Psamments at the sub-order level because it contained less than 35% rock fragments by volume and had a texture of sand to loamy sand throughout its layers. At the great group level, it was classified as Udipsamments due to the presence of an udic moisture regime in the study area. At the subgroup level, it was further classified as Typic Udipsamments, indicating the absence of lithic contact, redox depletion, plaggen epipedon, and water saturation in the pedon. According to the USDA soil taxonomy (Soil Survey Staff, 2014), it was classified at the family level as Sandy Kaolinitic Isohyperthermic Typic Udipsamment, and locally, it was identified as the Ahiara series (Sandy phase) due to its sand texture at depths of 30−60 cm and loamy sand at depths of 90−120 cm. The Ahiara series is known for its acid sands and is generally sandier due to the accumulation of colluvial sand from higher elevations, typically lacking gravel, stones, or concretions (Ogidiolu and Adebayo, 2021; Onweremadu et al., 2022; Nwakaudu et al., 2023). It correlates with Protic Rhodic Arenosols

(Ochric).

Pedon 1B was classified as Udepts at the sub-order level due to the presence of an udic moisture regime. At the great group level, it was identified as Dystrudepts because its Base Saturation was less than 60% in most horizons at depths between 25 and 75 cm of the mineral soil. At the subgroup level, it was classified as Typic Dystrudepts because it exhibited typical characteristics of Dystrudepts. At the family level, the pedon was further classified as Sandy Kaolinitic Isohyperthermic Typic Dystrudept according to the USDA Soil Taxonomy (Soil Survey Staff, 2014). Locally, it was identified as the Kulfo series (normal phase) due to its loamy sand texture at depths of 30–60 cm

Table 4. Summary of soil classification in the study area

Site	Pedon	Size (Ha)	USDA	Local/Series	WRB
A	1	1.65	Sandy Kaolinitic Isohyperthermic Typic Udipsamment	Ahiara Sandy	Protic Rhodic Arenosols (Ochric)
	2	2.64	Sandy Kaolinitic Isohyperthermic Rhodic Kandiudult	Orlu normal	Rhodic Nudiargic Acrisols (Loamic, Vetic)
B	1	6.4	Sandy Kaolinitic Isohyperthermic Typic Dystrudept	Kulfo normal	Dystric Rhodic Cambisols (Arenic, Ochric)
	2	5.69	Sandy Kaolinitic Isohyperthermic Rhodic Kandiudult	Orlu Clayey	Rhodic Nudiargic Acrisols (Loamic, Vetic)

