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Morphological Characterization and Classification of Soils in Khana Area of Niger Delta, Nigeria

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Abstract
The soils in Khana area, Rivers State, were classified using the USDA Soil Taxonomy Classification System. Seven soil pedons were sampled, focusing on genetic horizons, along three transects and on five major land-use types. All pedons displayed Cambic subsurface horizons beneath epipedons. USDA Soil classification of pedons in Khana area are mainly Inceptisols and Ultisols. Soil pH ranged from moderately acidic (5.7 – 6.9) across various pedons. Total Nitrogen content varied significantly ($p < 0.05$), with cultivated land having the lowest (0.4g/kg) and forested soil having the highest (2.3g/kg) surface horizon values. Exchangeable bases (Potassium, Magnesium, Calcium, Sodium) also varied significantly ($p < 0.05$), spanning from 0.28 - 2.00 cmol/kg; 0.01 - 1.96 cmol/kg; 0.50 - 2.00 cmol/kg; and 0.25 - 1.64 cmol/kg for Potassium, Magnesium, Calcium, and Sodium, respectively. Bulk density, saturated hydraulic conductivity, and mean weight diameter differed significantly ($P < 0.05$) among land-use types. Saturated hydraulic conductivity ranged from 1.0 - 54.0 cm/hr, bulk density from 1.64 – 1.59 g/cm^3, and mean weight diameter from 1.677 – 0.597. Particle size distribution ranged from 437.0 - 787.0 g/kg; 137.0 - 300 g/kg; and 46.0 - 350.0 g/kg for sand, silt, and clay fractions, respectively. Clay content increased with depth. Among the pedons, four were generally Ultisols (Typic Hapludolls), while three (from Eeke, Taabaa, and Okwale communities) were Inceptisols (Arenic Eutrudepts). Overall, this study provides insight into the soil properties of Khana area, enabling recommendations for optimized crop cultivation, and soil management in poorly drained subsoil regions.
Key Words: *Diagnostic horizons, Morphological characterization, Inceptisols, and Ultisols.*

1.0 INTRODUCTION

The soil is a critical natural resource that plays a pivotal role in supporting agricultural productivity, ecosystem functioning, and human well-being (Adhikari & Hartemink, 2016). Its characterization and classification are

fundamental for informed land-use planning, sustainable agricultural practices, and environmental management (Esu, 2010; Brevik *et al.*, 2016). The Niger Delta region of Nigeria, known for its diverse ecosystems and significant contributions to the nation's economy, presents a unique set of soil types and properties (Adekola & Mitchell, 2011). The Niger Delta characterized by its complex network of rivers, estuaries, and wetlands, is an ecologically sensitive region that is prone to environmental challenges such as soil degradation, erosion, and pollution (Zabbey *et al.*, 2019; Abam, 2001)). Additionally, the region hosts a burgeoning agricultural sector that depends heavily on the fertility and suitability of its soils (Njoku, 2013; Udoh *et al.,* 2013). The soils of coastal plains in Nigeria have generally been derived from the alluvial deposits during the Quaternary period of the late Pleistocene to Early-Holocene times forming the coastal alluvial sands of the Niger Delta (Ugwa *et al.*, 2017; Kamalu *et al.*, 2017). Therefore, understanding the morphology and classification of soils in Khana area is imperative for the sustainable development of agriculture and the conservation of its unique ecosystems. Within this region, Khana area stands out as an intriguing site due to its geological and ecological diversity. However, comprehensive studies on the morphological characteristics and classification of soils in this specific region are limited.

Soil morphology, the study of soil form and structure, provides essential insights into soil properties, behavior, and potential uses. By examining soil profiles, texture, color, and other physical attributes, researchers can gain a deeper understanding of the soils' properties and their suitability for various land uses. Moreover, soil classification systems, such as the widely used USDA Soil Taxonomy or World Reference Base for Soil Resources, enable the categorization of soils based on their shared characteristics, aiding in land management decisions and sustainable land-use planning. The study of soil classification is crucial for soil knowledge, classification, and a complete understanding of the environment. It is the process of classifying soils according to their features. The main purpose of soil classification is to grade it into classes that give us a better understanding of the relationship among soils and between soils and the factors responsible for their characteristics (Soil Survey Staff, 1999).

