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Pedology of coastal plain sands and sandstones of the Imo River Basin, Southeastern Nigeria

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ABSTRACT

There is a general perception that the soils of Southeastern Nigeria are inherently acidic, low in nutrients and stability. While this may be true of some soils, it is not universal. Two soils on two geologic formations in the region were consequently characterized and classified to determine whether they are in line with the aforementioned perception. Profile pits were dug on the Coastal Plain and the Igbaku Sandstone soils. The soils were subsequently characterized and classified. The variability of most physicochemical soil properties was relatively high across the study area. The soils formed from both geologic formations are consequently very dissimilar. The soils on the Coastal Plain Sands were classified as Typic Dystrudepts (Dystric Cambisols), whereas those on the Igbaku Sandstones were classified as Aeric Umbric Kandiaqualfs (Gleyic Lixisols). The USDA land capability classes for the Coastal Plain and the Igbaku Sandstone soils were IVs and IIIsw respectively. Similarly, their USBR land capability classes were 3v/C and 2w/C respectively. The results show that while both pedons are located on similar physiographic positions on the Imo River Basin of southeastern Nigeria, they exhibited a wide range of morphological, physical and chemical properties. We must consequently eschew undue generalization when dealing with the soils of southeastern Nigeria, paying particular attention to the underlying geology of the site and the topography.

1.0 Introduction

There is a general misconception that the soils of Southeastern Nigeria are inherently acidic, low in basic cations, fertility and stability (Osuji et al., 2002; Obi, 2015; Osujieke et al., 2018; Abam & Orji, 2019). While this may be true for some soils, it may not be universal. This unduly generalized perception of southeastern Nigerian soils has resulted in improper and misguided land and soil resource use, giving rise to land degradation that is devastating in both its extent and magnitude. This is evidenced in the extent and magnitude of the gully erosion that now devastates the region; a problem compounded by the very high annual rainfall recorded in the region.

Consequently, the need for a holistic understanding of the soils of Southeastern Nigeria, with a view towards determining their classification and sustainable land use types, cannot be overemphasized. In line with this, Ogunkunle (2004) asserted that reliable information on the location, extent and quality of soil and land resources is the first requirement in planning for sustainable management of land resources. Esu (2004) further reiterated that a very good understanding of soil characterization and classification can assist Nigeria to get a better perspective on how to arrest her food insecurity problems and fast-deteriorating environment. Furthermore, according to the FAO (2015), the availability of good quality, detailed or semi-detailed soil data is a prerequisite for the sustainable use and management of this limited resource.

Unfortunately, good quality soil data is not available in Nigeria. The most up-to-date available soil data was generated from the reconnaissance survey of 1985 (FDALR, 1985). Esu (2004) contended that as far as food security and environmental sustainability determinations are concerned, the available soil data is of little or no value. Similarly, Fagbami & Ogunkunle (2000) stated that the soil map of Nigeria has credibility problems and is too small a scale to give satisfactory direction on project site selection, soil management and land use planning. Given the inadequacy of soil data and the tendency to over-generalize, there arises the need to determine whether the soils of the Imo River Basin of Southeastern Nigeria are homogenously poor and unstable.

In line with the foregoing, it is noteworthy that, locally, variations in soils are due primarily to variations of topography and parent materials (Akamigbo & Asadu, 1983; Foth, 1990; Madueke et al., 2021b), even though the physical and chemical properties of any soil are a function of climate, living organisms, parent materials, topography and time. The nature of minerals present within a parent material markedly affects the kind of soil that develops (Brady & Weil, 2016) and their erodibility. This necessitates the need to assess and characterize soils formed on different geological formations in Southeastern Nigeria.

Therefore, the major objective of this study is to evaluate soils formed from the Coastal Plain Sands and the Igbaku Sandstones of Southeastern Nigeria to determine the degree of heterogeneity. The specific objectives are to:

- characterize the soils formed from the Coastal Plain Sands and the Igbaku Sandstones
- determine the degree of variability of some physical and chemical properties of the soils
- determine the USDA and USBR land capability classes of the soils
- determine the Taxonomic and World Reference Base Classifications of the soils
- make land use and management recommendations.

2.0 Materials and Methods

2.1 The Physical Environment of the Study Area

The Imo River Basin has double maxima rainfall (with a break occurring in July or August), receiving over 2,000 mm of rainfall distributed over up to 140 days per annum (Madueke et al., 2021a, 2021b). The daily temperature ranges from a minimum of 21^{o}C to a maximum of 34^{o}C. The relative humidity reaches a minimum of 60 % in January (at the peak of the dry season) and rises to 80 - 90 % in July (at the peak of the rains) (Monanu, 1975) . The original vegetation of the study area was the tropical rain forest (FDALR, 1985; Igbozuruike, 1975). The rain forest has however been destroyed largely through human activities and supplanted with what is today referred to as the oil palm bush.

2.2 Selection of Study Area

Profile pits were dug on the foot slope of two soil catenae on the Coastal Plain Sands and the Igbaku Sandstones on the

Table 1: Geo-Information of the Study Areas

Site	Geology	Location	Longitude	Latitude	Altitude	Slope
I	Coastal Plain Sands (Benin Formation)	Umungwa	E 007^{o} 24' 19.7"	N 05^{o} 33' 39.1"	100m	< 5%
II	Igbaku Sandstones (Imo Shale Group)	Ikpem	E 007^{o} 17' 00.7"	N 05^{o} 44' 43.0"	126m	< 5%

