RESEARCH ARTICLE

COMPARATIVE ASSESSMENT OF TROPICAL RAINFOREST SOILS FORMED FROM DIFFERENT GEOLOGIC FORMATIONS IN SOUTHEASTERN NIGERIA

Chike Onyeke Madueke^a, Ikokuw Kalu Okore^a, Ebubechukwu Chizoba Maduekeh^b, Akudo Ogechukwu Onunwa^a, Maduabuchi Johnbosco Okafor^a, Emmanuel Chinweike Nnabuihe^a, Tochukwu Victor Nwosu^a

^a Department of Soil Science and Land Resources Management, Nnamdi Azikiwe University, P.M.B. 5025, Awka, Anambra State, Nigeria.

^b Department of Science Laboratory Technology, Federal College of Agriculture, Ishiagu, Ebonyi State, Nigeria

*Corresponding Author Email: co.madueke@unizik.edu.ng

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ABSTRACT

Data on the nature, properties and potentials of soils is grossly inadequate in the rainforest belt of southeastern Nigeria. As such, policymakers and other land users have tended to subscribe to unduly generalized ideas about the soils of the region. This has led to improper land use planning and aggravated land degradation. This necessitated the need for the comparative evaluation of the nature and potentials of the soils of the region to determine their degree of variability. Profile pits were dug in four towns underlain by different geologic formations: Umungwa (Benin Formation), Umuawa Ogii (Nsukka Formation), Ikpem (Igbaku Sandstones) and Amuro (Imo Clay Shales). The soils were characterized and classified using the World Reference Base for Soil Resources (WRB), United States Department of Agriculture (USDA) Soil Taxonomy and land capability classification. The variability of soils across the different sites was subsequently analysed using the coefficient of variation (CV). The results show that the variability of sand across the study sites was moderate (20 – 21 %), silt was high (63 %), clay ranged from moderate (34 %) to high (52 %), while hydraulic conductivity was very high (128 - 144 %). Similarly, with regards to the chemical properties, soil pH and base saturation ranged from moderate (20 - 49 %) to high (52 %), while effective cation exchange capacity (ECEC) and aluminium saturation were high (70 - 77 %). It was concluded that the soils of southeastern Nigeria are very heterogeneous. Undue generalization should consequently be discouraged.

KEYWORDS

Benin Formation, Igbaku Sandstones, Imo Clay Shales, Nsukka Formation, Land Use Planning, Pedology.

1. INTRODUCTION

The rapidly expanding population of Southeastern Nigeria is putting severe pressure on the static soil resource base, resulting in the shortening of the fallow period, with an attendant decline in soil productivity. And as more and more marginal lands continue to be brought into production, losses due to erosion are occurring at a much more rapid pace than in the past, resulting in the spectacular gullies that are evident in every part of the region. It has been reported that the key features that predispose the soils of Southeastern Nigeria to degradation include shortened fallow length, very low crop yield and biomass turnover, farming along slopes, numerous footpaths and sand mining activities (Osuji et al., 2002). Poor soil management practices and inadequate land use planning have exacerbated the hazardous situation, leading to accelerated land degradation.

This buttresses the need for a holistic understanding of the soils of Southeastern Nigeria, with a view towards determining their classification and sustainable land use types. More, so, as reported by several researchers, a very good understanding of the nature, characteristics and

classification of her soils, can assist Nigeria to get a better insight on how to arrest her food insecurity and fast-deteriorating environment (Esu, 2004; Ogunkunle, 2004). Unfortunately, the most up-to-date soil data for Nigeria was generated from the reconnaissance soil survey of 1985 (FDALR [Federal Department of Agricultural Land Resources], 1985). The data is grossly inadequate for project site selection, land use planning, soil management and environmental sustainability determination (Fagbami and Ogunkunle, 2000; Esu, 2004).

As a result of the overwhelming inadequacy of data on the nature, properties and potentials of soils in the rainforest belt of southeastern Nigeria, policymakers and other land users have tended to subscribe to unduly generalized ideas about the soils of the region. The general perception, as reported by several researchers, is that the soils of the region are highly weathered, strongly acidic, coarse textured, easily eroded and of low CEC, base saturation and inherent soil fertility (Osuji et al., 2002; Abam and Orji, 2019). This over-generalization has led to improper land use planning and aggravated land degradation, necessitating a quantitative assessment of the soils to buttress their degree of variability. This will underscore the need for more detailed and

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up-to-date soil data as a prerequisite to sustainable land use planning (Ogunkunle, 2004).