To ensure that the soil is put to the most appropriate and sustainable use, there is every need for characterization and classification of the soil (Andrews *et al.*, 2004). Classifying the soil and its sources of variation will not only help in increasing agricultural productivity and good soil management but will estimate future effects of factors that may lead to soil development in the area (Soil Survey Staff - NRCS/USDA, 2014; Sanchez *et al.*, 2003). This scientific paper aims to address the gap in knowledge regarding the morphological characteristics and classification of soils in the Khana area of the Niger Delta. The objectives of this study include:

i. Characterizing the morphological properties of soils in Khana area of Niger Delta, Nigeria, including soil profile descriptions, texture analysis, and color assessments.

ii. Identify and classify soil types within the study area using the USDA soil classification system.

In the pursuit of these objectives, this research will contribute to the broader understanding of the soils in the Niger Delta region, shedding light on their unique properties and potential challenges. Furthermore, the findings of this study may serve as a foundation for the development of soil management strategies that promote agricultural sustainability and environmental conservation in the Khana area and beyond.

2.0 METHODS

2.1 Description of the Study Area

The research was conducted in Khana local government area of Rivers State, situated approximately between Latitude 4^0 40ˈ 22ˈˈ N and Longitude 7^0 21ˈ13ˈˈE. Khana LGA is one of the four local government areas in Ogoni, sharing boundaries with Oyigbo, Opobo-Nkoro, Akwa-Ibom, and Gokana in the North, South, East, and West respectively (Needam *et al.*, 2020). With a total area of about 570km^2, Khana is the largest local government in Ogoni covering approximately 56% of the total land area of Ogoni (Google-earth, 2017). Situated close to the Gulf of Guinea (Tuttle *et al.*, 1999), landform in this area was a result of alluvial deposits during the Quaternary period of the late Pleistocene to Early-Holocene times forming the coastal alluvial sands of the Niger Delta (Gradstein *et al.*, 2004, Ugwa *et al.*, 2017). The terrain is mostly flat, with moderate undulating slopes divided by shallow valleys that transport water periodically, and the texture ranges from sand to sandy loam. The study area has a tropical climate with two different seasons: wet and dry (Harmattan). The latter is generated by dusty easterly or north-easterly winds on the West African coast, which occur between December and February (Encyclopedia Britannica, 2015). With an annual average total rainfall of around 3004mm and at least seven (7) months of rain.

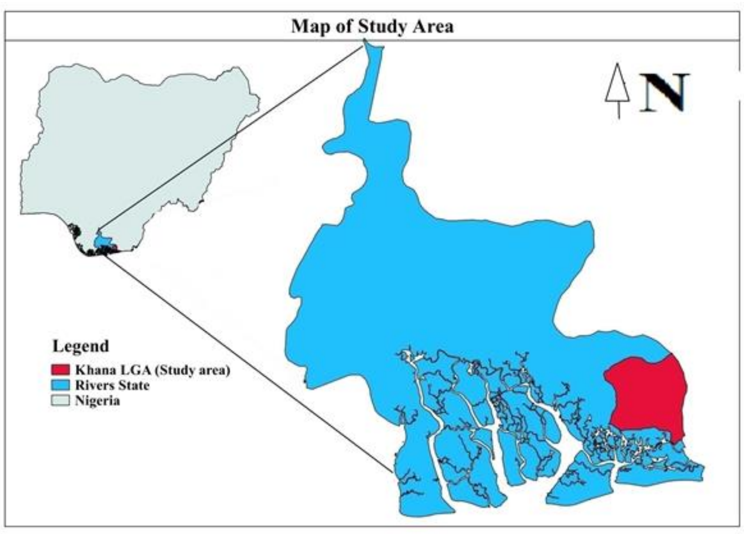

Fig. 1: Map of Study area (Source: Needam *et al.*, 2020)