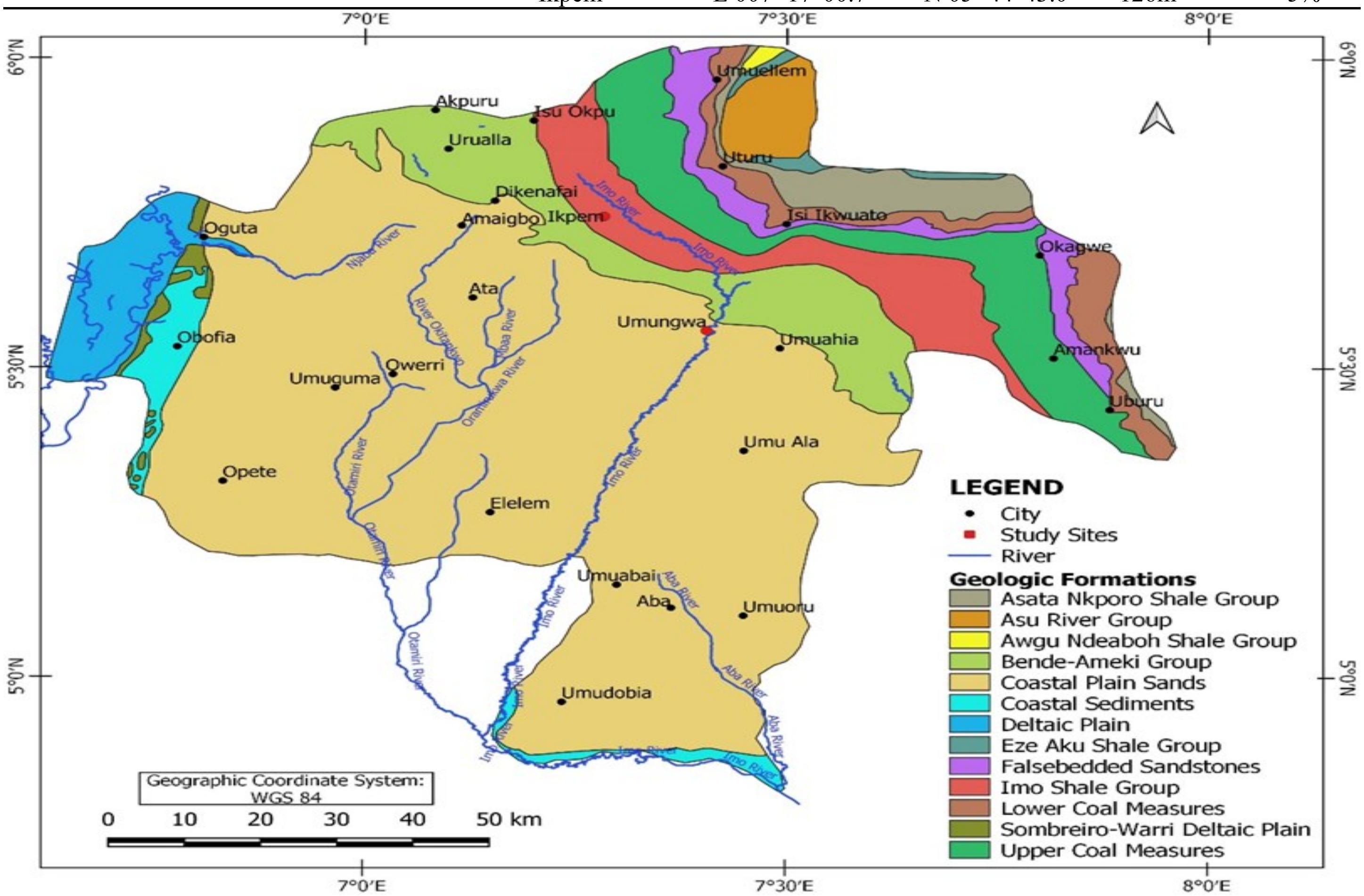


Figure 1: Geologic Map of the Imo River Basin Showing the Study Sites

Imo River Basin of Southeastern Nigeria (Figure 1). Pedon I was located at Umungwa on the Coastal Plain Sands, while Pedon II was located at Ikpem on the Igbaku Sandstones (Table 1, Figure 1).

2.3 Soil Characterization

2.3.1 Fieldwork

Two profile pits were dug in two different towns on the Imo River Basin, viz: Umungwa (Coastal Plain Sands) and Ikpem (Igbaku Sandstones). The site and profile descriptions were based on the FAO guidelines for profile description (FAO, 2006). Delineation of horizon boundaries was accomplished before actual sample collection for laboratory analysis. Composite soil samples were taken from each of the constituent horizons, starting from the bottom horizon. These samples were placed in appropriately labeled polythene bags and transported to the laboratory. The samples were air-dried for three days, crushed and passed through a 2 mm sieve before routine laboratory analysis. A small quantity (about 10 g) of each sample was finely ground and preserved for the determination of organic carbon and total nitrogen. Undisturbed soil samples for the determination of saturated hydraulic conductivity and bulk density were collected in cylindrical metal canisters.

2.4 Laboratory Soil Analyses

The physical and chemical properties of the soil samples were determined using routine analytical methods. The moisture content was determined gravimetrically. Particle size distribution was carried out by the hydrometer method (Gee & Bauder, 1986). Bulk density was determined using the procedure outlined by Arshad et al. (1996). Porosity was computed from bulk and particle density as described by Vomocil (1965). Saturated hydraulic conductivity was determined by the Falling Head Method, as reported by McWhorter & Sunda (1977). Soil pH (in water) was measured electrometrically by glass electrode in pH meter using a soil: liquid ratio of 1: 2.5 (International Institute for Tropical Agriculture [IITA], 1979). Electrical conductivity was determined electrometrically with the electrical conductivity meter using a soil: liquid ratio of 1: 2.5. Exchangeable basic cations were extracted with neutral ammonium acetate (NH_4OAC). Exchangeable calcium and magnesium were determined by the ethylene diamine-tetraacetic acid (EDTA) titration method while exchangeable potassium and sodium were estimated by flame photometry (Jackson, 1962). Exchangeable acidity was extracted with KCl (1 N) and measured titrimetrically according to the procedure of Mclean (1982). Effective Cation Exchange Capacity (ECEC) was computed as the sum of the exchangeable bases and the exchange acidity, while base saturation and aluminium saturation were computed as the percentage of the ratios of exchangeable bases and exchangeable aluminium respectively to ECEC. Soil organic carbon (SOC) was determined by Walkley and Black digestion method (Nelson & Sommers, 1982). Total Nitrogen was estimated by the micro-Kjeldahl digestion method (Bremner & Mulvaney, 1982) while available phosphorus was determined by Bray II Method (Olsen & Somers, 1982).

2.5 Soil Classification

The soils of the study area were classified following the USDA Soil Taxonomy (Soil Survey Staff, 2014) and the World Reference Base for Soil Resources (FAO, 2001; IUSS Working Group WRB, 2006). The soils were further classified based on the USDA (Klingebiel & Montgomery, 1961) and the USBR (United States Bureau of Land Reclamation) Land Capability Classification (USBR, 1953; Landon, 2013). The land use recommendations were then made with respect to these classifications and the physical and chemical properties of the soils.

2.6 Data Analysis

The coefficient of variation (CV), which was defined as $STANDARD\ DEVIATION/MEAN \times 100$ was determined for various physical and chemical properties across the study area. It gave an estimate of the degree of variability of the properties across the study area. It was also used to determine the vertical variability of clay down each of the soil profiles exposed. According to the estimate of Aweto (1982), soils with a CV of < 20 %, 20 – 50 % or ≥ 50 %, were said to have low, moderate or high variability respectively. Horizontal bar charts were also used to depict the depth function of clay, while vertical bar charts were used to depict the variability of the physical and chemical soil properties across the study area.

3.0 Results and Discussion

3.1 Variation of the Morphological and Physical Properties

The physical properties of the soils are shown in Table 2. Figure 2 shows a schematic diagram of the soil profiles, showing the sequence of horizonation, horizon depths, colour and texture.