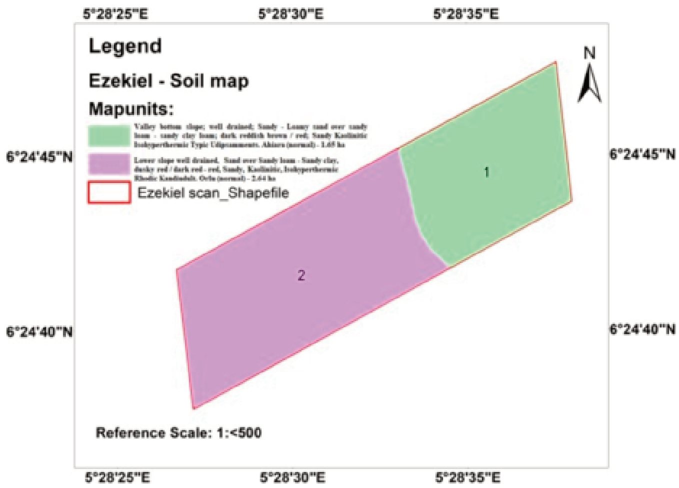

Figure 5. Soil map for site A

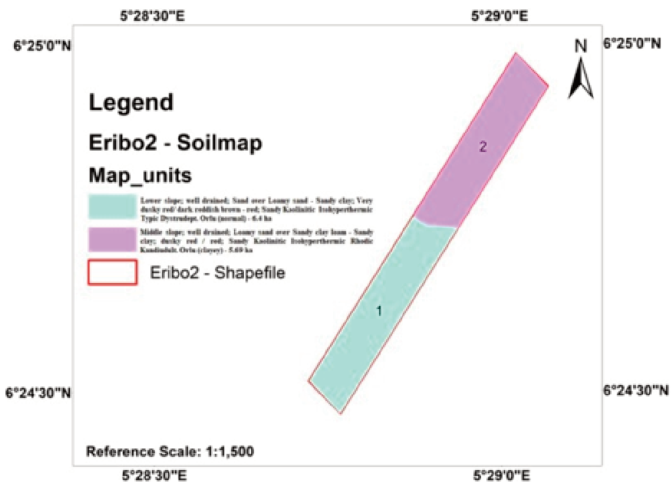

Figure 6. Soil map for site B

and sandy loam texture at depths of 90–120 cm (Ogunkunle, 1983). The Kulfo series is characterized by homogeneous, reddish-brown to red, and well-drained soils with low exchangeable bases and base saturation, indicating that the exchange sites on soil colloids are primarily occupied by reserved acidity (Akamigbo, 2021; Oguike et al., 2023). It corresponds to Dystric Rhodic Cambisols (Arenic, Ochric) in WRB.

Soil classification by the two systems, USDA Soil Taxonomy and WRB, gave different nomenclature for the study area; these differences are traceable to the categories and hierarchical nature of both taxonomic systems. The USDA consists of 6 categories and soil order, in which the highest category is based on the presence of diagnostic horizons including consequences of variation in climatic conditions (Soil Survey Staff, 2014); while the WRB system of soil taxonomy has two categories; the higher category (Reference Soil Group) roughly correlates with USDA at the Great group level because classification is mainly based on the presence of diagnostic horizons (IUSS, 2015; Deckers et al., 2003). Moreover, the USDA soil taxonomy has 12 soil orders, while WRB has 52 Soil Reference Groups (Soil Survey Staff, 2014; IUSS, 2015); thus, both systems are intrinsically different.

Soil classification using the USDA Soil Taxonomy and the WRB systems resulted in different nomenclature for the study area. These differences arise from the categories and hierarchical structures of the two taxonomic systems. The USDA Soil Taxonomy features six categories, with the highest level being the soil order, which is determined by the presence of diagnostic horizons and the effects of climatic variations (Soil Survey Staff, 2014). In contrast, the WRB system has two categories, with the highest category, the Reference Soil Group, roughly corresponding to the USDA's Great Group level, as it also relies on diagnostic horizons for classification (IUSS, 2015; Deckers et al., 2003). Furthermore, the USDA system includes 12 soil orders, while the WRB system has 52 Soil Reference Groups (Soil Survey Staff, 2014; IUSS, 2015), highlighting the fundamental differences between the two systems.

In the study area, Moss classification, updated by Ogunkunle, identified three soil series, consisting of Ahiara, Kulfo, and Orlu. These correspond to Entisols, Inceptisols, and Ultisols in USDA soil taxonomy and Arenosols, Cambisols, and Acrisols in WRB. Table 4 summarizes the soil classification and the area covered by each soil type, while Figures 5 and 6 present the soil maps. A direct correlation between USDA soil taxonomy and WRB is challenging; for example, Ultisols, which classifies soils with clay-rich subsoil and base saturation below 35% at a given depth, might be categorized as Acrisols or Alisols in WRB. This aligns with the view that perfect correlation between the two systems is only achievable for a few Reference Soil Groups−Andosols, Histosols, and Vertisols−while others only partially match (Deckers et al., 2003). Additionally, classifying soils at the series level in USDA soil taxonomy helps reduce variability in soil properties, promoting consistency in management practices, crop yields, and environmental sustainability (Obi et al., 2020).

CONCLUSIONS

This study identified three soil orders, including Entisols (Arenosols) and Ultisols (Acrisols) at site A and Inceptisols (Camisols) and Ultisols (Acrisols) at site B. The study area also contained three soil series, namely Ahiara and Orlu at site A and Orlu and Kulfo at site B. Morphologically, pedons 2A, 1B, and 2B had an Ochric epipedon; pedons 2A and 2B had a Kandic endopedon; pedon 1B had a Cambic endopedon; and pedon 1A lacked a clearly defined diagnostic horizon. The USDA soil taxonomy requires both meteorological and laboratory data along with field data, whereas the WRB only needs laboratory and field data. Meteorological data are often scarce in developing countries, particularly in rural areas, making the WRB a useful alternative. Despite its limited global acceptance, the USDA soil taxonomy is recommended for this study due to its inclusion of the series category and its comprehensive approach, given the scope of this work. In general, both taxonomic systems are valuable for providing balanced information on tropical soils.

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