2.2 Field Study

A semi-detailed, free soil survey was conducted in Khana area at a scale of 1: 5,000 following the procedures described in the USDA Soil Description Handbook (2014), using a contour map, pegs, and GPS instrument. Five predominant land-use types (Residential area, Farmland, Fallow land, Oil palm plantation, and Forestland) were identified along Three (3) transects across the area. Seven (7) soil pedons were dug and samples were collected based on genetic horizons. Both composite and core sampling methods were employed for the collection of samples for laboratory analysis. Soil morphological, physical, and chemical properties were determined in the field and the laboratory including depth intervals of horizons, soil color, horizon boundary characteristics, Texture, Structure, Consistency, Soil reaction, Electrical conductivity, Total organic carbon, Total Nitrogen, Available Phosphorus, Particle size distribution, Exchangeable Bases, Cation exchange capacity, exchangeable acidity, bulk density, moisture content, water holding capacity, Aggregate stability, and hydraulic conductivity. Before sample collections, each soil pedon was described based on morphological properties using the United States Soil Taxonomy Classification System (USDA) (2014) soil description handbook and Munsell color chart. Soil pedons were classified using the USDA (Soil Survey Staff, 1999), using soil pedon descriptions and laboratory results from the soil samples.

2.3 Laboratory Methods

Soil pH was measured potentiometrically using the pH electrode meter. Soil electrical conductivity (EC) was measured in a conductivity cell using an EC-meter by measuring the electrical resistance of a 1:5 (10g of soil to 50ml of distilled water) soil water suspension. (Rayment & Higginson, 1992). Exchangeable acidity in soil was determined using the titration method. Exchangeable cations (Calcium, Potassium, Sodium, and Magnesium), and Effective cation exchange capacity in soil. An atomic absorption spectrophotometer (Perkin-Elmer Model 403) was used for the determination of Potassium and Sodium, Magnesium, and Calcium from soil extracts. Thus, Effective cation exchange capacity (ECEC) is calculated by the sum of exchangeable bases (Ca, Mg, K, Na) and exchangeable Al and H expressed in milliequivalent per 100gram (meq/100g) (Black & Hartge, 1986). Total Organic carbon was determined by the wet combustion method of the Walkley and Black procedure (Nelson & Sommers, 1996). Available Phosphorus was determined using the Bray Number 1 method. Total Nitrogen was determined using the Semi-micro Kjeldahl digestion method. Particle size analysis (Bouyoucos Hydrometer method) was analyzed following the modified hydrometer method (Gee & Or, 2002), using sodium hexametaphosphate (Calgon) as a dispersant. Aggregate stability was measured by the Mean Wet Diameter (MWD) method of water-stable aggregates as described by Kemper and Rosenau (1986). Bulk density and Moisture content were measured with the ratio of the oven-dried mass of soil to its volume either at the time of sampling or at specified moisture. Saturated hydraulic conductivity was measured by the constant head permeameter technique as described by (Black & Hartge, 1986).

3.0 RESULTS

The morphological properties, physical and chemical properties, and Soil classification of the study area are presented in Tables 1, 2, 3, and 4 respectively.