The texture of the topsoils ranged from sand on the Coastal Plain Sands to sandy loam on the Igbaku Sandstones, while that of the subsoil ranged from Loamy sand to Sandy Clay respectively. Clay content generally tended to increase down the profile (Figure 3). Eshett (1987) reported that this is diagnostic of the existence of argillic horizons. Nevertheless, while the vertical variability was moderate on the Igbaku Sandstones, it was low on the Coastal Plain Sands (Table 3). The low vertical variability of clay on the Coastal Plain Sands precludes the existence of well-developed argillic horizons.

The variability of sand across the study area was low in the topsoil and moderate in the subsoil (Figure 4[a], Table 4). The variability of silt and clay across the study area was high in both the topsoil and subsoil (Figure 4[b] and [c], Table 4). This indicates that the difference in geologic formation considerably affected the different size fractions of the soils, and would consequently affect their land use and management. Though Akamigbo (1984) reported that soils of Southeastern Nigeria are low in silt as a result of the high degree and extent of weathering and leaching they have undergone, the relatively higher silt content on the Igbaku Sandstones, ranging from 3 % to 7 %, may be attributed to the nature of the geologic formation.

The bulk density ranged from 1.43 Mg/m^3 in the topsoil of the Igbaku Sandstones to 1.51 Mg/m^3 in the topsoil of the Coastal Plain Sands, and from 1.52 Mg/m^3 in the subsoil of the Coastal Plain Sands to 1.65 Mg/m^3 in the subsoil of the Igbaku Sandstones (Table 2). Nevertheless, variability was low in both the topsoil and the subsoil (Table 4, Figure 4[d]). In all the constituent horizons, bulk density was below the value quoted as the minimum bulk density at which root-restricting conditions will occur on sandy loam soils (1.75 – 1.80 Mg/m^3) (USDA Natural Resources Conservation Service, 2001), sand (1.6 Mg/m^3) and clay (1.4 Mg/m^3) (Donahue et al., 1990), except in the mottled sandy clay Cg horizon (140 – 180 cm) of soils on the Igbaku Sandstones, where it was as high as 1.65 Mg/m^3.

Saturated hydraulic conductivity ranged from 2.16 cm/s in the topsoil of the Igbaku Sandstones to 4.0 cm/s in the topsoil of the Coastal Plain Sands, and from 0.01 cm/s in the subsoil of the Igbaku Sandstones to up to 2 cm/s in the subsoil of the Coastal Plain Sands (Table 2). It was generally highest in the topsoil, decreasing down the profile. The variability of saturated hydraulic conductivity across the study area was however very high in both the topsoil and the subsoil (Figure 4 [e], Table 4), indicating that it is greatly affected by variation

Table 1: Geo-Information of the Study Areas

Hor.	Depth (cm)	Moisture Content (%)	Particle Size Distribution Sand (%)	Silt (%)	Clay (%)	Textural Class	Bulk Density (Mg/m^3)	Porosity (%)	Ksat (cm/s)
			Pedon I – Umungwa – Coastal Plain Sands						
Ap	0-16	0.85	91	1	8	Sand	1.49	43.66	4.00
A_2	16-65	0.89	92	1	8	Sand	1.51	42.87	2.59
BA	65-94	0.92	89	1	10	Loamy Sand	1.52	42.79	2.27
B_1	94-140	0.93	89	1	10	Loamy Sand	1.52	42.53	1.73
B_2	140-175	1.87	88	1	11	Loamy Sand	1.53	42.43	1.41
B_3	175-180	1.79	88	1	11	Loamy Sand	1.59	39.85	1.19
			Pedon II – Ikpem – Igbaku Sandstone						
Ap	0-19	3.77	86	3	11	Loamy Sand	1.43	46.23	2.16
A_2	19-26	7.14	81	3	16	Sandy Loam	1.46	44.79	0.22
A_3	26-40	6.86	79	3	18	Sandy Loam	1.46	44.75	0.04
BA	40-51	7.07	75	3	22	Sandy Clay Loam	1.52	42.91	0.01
Bgt_1	51-82	9.09	71	3	26	Sandy Clay Loam	1.52	42.72	0.01
Bgt_2	82-140	9.70	71	3	26	Sandy Clay Loam	1.52	42.68	0.01
Cg	140-180	10.10	57	7	36	Sandy Clay	1.65	37.82	0.01

Hor. = Horizon, Ksat = Saturated Hydraulic Conductivity

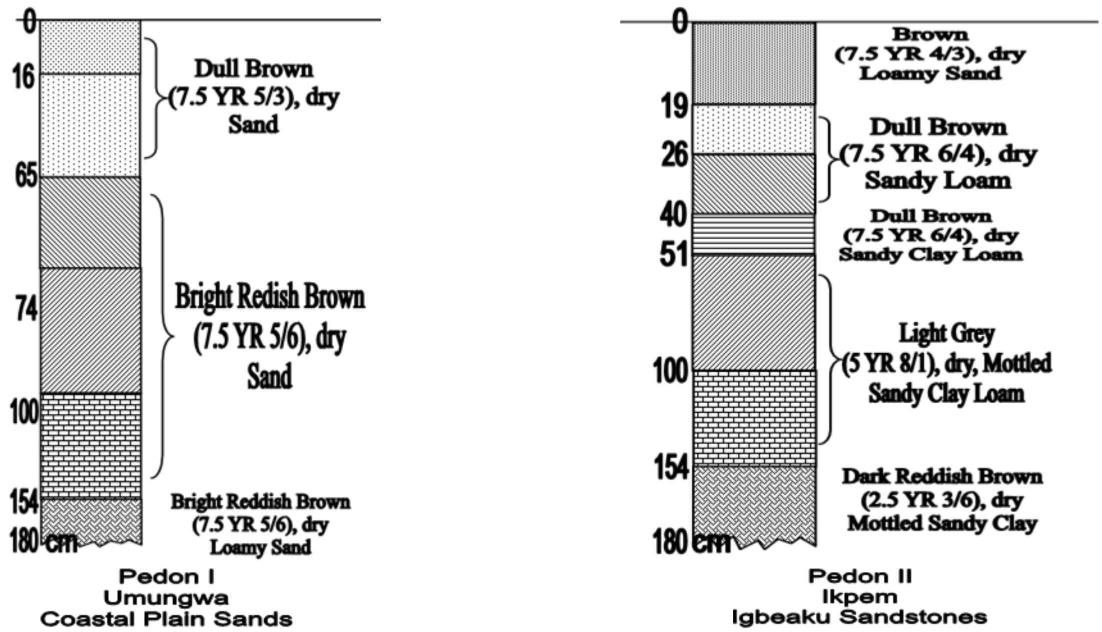
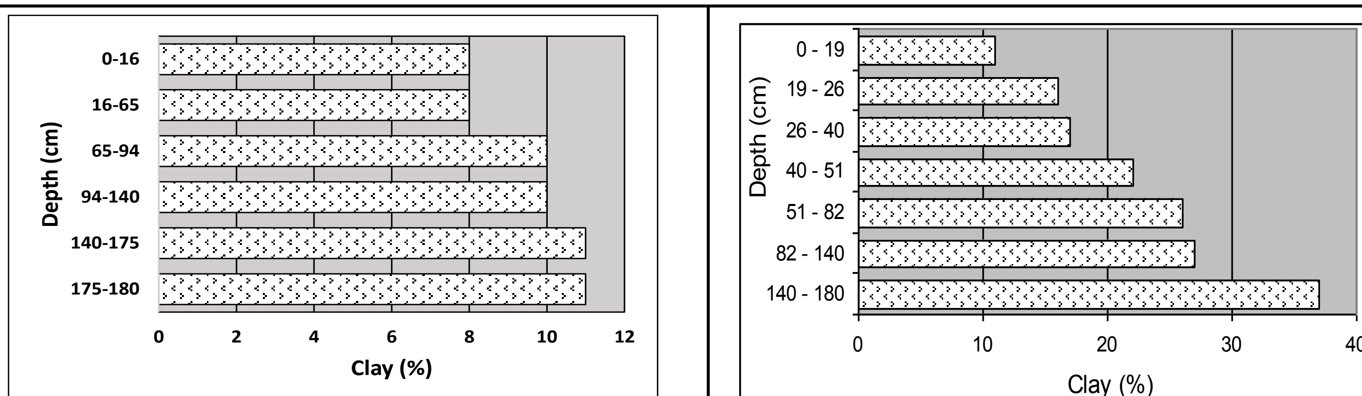


Figure 2: Schematic Diagram of the Soil Profiles



(a) (b)

Figure 3: Depth Function of Clay on the Coastal Plain Sands (a) and Igbaku Sandstones (b)

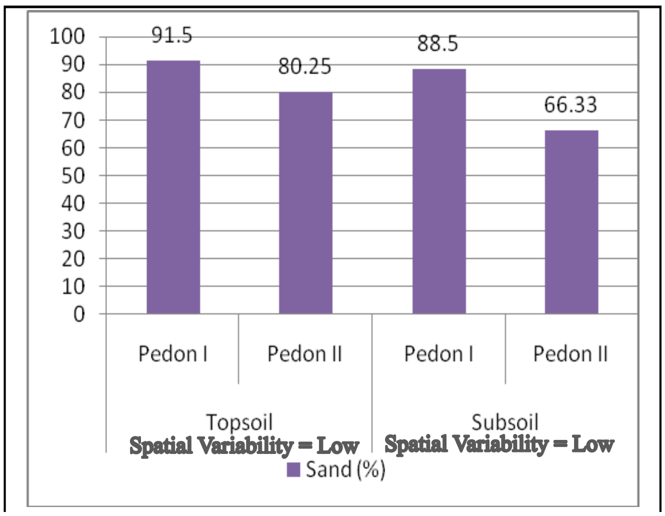
Table 3: Vertical Variation of Clay down the Profiles

Pedon	Location	Geologic Formation	Statistics			
			Mean	Std. Dev.	Coeff. of Var. (CV)	Variability
I	Umungwa	Coastal Plain Sands	9.67	1.37	14.17	Low
II	Ikpem	Igbaku Sandstones	22.14	8.17	36.90	Moderate

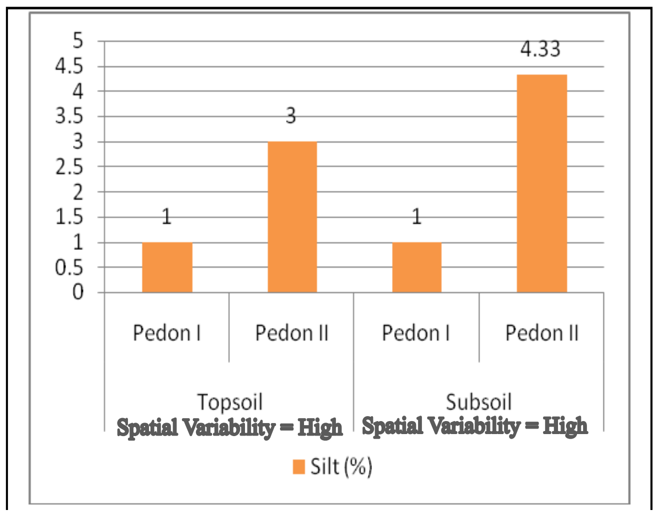
Table 4: Variability of some Physical Properties across the Study Area

Soils	Statistics	Moisture (%)	Sand (%)	Silt (%)	Clay (%)	Bulk Density (Mg/m3)	Porosity (%)	Ksat (cm/s)
Topsoil	SD	3.78	7.95	1.41	6.19	0.02	0.99	1.9
	X	3.54	85.88	2	12.38	1.49	43.97	1.96
	CV (%)	106.78	9.26	70.5	50	1.34	2.25	96.94
	Variability	High	Low	High	High	Low	Low	High
Subsoil	SD	5.83	15.68	2.35	13.31	0.01	0.59	1.16
	X	5.51	77.42	2.67	19.92	1.55	41.49	0.83
	CV (%)	105.81	20.25	88.01	66.82	0.65	1.42	139.76
	Variability	High	Mod.	High	High	Low	Low	High

SD = Standard Deviation, X = Mean, CV = Coefficient of Variation, Ksat = Saturated Hydraulic Conductivity, Mod. = Moderate, SD = Standard Deviation, X = Mean, CV = Coefficient of Variation



(a)



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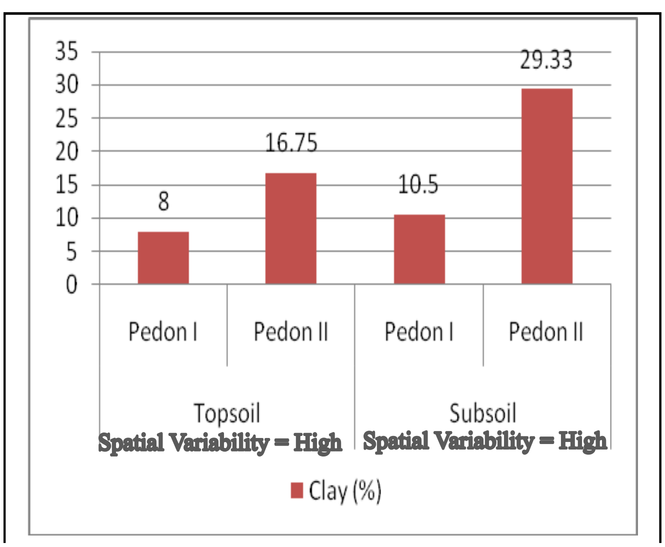