Table 1: Morphological characterization of soils in the study area

Horizon	Depth(cm)	Soil colour	Mottles	Soil texture	Soil structure	Soil consistency	Boundary	Others
Zor-Sogho (Oil palm plantation)								
Ap	0 -15	10YR 3/3 (Dark brown)		SL	Wfg	Ns,Np	Gw	Many macro roots
Bt1	15 – 47	10YR 4/6 (Dark Yellowish-brown)		SL	Wfsab	Ns,Np	Ds	Few macro roots, many fine roots
Bt2	47 -74	10YR 3/6 (Dark Yellowish-brown)		SC	Wfsab	Ss,Sp	Ds	
BC	74 -120	10YR 5/8 (Yellowish brown)		SC	Mmsab	Ms,vp	Ds	Poorly drained.
Taabaa (Cassava farm)								
Ap	0 -17	10YR 3/3 (Dark brown)		SL	Wfg	Ns,Np	Cs	Very few root distribution
BA	17 – 54	10YR 3/3 (Dark brown)		SL	Wfsab	Ns,Np	Cw	Signs of rodent holes
BC	54 -79	7.5YR 6/8 (Reddish Yellow)		SCL	Mmsab	Ss,Sp	Gw	Signs of rodent holes
C	79 – 200	7.5YR 6/8 (Reddish Yellow)		SCL	Mmsab	Ms,vp	Gw	
Kono (cassava farm)								
Ap	0 – 12	10YR 3/4 (Dark yellowish brown)	Red	SL	Wfg	Ns,Np	Cs	many macro root distribution
Bt1	12 – 49	10YR 3/4 (Dark yellowish brown)		SL	Wfsab	Ss,Sp	Cs	Many macro root distribution
Bt2	49 – 91	10YR 3/6 (Dark yellowish brown)		SCL	Mmsab	Ss,Sp	Gw	few macro roots distribution
BC	91 - 200	7.5YR 6/8 (Reddish Yellow)		SCL	Mmsab	Ms,vp	Gw	
Bori (Fallow land)								
Ap	0 – 25	10YR 3/4 (Dark yellowish brown)		S	Wfg	Ns,Np	Dw	Few fibrous root distribution
Bt1	25 - 63	10YR 3/6 (Dark yellowish brown)		SL	Wfsab	Ss,Sp	Dw	Few fibrous root distribution
Bt2	63 – 105	10YR 5/8 (Yellowish brown)		CL	Mmsab	Ms,vp	Dw	
BC	105 – 185	10YR 6/6 (Brownish yellow)		CL	Mmsab	Ms,vp	Ds	
Baen (Forest)								
A	0 – 21	10YR 3/3 (Dark brown)		SL	Wfg	Ns,Np	Gs	Many fibrous root distribution.
Bt1	21 – 51	10YR 3/6 (Dark yellowish brown)		SCL	Wfsab	Ns,Np	Gs	Many fibrous root distribution.
Bt2	51 – 108	10YR 5/6 (Yellowish brown)		SCL	Mmsab	Ss,Sp	Gs	Few fibrous root distribution.
BC	108 – 200	10YR 6/6 (Brownish yellow)		SCL	Mmsab	Ms,vp	Gs	
Okwale (Residential)								
Ap	0 – 25	10YR 2/2 (Very dark brown)	Red	SL	Wfg	Ns,Np	As	Few fibrous root distribution
BA	25 – 106	10YR 4/6 (Dark Yellowish-brown)		SCL	Wfsab	Ss,Sp	As	
CB	106 – 151	7.5YR 6/8 (Reddish Yellow)		SCL	Mmsab	Ms,vp	As	
C	151 – 200	10YR 6/6 (Brownish yellow)		CL	Mmsab	Ms,vp	As	
Eeke (Fallow land)								
Ap	0 – 29	10YR 3/4 (Dark yellowish brown)		S	Wfg	Ns,Np	Ds	few fibrous root distribution
BA	29 - 54	10YR 3/6 (Dark yellowish brown)		SL	Wfsab	Ss,Sp	Ds	few fibrous root distribution
BC	54 – 160	10YR 5/8 (Yellowish brown)		CL	Mmsab	Ms,vp	Ds	
C	160 – 200	7.5YR 6/6 (Reddish Yellow)		CL	Mmsab	Ms,vp		

Wfg = Weak fine granular; Wfsab= weak fine sub-angular blocky; Moderate medium sub-angular blocky=Mmsab; Non sticky, Non plastic= Ns,Np; Slightly sticky, Slightly plastic=Ss,Sp; Moderately sticky, Very plastic= Ms, Vp; Moderately sticky, Slightly plastic= Ms, Sp; Boundary (Smooth=S, Wavy=W, Diffused=D, Clear= C, Abrupt= A, Irregular= I); Sand= S, Loam= L, Clay= C.