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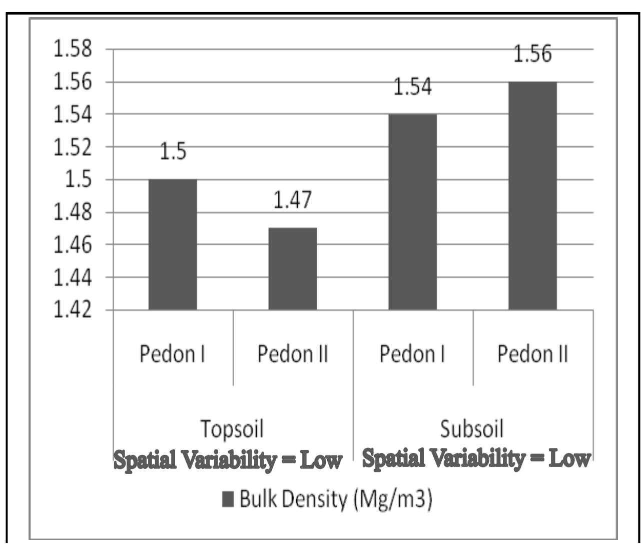
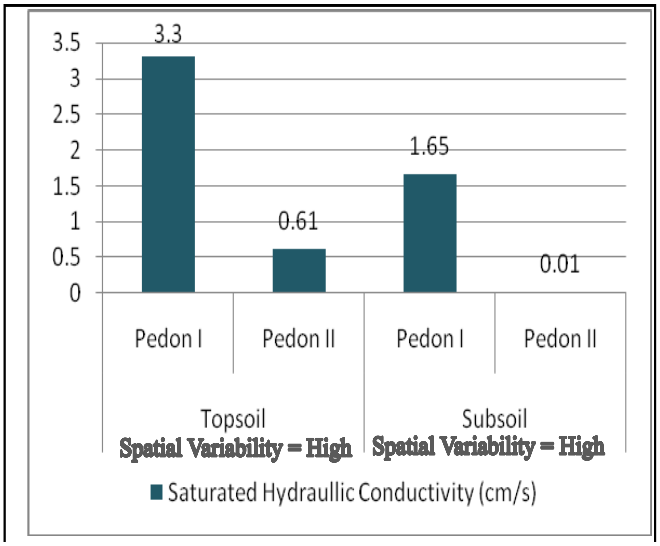


(d)



(e)

Figure 4: Variability of Sand (%) [a], Silt (%) [b], Clay (%) [c], Bulk Density (Mg/m3) [d] and Saturated Hydraulic Conductivity (cm/s) [e] across the Study Area

in a geologic formation.

3.2 Variation of the Chemical Properties

The chemical properties of the soils are shown in Table 5. The pH ranged from 5.60 in the topsoil of the Coastal Plain Sands to 5.82 in the topsoil of the Igbaku Sandstones, and 5.09 in the subsoil of the Coastal Plain Sands to 6.04 in the subsoil of the Igbaku Sandstones (Table 5). This relatively low soil pH was also reported by Akpa et al. (2019). Nevertheless, even though the soils of the Coastal Plain Sands were more acidic than the soils of the Igbaku Sandstones, soil pH exhibited low variability across the study area (Table 6, Figure 5[a]). The generally acidic soil reaction is characteristic of soils in the rainforest belt of Southeastern Nigeria and may be the result of the acidic nature of the parent rocks, coupled with the influence of the leached profile under the high annual rainfall condition (Eshett et al., 1990; Townsend et al., 2002). However, the less acidic nature of the soils on the Igbaku Sandstones is a result of the relatively basic nature of the parent material, which is a member of the Imo Shale Group.

The soil organic carbon content ranged from 1.7 % in the topsoil of the Coastal Plain Sands to 2.99 % in the topsoil of the Igbaku Sandstones, and from 0.45 % in the subsoil of the Igbaku Sandstones to 0.55 % in the subsoil of the Coastal Plain Sands (Table 5). This is in line with the assertion of Brady & Weil (2016) that most cultivable soils contain 1 – 6 % organic matter, which is mostly within the top 25 cm of the soil. Total Nitrogen ranged from 0.12 % in the topsoil of the Coastal Plain Sands to 0.21 % in the topsoil of the Igbaku Sandstones, and from 0.04 % in the subsoil of the Igbaku Sandstones to 0.10 in the subsoil of the Coastal Plain Sands (Table 5). The low nitrogen concentration is a common phenomenon in the soils of Southeastern Nigeria and is a result of the high nitrogen losses sustained in these soils through the leaching of nitrates, as well as the rapid mineralization of organic matter under the isohyperthermic soil temperature regime (Eshett et al., 1990). Nevertheless, across the study area, the variability of organic carbon and total nitrogen was low in the topsoil and moderate in the subsoil (Table 6, Figure 5[b]).

The soils were acutely deficient in available phosphorus (< 3.0 ppm), except for the topsoil of the Coastal Plain Sands (Table 5). Available phosphorus was highly variable in the topsoil of the study area and moderately variable in the subsoil (Table 6, Figure 5[c]). The moderate to low available phosphorus concentration is, however, a widespread phenomenon in the humid tropical soils of Southeastern Nigeria. This may be attributed to the high phosphate fixation capacity of tropical soils (De Moura et al., 2016; Eshett et al., 1990; Townsend et al., 2002).

The ECEC of the soils ranged from 1.69 cmol/kg in the topsoil of the Coastal Plain Sands to 5.26 cmol/kg in the topsoil of the Igbaku Sandstones and from 1.79 cmol/kg in the subsoil of the Coastal Plain Sands to 8.18 cmol/kg in the subsoil of the Igbaku Sandstones (Table 5). The low ECEC in the Coastal Plain Sands is in line with the assertion by Osuji et al. (2002) that soils formed on Coastal Plain Sands and sandstones are acidic, have low CEC, low base saturation and low fertility levels. Similarly, Amberger (2006) and De Moura et al. (2016) asserted that soils in the humid tropics have low CEC, resulting in a low nutrient retention rate against the agents of erosion and leaching. Though the relatively higher ECEC recorded in the soils of the Igbaku Sandstones seemed to contradict the assertion of Osuji et al. (2002), it is as a result of the nature of the parent material, which, though a sandstone, is a member of the Imo Shale Group. Similarly, the spatial variability of ECEC across the study area was high both in the topsoil and the subsoil (Table 6, Figure 5[d]), showing that variation in geologic formation affects the nature and properties of the soils. CEC is an important determinant of soil fertility and productivity (Amberger, 2006); its high variability indicating that soil productivity is quite variable across the study area.

Base saturation generally ranged from 51 % in the topsoil of the Coastal Plain Sands to 62 % in the topsoil of the Igbaku Sandstones, and 29 % in the subsoil of the Coastal Plain Sands to 60 % in the subsoil of the Igbaku Sandstones (Table 5). Base saturation was generally highest in the topsoil. Eshett (1985) reported that base saturation was generally high in the A horizon, apparently due to the influence of organic matter. Foth (1990) also reported that there exists a positive correlation between pH and base saturation. As such, the decrease of base saturation with increasing depth can be attributed to pH, which tended to decrease with increasing depth. Juo (1984) attributed the low base saturation of southeastern Nigeria soils to the coarse texture of the soils and/or the heavy precipitation and leaching that characterize the soils of the region. This is in agreement with the contention of Amberger (2006) that basic cations are generally deficient in soils of the humid tropics.

The higher base saturation of the soils of the Igbaku Sandstones may then be attributed to the nature of the parent materials. This is in line with the variability of base saturation across the study area, which, though low in the topsoil, was moderate in the subsoil (Table 6, Figure 5[e]), showing that base saturation is affected by the nature of the geologic formation from which the soil was formed.

Aluminium saturation ranged from 16 % in the topsoil of the Igbaku Sandstones to 27 % in the topsoil of the Coastal Plain Sands, and from 11 % in the subsoil of the Coastal Plain Sands to up to 50 % in the subsoil of the Igbaku Sandstones (Table 5). Amberger (2006) reported that aluminium concentration higher than 1.0 ppm translates into an aluminium saturation that may be as high as 70 %. This, in turn, results in aluminium toxicity, which restricts root development, water and nutrient absorption (Amberger, 2006). Consequently, due to the relatively low aluminium saturation (< 70%) in the study area, there is little risk of aluminium concentration attaining toxic levels. Nevertheless, the variability of Aluminium saturation across the study area was moderate both in the topsoil and in the subsoil (Table 6, Figure 5[e]), showing that Aluminium saturation is affected by the nature of the geologic formation from which the soil was formed.

3.3 Soil Classification

Table 5: Chemical Properties of the Study Area

Hor.	**Depth**	**pH**	**Org. C (%)**	**Tot. N (%)**	**Ava. P (ppm)**	**Exchangeable Bases (cmol/kg) Ca**	**Mg**	**K**	**Na**	**E.A. (cmol/kg) Al**	**H**	**ECEC (cmol/kg)**	**Base Sat. (%)**	**Al Sat. (%)**
					Pedon I – Umungwa – Coastal Plain Sands									
Ap	0-16	5.51	1.70	0.12	11.19	0.38	0.11	0.28	0.09	0.45	0.38	1.69	51	27
A_2	16-65	5.60	1.40	0.10	4.66	0.28	0.10	0.30	0.10	0.45	0.68	1.91	41	24
BA	65-94	5.16	1.30	0.10	2.80	0.20	0.09	0.32	0.10	0.51	0.96	2.18	33	23
B_1	94-140	5.17	1.20	0.10	2.80	0.17	0.08	0.28	0.08	0.57	0.90	2.08	29	27
B_2	140-175	5.17	1.10	0.09	2.80	0.16	0.10	0.30	0.10	0.25	0.99	1.90	35	13
B_3	175-180	5.09	0.55	0.05	2.80	0.13	0.07	0.39	0.10	0.20	0.90	1.79	39	11
					Pedon II – Ikpem – Igbaku Sandstone									
Ap	0-19	5.67	2.99	0.21	1.87	1.20	1.24	0.54	0.19	0.82	1.10	5.09	62	16
A_2	19-26	5.80	1.80	0.13	2.80	1.10	1.26	0.36	0.18	1.30	1.06	5.26	55	25
A_3	26-40	5.82	1.50	0.12	1.87	0.24	1.40	0.36	0.14	2.00	0.76	4.91	44	41
BA	40-51	5.62	1.30	0.10	1.87	0.34	1.34	0.31	0.17	3.40	0.18	5.74	38	59
Bgt_1	51-82	5.75	0.57	0.05	1.87	1.36	1.58	0.73	0.39	3.26	0.86	8.18	50	40
Bgt_2	82-140	5.80	0.60	0.05	1.87	1.36	1.86	0.43	0.20	2.76	1.06	7.67	50	36
Cg	140-180	6.04	0.45	0.04	1.87	0.40	2.18	0.39	0.19	1.09	1.01	5.26	60	21

Hor. = Horizon, Org. C = Organic Carbon, Tot. N = Total Nitrogen, Ava. P = Available Phosphorus, Ca = Calcium, Mg = Magnesium, K = Potassium, Na = Sodium, Al = Aluminium, H = Hydrogen, E.A. = Exchangeable Acidity, ECEC = Effective Cation Exchange Capacity, Base Sat. = Base Saturation, Al Sat. = Aluminium Saturation.

Table 6: Variability of some Chemical Properties across the Study Area

Soils	**Statistics**	**pH**	**Org. C (%)**	**Total N (%)**	**Ava. P (ppm)**	**ECEC (cmol/kg)**	**Base Sat. (%)**	**Al Sat. (%)**
Topsoil	*SD*	0.12	0.25	0.02	4.12	2.44	2.65	6.89
	X	5.65	1.73	0.13	5.02	3.53	47.89	30.36
	CV (%)	2.12	14.45	15.38	82.07	69.12	5.53	22.69
	Variability	Low	Low	Low	High	High	Low	Mod.
Subsoil	*SD*	0.5	0.35	0.03	0.66	3.57	13.67	9.78
	X	5.51	0.79	0.07	2.34	4.52	43.67	25.42
	CV (%)	9.07	44.3	42.86	28.21	78.98	31.3	38.47
	Variability	Low	Mod.	Mod.	Mod.	High	Mod.	Mod.

Org. C = Organic Carbon, Total N = Total Nitrogen, Ava. P = Available Phosphorus, Sat. = Saturation, Mod. = Moderate, SD = Standard Deviation, X = Mean, CV = Coefficient of Variation