Table 2: Physical Properties of Soils in the study area

Horizon	Depth(cm)	Ksat (cm/hr)	MOISTURE CONTENT (%)	BULK DENSITY (g/cm3)	SAND (g/Kg)	SILT (g/Kg)	CLAY (g/Kg)	MWD
Zor-Sogho (Oil palm plantation)								
Ap	0 -15	28	6.55	1.32	620	360	70	0.52
Bt1	15 – 47	61	6.73	1.38	570	270	110	0.52
Bt2	47 -74	18	9.25	1.41	510	270	220	0.38
BC	74 -120	1	8.54	1.52	470	240	290	0.34
Taabaa (Cassava farm)								
Ap	0 -17	45	7.25	1.61	760	170	70	0.43
BA	17 – 54	12	6.92	1.64	640	250	110	0.43
BC	54 -79	1	8.79	1.65	550	220	230	0.38
C	79 - 200	1	7.66	1.67	500	220	280	0.35
Kono (cassava farm)								
Ap	0 – 12	42	10.18	1.55	810	130	60	0.36
Bt1	12 -49	68	8.9	1.57	750	140	110	0.34
Bt2	49 - 91	4	11.13	1.62	590	170	240	0.32
BC	91 - 200	1	10.11	1.64	510	170	320	0.31
Bori (Fallow land)								
Ap	0 – 25	33	8.83	1.29	670	270	60	0.46
Bt1	25 - 63	17	10.65	1.33	540	340	120	0.54
Bt2	63 – 105	1	13.25	1.35	490	270	260	0.54
BC	105 - 185	2	12.65	1.45	420	220	360	0.61
Baen (Forest)								
A	0 – 21	27	10.62	1.28	600	340	60	0.72
Bt1	21 – 51	5	10.31	1.29	570	320	110	0.72
Bt2	51 – 108	6	10.91	1.31	520	220	260	0.59
BC	108 – 200	2	9.41	1.55	500	240	260	0.54
Okwale (Residential)								
Ap	0 – 25	34	8.42	1.58	700	250	50	0.36
BA	25 – 106	46	12.32	1.61	630	240	130	0.33
CB	106 – 151	4	10.03	1.64	560	270	170	0.33
C	151 – 200	1	9.56	1.69	490	220	290	0.33
Eeke (Fallow land)								
Ap	0 – 29	30	4.51	1.26	760	140	100	0.5
BA	29 - 54	60	8.84	1.31	750	110	140	0.5
BC	54 – 160	4	15.53	1.33	680	160	160	0.46
C	160 – 200	2	13.87	1.43	450	210	340	0.46

Table 3: Chemical Properties of Soils in the study area

Horizon	Depth(cm)	pH	EC	TN(g/kg)	OM%	AV. P(mg/Kg)	Ca	Mg	K	Na	EA(mg/kg)	ECEC	PBS	SAR
Zor-Sogho (Oil palm plantation)														
Ap	0 -15	6.5	12.14	1.5	2.07	10	1.88	1.57	1.86	0.71	1.08	7.1	84.79	0.76
Bt1	15 - 47	6.6	11.56	1.1	1.57	12.03	1.06	0.55	1.42	0.68	2.8	6.51	56.99	1.07
Bt2	47 -74	6.6	9.08	1	1.24	12.76	0.82	0.08	0.85	0.36	2.6	4.71	44.8	0.76
BC	74 -120	6.6	14.22	0.5	0.91	11.78	0.73	0.06	0.42	0.27	2.1	3.58	41.34	0.61
Taabaa (Cassava farm)														
Ap	0 -17	6	12.95	1.3	2.24	14.37	0.6	0.87	1.9	0.59	2.4	6.36	62.26	0.97
BA	17 – 54	5.7	11.73	0.7	1.28	16.29	1.12	0.63	1.5	0.68	2.5	6.43	61.12	1.03
BC	54 -79	6.8	11.07	0.6	0.93	15.72	0.93	0.06	0.91	0.31	2.6	4.81	45.95	0.62
C	79 – 200	6.2	10.55	0.3	0.4	12.29	0.76	0.01	0.61	0.26	2.5	4.14	39.61	0.59
Kono (cassava farm)														
Ap	0 - 12	6.1	13.98	1.8	2.07	14.07	0.61	0.76	1.87	0.86	2.5	6.6	62.12	1.47
Bt1	12 -49	6.1	12.65	0.7	1.26	15.09	1.03	0.44	1.68	0.71	2.6	6.46	59.75	1.17
Bt2	49 - 91	6.5	11.62	0.5	0.66	15.22	0.96	0.03	0.95	0.25	2.6	4.79	45.72	0.5
BC	91 - 200	6.6	11.13	0.3	0.36	17.33	0.68	0.01	0.46	0.22	2.3	3.67	37.33	0.53
Bori (Fallow land)														
Ap	0 - 25	6.6	13.66	1.6	2.1	15.33	1.91	1.53	1.56	1.37	0.92	7.29	87.38	1.48
Bt1	25 - 63	6.6	17.28	1	1.57	16.89	1.74	0.31	1.33	0.75	2.6	6.73	61.37	1.05
Bt2	63 - 105	6.5	17.59	0.8	1.24	12.63	0.6	0.09	0.87	0.31	2.4	4.27	43.79	0.75
BC	105 - 185	6.6	16.95	0.4	0.78	12.72	0.44	0.06	0.47	0.28	2.3	3.55	35.21	0.79
Baen (Forest)														
A	0 – 21	6.8	13.22	2.3	3.28	13.22	1.85	1.98	2.01	1.86	0.81	8.51	90.48	1.9
Bt1	21 – 51	6.6	11.41	1.4	3.21	15.83	0.76	0.53	1.84	0.72	2.2	6.05	63.64	1.27
Bt2	51 – 108	6.6	10.08	1	1.71	10.33	0.89	0.1	0.88	0.3	2.1	4.27	50.82	0.6
BC	108 – 200	6.5	9.44	0.6	1.28	9.25	0.87	0.09	0.58	0.24	1.9	3.68	48.37	0.49
Okwale (Residential)														
Ap	0 – 25	6.4	12.77	1.1	2.16	12	0.63	0.5	1.81	0.52	2.42	5.88	58.84	0.98
BA	25 – 106	6.3	12.14	0.7	2.21	14.65	0.52	0.4	1.33	0.64	1	3.89	74.29	1.33
CB	106 – 151	6.4	13.56	0.6	1.88	11.34	0.76	0.1	0.89	0.3	0.8	2.85	71.93	0.65
C	151 – 200	6.7	11.87	0.4	0.64	16.92	0.77	0.08	0.39	0.24	0.8	2.28	64.91	0.52
Eeke (Fallow land)														
Ap	0 – 29	6.7	11.29	1.7	2.67	15.54	1.86	1.67	1.74	1.43	0.96	7.66	87.47	1.52
BA	29 - 54	6.6	14.78	1.2	1.74	17.65	1.54	0.34	1.45	0.69	2.6	6.62	60.73	1.01
BC	54 – 160	6.6	16.54	1	1.66	14.11	0.94	0.11	0.94	0.3	2.5	4.79	47.81	0.59
C	160 – 200	6.6	15.88	0.5	0.97	13.14	0.86	0.04	0.48	0.25	2.4	4.03	40.45	0.53

Table 4: Soil Classification of pedons in the Study Area

Soil pedon(Land use)	USDA Classification	Description
Zor-Sogho (Oil palm plantation)	Arenic Hapludults	**Arenic Hapludults** are defined by the presence of an argillic horizon (Bt horizon), which is a subsurface horizon rich in clay minerals (clay accumulation). The accumulation of clay in this horizon indicates that minerals have been leached from above and have accumulated here, making it more clay-rich than the horizons above.
Bori (Fallow land)	Arenic Hapludults	
Kono (cassava farm)	Arenic Hapludults	
Baen (Forest)	Arenic Hapludults	
Taabaa (Cassava farm)	Arenic Eutrudepts	**Arenic Eutrudepts** are Inceptisols that have a surface mantle of sand or loamy sand that is more than 50 cm thick and is underlain by a cambic horizon under an udic soil moisture regime. Formed in Late-Pleistocene sediments and have gentle or moderate slopes.
Okwale (Residential)	Arenic Eutrudepts	
Eeke (Fallow land)	Arenic Eutrudepts	