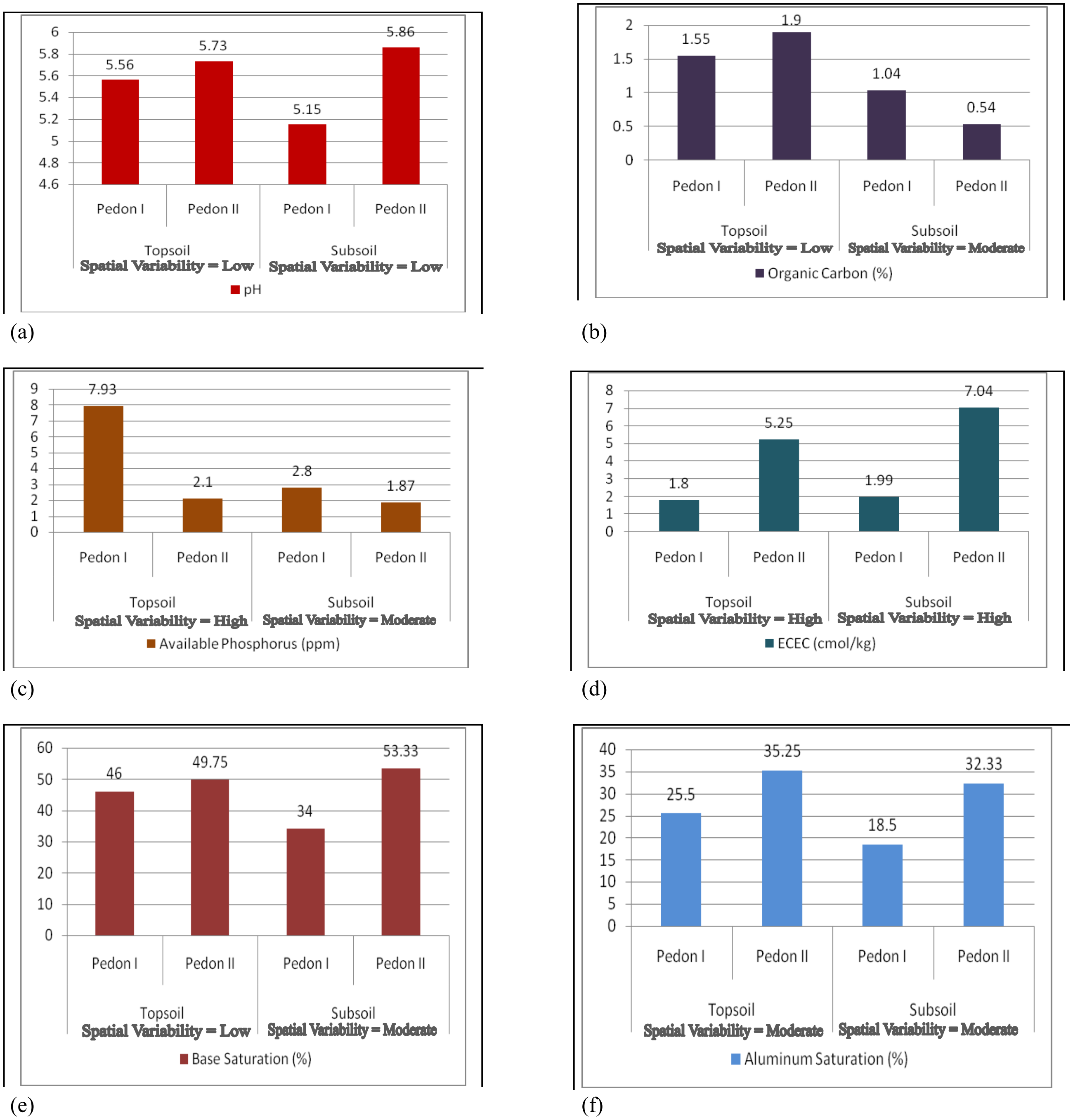


Figure 5: Variability of Soil pH [a], Organic Carbon (%) [b], Available Phosphorus (ppm) [c], ECEC (cmol/kg) [d], Base Saturation (%) [e] and Aluminum Saturation (%) across the Study Area

The Taxonomic classification and the World Reference Base for Soil Resources (WRB) classification of the soils of the study area are shown in Table 7.

3.3.1 Taxonomic Classification

Order: Due to the poor structural stability and diagnostic features, such as minimal variation in soil colour and clay with increasing depth, the soils of Umungwa (Pedon I) on the Coastal Plain Sands were classified as Inceptisols. The soils of Ikpem (Pedon II) on the Igbaku Sandstone were characterized by the presence of kandic (subsoil) horizons with base saturation greater than 35% (Table 2) and were thus classified as Alfisols.

Sub-order: Umungwa soils (Pedon I) were classified as Udepts due to the existence of a udic soil moisture regime. The soils of Ikpem (Pedon II) were classified as Aqualfs due to the preponderance of reducing conditions as indicated by the mottled subsoil horizons.

Great Group: Umungwa soils (Pedon I) were classified as Dystrudepts due to an ECEC less than 15 cmol kg^{-1} and a base saturation that was generally less than 60 %. Ikpem soils (Pedon II) were classified as Kandiaqualfs due to the presence of kandic features (clay illuviation subsurface horizons with ECEC less than 12 cmol/kg and the absence of progressively lower clay content with depth of 20 % relative to the highest clay content within a depth of 150 cm).

Sub-group: Due to the absence of densic, lithic or paralithic contact, mollic or umbric epipedon, a network of cracks, aquic moisture regime, andic soil properties, fragipans, argillic, kandic or natric horizon, human-transported materials or stratified alluvial sediments, Umungwa soils (Pedon I) were classified as Typic Dystrudepts. Ikpem soils (Pedon II) were classified as Aeric Umbric Kandiaqualfs as a result of a colour value of less than 5 within 19 cm soil depth, a hue of 7.5YR and a chroma of greater than 2 in all horizons within 51 cm soil depth.

3.3.2 WRB Classification

Umungwa soils (Pedon I) were classified as Cambisols as a result of the existence of cambic horizons with soil texture ranging from sand to loamy sand, absence of rock fragments or structures in the entire profile, evidence of pedogenic alteration (e.g. poor structural stability and minimal variation in soil colour down the profile) and a thickness of greater than 15 cm.

Umungwa soils were further classified as a Dystric Cambisol due to the preponderance of a base saturation less than 50 % in all horizons at soil depths beyond 16 cm.

Ikpem soils (Pedon II) were classified as Lixisols due to their low ECEC (< 24 cmol/kg) and medium to high base saturation (> 50 %) in the argic horizon starting within 100 cm from the soil surface or within 200 cm from the soil surface if the argic horizon is overlain by loamy sand or coarser textures throughout.

Table 7: Classification of the Soils of the Study Area

Pedon	Geologic Formation	Taxonomic Classification	WRB Classification
I	Coastal Plain Sands	Typic Dystrudept	Dystric Cambisol
II	Igbaku Sandstones	Aeric Umbric Kandiaqualf	Gleyic Lixisols

Ikpem was further classified as Gleyic Lixisols because of the presence of Gleyic properties as visible evidence of prolonged water-logging by shallow groundwater.

3.3.3 USDA and USBR Land Capability Classification / Land Use Recommendations

The USDA and USBR land capability classifications, along with the attendant land use recommendations are shown in Table 8. Being of USDA capability classes III and IV, the soils were found to be suitable for intense grazing, forestry, wildlife, water supply, aesthetic purposes and different intensities of arable crop production.