3.1. Discussion

3.1.1 Morphological properties of the soils

Table 1 provides a comprehensive overview of the morphological attributes of the studied pedons. The seven representative pedons sampled exhibit varying characteristics along the soil profile, encompassing differences in depth, color, drainage capacity, consistency, structure, and texture. Across all pedons, the topsoil horizon is primarily composed of the plow layer (Ap), with depth ranging from 0 to 10 cm to 0 to 26 cm. Generally, the upper soil layers of these pedons demonstrate superior drainage compared to the subsoil, with some regions displaying visible groundwater and poor drainage capacity. Notably, the Zor-Sogho pedon exhibited inadequate drainage at a depth of 120 cm, likely attributed to variations in clay content and regional water table levels. In this case, the higher clay content near the surface limits water infiltration (Ahn, 1970). Soil colors in the various pedons predominantly range from dark brown and dark yellowish brown in the topsoil to reddish yellow and yellowish brown in the subsoil (see Table 1). Furthermore, the soil structure in the upper horizons of the sampled pedons is predominantly characterized as weak, fine, and granular, gradually transitioning to moderate, medium sub-angular blocky structures as one descends through the soil profile. Notably, red mottles were observed at various depths in the Kono and Okwale pedons.

3.1.2 Physical properties of soils in the study area

The table in Table 2 displays the particle size distribution data for soils across various land-use categories. The particle size distribution within the soil profiles exhibited varying ranges: 787.0 to 437.0 g/kg for sand, 300 to 137.0 g/kg for silt, and 350.0 to 46.0 g/kg for clay fractions. Notably, the dominant fraction in the particle size distribution was sand, with the pedons containing a high sand content that decreased with depth, particularly in the sub-soil horizon. Conversely, clay content was lower at the surface horizons but increased as one delved deeper. Table 2 also presents information on saturated hydraulic conductivity, bulk density, and mean weight diameter for soils in different land-use scenarios. The data in Table 4.5 indicates that these parameters exhibited significant variations ($P < 0.05$) across the various land-use types within the soil profiles. Specifically, saturated hydraulic conductivity values ranged from 54.0 to 1.0 cm/hr. Bulk density values ranged from 1.64 to 1.59 g/cm³, and mean weight diameter values spanned from 1.677 to 0.597.

3.1.3 Chemical properties of the soil in the study area

Table 3 displays data concerning various soil parameters, including Total Nitrogen, organic matter, electrical conductivity, pH, Potassium, Magnesium, Calcium, Sodium, exchangeable acidity, effective cation exchange capacity, and base saturation. In the pedons of the study area, soil organic matter (SOM) was significantly different ($P < 0.05$) in the soil profiles studied. Its distribution ranged from 3.16 – 0.40%. Organic matter was highest in forested soil (3.28%) at the surface horizon and lowest with a value of 2.07% in cultivated soil surface horizons (Table 3). pH was moderately acidic, its values ranged from 6.9 to 5.7 in the various pedons. Electrical conductivity ranged from 15.10 – 10.43µs. Total Nitrogen exhibited a range from 0.20% to 0.04%. Notably, Nitrogen content significantly varied ($p < 0.05$) among the pedons, with the highest levels observed in the surface horizons of forested soil. Furthermore, the concentrations of exchangeable bases, namely potassium, magnesium, calcium, and sodium, exhibited significant differences ($p < 0.05$) among the pedons. The values ranged from 2.00 to 0.28 cmol/kg for potassium, 1.96 to 0.01 cmol/kg for magnesium, 2.00 to 0.50 cmol/kg for calcium, and 1.64 to 0.25 cmol/kg for sodium. These exchangeable bases displayed inconsistent patterns of decrease from the surface to the subsurface horizons across different land uses within the soil profiles. Generally, the exchangeable bases (K, Ca, Mg, and Na) were found to be at low levels, with the exchange complex of all pedons predominantly dominated by K, Mg, and Ca. The Exchangeable Acidity (EA) ranged from 2.90 to 0.81 cmol/kg and exhibited irregular fluctuations with depth in the pedons. Effective Cation Exchange Capacity (ECEC) also displayed significant differences ($p < 0.05$) among the profiles studied, with concentrations generally ranging from 8.30 to 2.40 cmol/kg, with the highest values observed in the surface horizon of the pedons. Furthermore, base saturation was notably high in the surface horizons of all profiles but displayed irregular fluctuations with depth. The available phosphorus content of the soil was low to moderate and varied significantly ($p < 0.05$) across the pedons. Available phosphorus ranged from 17.30 – 9.08 mg/kg in the pedons studied.

3.1.4 Soil Classification of Soils in the Study Area

The soil classification report has provided valuable insights into the characteristics and formation of Arenic Hapludults and Arenic Eutrudepts (Table 4). Arenic Hapludults are distinguished by the presence of an argillic horizon (Bt horizon) that exhibits significant clay accumulation. This accumulation is indicative of leaching and mineral migration from upper horizons, resulting in a clay-rich subsurface layer. These soils are crucial in agricultural and environmental contexts, given their unique properties and potential for supporting various vegetation types. On the other hand, Arenic Eutrudepts are Inceptisols that possess a surface layer predominantly composed of sand or loamy sand, extending to a considerable depth of over 50 cm. Below this surface layer lies a cambic horizon, indicating active soil development processes. These soils are typically associated with Late-Pleistocene sediments, characterized by gentle to moderate slopes, and are typically found under udic soil moisture regimes. Their notable base saturation of 60 percent or more within specific sub-horizons between 25 and 75 cm below the mineral soil surface further distinguishes them within the soil classification system.

4.0 CONCLUSION

In conclusion, the morphological properties of the soils in the study area exhibit significant variability, reflecting diverse conditions along the soil profiles. The topsoil horizon, primarily composed of the plow layer (Ap), varies in depth across the sampled pedons, leading to differences in drainage capacity. The presence of inadequate drainage in certain pedons, like the Zor-Sogho pedon, highlights the impact of clay content and regional water table levels on soil properties. Soil colors also vary between the topsoil and subsoil, with reddish and yellowish tones becoming more pronounced in deeper horizons. The evolution of soil structure from weak, fine, and granular to moderate, medium sub-angular blocky structures with depth suggests dynamic processes such as leaching, shape these soils. Moving on to the physical and chemical properties, particle size distribution data revealed shifting proportions of sand, silt, and clay with depth, impacting soil texture and hydraulic conductivity. Bulk density and mean weight diameter values also displayed variations across different land-use categories, underlining the influence of human activities on soil compaction and aggregation. In terms of chemical properties, the distribution of organic matter, pH, and nutrient content varied significantly among the studied pedons. Organic matter was highest in forested soils, while pH remained moderately acidic. Nitrogen content showed substantial differences among pedons, potentially influencing vegetation growth. Exchangeable base concentrations fluctuated, with potassium, magnesium, and calcium dominating the exchange complex. Exchangeable acidity and effective cation exchange capacity exhibited variations, suggesting diverse soil buffering capacities. Base saturation levels were generally high in surface horizons but displayed irregular changes with depth. Lastly, available phosphorus content ranged from low to moderate, emphasizing the importance of nutrient management practices in the study area's agricultural systems. This comprehensive assessment of soil properties underscores the need for tailored soil management strategies to optimize land use and sustainability in the region.

Understanding the properties and formation processes of these soil types is essential for informed land management and agricultural practices. Proper soil classification enables us to make informed decisions regarding land use, crop selection, and conservation efforts, contributing to sustainable and productive ecosystems. This report serves as a valuable reference for those working in the fields of agriculture, ecology, and land management, offering critical insights into the unique characteristics of Arenic Hapludults and Arenic Eutrudepts within their respective geological and ecological contexts.

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