1. **Umungwa Soils (Pedon I):** Umungwa soils were placed under USDA capability class IVs and USBR capability class 3v/C due to their sandy topsoil texture (Table 2). However, it also had moderate susceptibility to erosion and moderate subsoil permeability.
2. Umungwa soils are suitable for limited cultivation (IVs). There is a limited range of crops that can be substantially grown on these soils even with careful management. As such, Landon (2013) asserted that to avoid dwindling net returns and increasing land degradation, soils in this class (IV) should be subjected to few adaptable common crops. Nevertheless, though acidic Cambisols are infertile, they can be used for mixed arable farming, grazing, farm plantations and forest land (IUSS Working Group WRB, 2015). Also, due to the ease of tillage, planting, root development and harvesting of root/tuber crops on these soils, with careful management, the soils can sustainably support the cultivation of crops like cassava, yam and groundnuts. They require high organic matter input and conservation tillage to improve soil available water holding capacity and curb erosion by water.
3. Finally, these soils were classified as marginally irrigable (3v/C). Being so sandy, they are adapted to the use of drip irrigation system whereas much water to meet plant needs is supplied at any particular moment in time, and not more.
4. **Ikpem Soils (Pedon II):** Ikpem soils were placed under USDA capability class IIIsw on account of their very slow subsoil permeability as reflected by the very low saturated hydraulic conductivity (Table 2) and its mottled subsoil, which is indicative of seasonal waterlogging. It was placed under USBR capability class 2w/C as a result of the minimal need for some drainage as indicated by its mottled subsoil.
5. The soils were moderately irrigable (class 2w/C). It is adapted to wetland farming, like rice cultivation, because of its clayey subsoil texture (Table 2) and fluctuating water table. High organic matter input may be necessary to ameliorate the effects of the clayey texture, improve soil porosity, reduce runoff and curb the menace of water erosion.

These soils (Class IIIsw) are suitable for moderate cultivation. The FDALR [Federal Department of Agricultural Land Resources] (1985) also recommended the cultivation of yam, cassava, cocoyam and maize on soils overlying Igbaku Sandstones, but the hydromorphic condition of the pedon may be a limiting factor. Drainage or planting on large mounds during the height of the rainy season may be required if the upland crops recommended by the FDALR (1985) are to be sustainably grown.

Similarly, having been classified as Alfisols, in line with the assertion of Brady and Weil (2016), adequate fertilization can drastically raise the productive potentials of the Ikpem soils. This was reiterated by the assertion of the FAO (2001) that Lixisols have low absolute level of plant nutrients and low cation retention, and require recurrent inputs of fertilizers and/or lime as a precondition for continuous cultivation.

Given the capability classes of III and 2w/C, the soils on the Igbaku Sandstones (Ikpem) have greater agronomic potentials and would require less capital investment to improve sustainable intensive use than the soils on the Coastal Plain sands (Umungwa) with classes IV and 3v/C. Consequently, the USDA and USBR land capability classes are dissimilar for both soils, irrespective of their location on similar physiographic positions. This variation is due to variation in a geologic formation, as also reported by Fasina et al. (2015) for soils of Southwestern Nigeria and Madueke et al. (2021b) for the soils of the rainforest belt of southeastern Nigeria. Similarly, the land use recommendations also varied considerably. Soils on the Imo

Table 8: Land Use Recommendations of Soils of the Study Area

Taxonomic Class	WRB Class	USDA Class	USBR Class	Land Use / Mgt. Recommendations
Pedon I – Umungwa – Coastal Plain Sands				
Typic Dystrudepts	Dystric Cambisols	IVs	3v C	- Marginally irrigable - Limited suitability for cultivation - Limited choice of plants - careful management required - very high organic matter input/minimum tillage is required to improve soil available water capacity, as well as reduce leaching and erosion - Adapted to use of drip irrigation system where as much water to meet plant need are supplied at any particular moment in time, and not more
Pedon II – Ikpem – Igbaku Sandstones				
Aeric Umbric Kandiaqualfs	Gleyic Lixisols	IIIsw	2w C	- Moderately irrigable - Moderate suitability for cultivation - The soil is adapted to wetland crops like rice during the rainy season or planting on large mounds. - Basin irrigation system is an adaptable option - It may be drained for upland crop production (if necessary) or the crops may be planted on large mounds or ridges - it may require deep ploughing/subsoiling and organic matter input to improve soil porosity and drainage

river basin of Southeastern Nigeria consequently have an inherent spatial variability that is a function of variation in topography and geologic formation.

4.0 Conclusion

The soils on the Coastal Plain Sands were classified as Typic Dystrudepts (Dystric Cambisols), while those on the Igbaku Sandstones were classified as Aeric Umbric Kandiaqualfs (Gleyic Lixisols). The soils on the Coastal Plain Sands had a USDA and USBR capability class of IVs and 3v/C respectively, while those on the Igbaku Sandstones have IIIsw and 2w/C respectively. This shows a distinct difference, which was a function of the underlying geologic formation since both sites were located on similar topographic positions.

The soils were found to be suitable for such land uses likegrazing, forestry, wildlife, water supply, aesthetics and different intensities of arable crop production. Nevertheless, the pedon on the Igbaku Sandstones (Ikpem) has greater agronomic potentials than the pedon on the Coastal Plain Sands (Umungwa). As such, if the soils are to produce increased and sustainable agricultural yield, the appropriate land use and husbandry practices should be adopted, as the soils are so different that they cannot be treated alike.

Moreover, though both soils are located in similar physiographic position, exist in the same climatic zone and are under the influence of the same species of living organisms, the difference in geologic formation ensured that the soils are of different physical and chemical properties, soil classification and potential land use. The parent materials of soils are consequently very important in determining the soil type and the sustainable use types.

The findings of this study consequently bring to light the obvious misconception that soils of Southeastern Nigeria are inherently acidic, of low ECEC and base saturation, of high Aluminium saturation, and are generally of low fertility. While this may be true of certain segments of the region, there are considerable exceptions, as determined by the geologic formations that gave rise to those soils. While Umungwa (Pedon I) on the Coastal Plain Sands may have properties that is in line with that line of thought, Ikpem (Pedon II) on the Igbaku Sandstones are relatively less acidic, of higher ECEC and base saturation, and generally of higher fertility.

Each soil consequently needs to be assessed on the strength of its properties, those of its parent materials and the physiography of the site, dispensing with undue generalizations. The geologic formation of any soil needs to be taken into consideration before the implementation of any agricultural or allied project. This reiterates the need for a current and up-to-date semi-detailed or detailed soil survey of Nigeria, to engender and ensure sustainable natural resources management.

Furthermore, given the capital- and labour-intensive nature of soil surveys, the physiography of the site may be digitally delineated to capture the different positions of the toposequence (Summit, Shoulder, Mid Slope, Foot Slope and Valley). This, when overlaid with the geologic map will provide a relatively detailed soil map, drastically reducing the expenditure invested in the soil survey process. A soil profile in each of these map units will provide an insight into the nature and properties of these soils, providing the data for site-specific soil characterization, classification and land use planning.

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