In line with the foregoing, it has been reported that locally, soil variability is predominantly dependent on topography and geologic formations (Foth, 1990). The soils of the region have diverse topography and geologic formations, but while the topographic features and their impacts on soil and land use planning are relatively evident, the impact of geology is not very widely reported. Therefore, the major objective of this study is to comparatively evaluate the nature and potentials of soils formed from different geologic formations in the rainforest belt of Southeastern Nigeria. The specific objectives are to

- characterize the soils on a specific physiographic position along 4 catenae underlain by different geologic formations
- determine the variability of soils using their physico-chemical properties
- classify the soils and make land use/management recommendations.

2. MATERIALS AND METHODS

2.1 Study Area

One profile pit was dug on each of the foot slopes of four (4) catena formed from different geologic formations in the rainforest belt of Southeastern Nigeria. The pits were located at Umungwa (Benin Formation), Umuawa

Ogii (Nsukka Formation), Ikpem (Igbaku Sandstones) and Amuro (Imo Clay Shale) (Figure 1). The properties of the parent materials are shown in Table 1.

Figure 1: Map of the study area, showing the tropical rainforest and the underlying geologic formations

Table 1: Description of the parent materials/geologic formation

S/N	FORMATION	PERIOD	EPOCH	DESCRIPTION
1	Benin Formation (Coastal Plain Sands)	Neogene	Pliocene, Holocene to Pleistocene	<ul style="list-style-type: none"> - Consists of unconsolidated yellow and white sand materials - Sometimes cross-bedded with clays, sandy clays and pebbles
2	Imo Clay Shale	Paleogene	Late Palaeocene to Early Eocene	<ul style="list-style-type: none"> - Consists of blue and dark grey shale - Has occasional bands of ironstones and siltstones - Thin bands of limestone found intercalated with the shale
3	Igbaku Sandstones	Paleogene	Late Palaeocene to Early Eocene	<ul style="list-style-type: none"> - A member of the Imo Shale Group. - It is consequently shaly sandstones usually associated with the Imo Clay Shale
4	Nsukka Formation (Upper Coal Measures)	Cretaceous / Palaeocene	Upper Cretaceous to Early Palaeocene	<ul style="list-style-type: none"> - Coarse sandstones, sandy shale and carbonaceous shale rocks. - Contain gritty and pebbly nodules of ironstones and ferruginized concretionary shales and sandstones. - Contains coal seams and well-bedded blue clays

2.2 Physical Environment of the Study Area

The area receives over 2,000 mm of rainfall distributed to about 140 days of the year (Madueke, 2010). It is double maxima, with a break occurring in July or August (Madueke et al., 2011). The daily temperature ranges from a minimum of 21°C to a maximum of 34°C. The relative humidity ranges from 60 % in the dry season to 90 % in the rainy season (Monanu, 1975). The original ecological zone of the study area was the tropical rainforest, which, due to human activities, is now predominantly an oil palm bush (Igbozurike, 1975; FDALR, 1985).

2.3 Site Description and Sample Collection

Four profile pits were dug in four locations within the rainforest, viz: Umungwa (Benin Formation), Umuawa Ogii (Nsukka Formation), Ikpem (Igbaku Sandstones) and Amuro (Imo Clay Shale). The site and profile descriptions were based on the FAO guidelines for profile description (FAO, 2006). 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. The samples were subsequently air-dried for three days and processed (crushed and sieved) in preparation for routine laboratory analysis. Undisturbed soil samples

for determination of saturated hydraulic conductivity and bulk density were collected using soil sample rings.

2.4 Laboratory Soil Analyses

The moisture content was determined gravimetrically. The hydrometer method (Gee and Bauder, 1986) was used to assess soil particle size distribution. Bulk density was analysed using standard operating procedures for undisturbed samples (Arshad et al., 1996). Porosity was calculated from the bulk and particle density values (Vomocil, 1965). Saturated hydraulic conductivity was determined by the Falling Head Method (McWhorter and Sunda, 1977). Soil pH (in water) and electrical conductivity were measured (1: 2.5 soil to liquid ratio) using the pH meter and the electrical conductivity meter respectively (International Institute for Tropical Agriculture [IITA], 1979). Exchangeable basic cations were extracted with neutral ammonium acetate (1N NH₄OAC). Exchangeable calcium and magnesium were determined by the ethylene diamine-tetraacetic acid (EDTA) titration method; exchangeable potassium and sodium were analysed using flame photometry (Jackson, 1962).

Exchangeable acidity was extracted with KCl (1 N) and measured

titrimetrically with 0.05N NaOH (Mclean, 1982). Effective Cation Exchange Capacity (ECEC) was computed as the sum of the exchangeable bases and the exchange acidity. Base saturation and aluminium saturation were computed as the percentages of the ratios of exchangeable bases and exchangeable aluminium respectively to ECEC. Walkley and Black digestion method (Nelson and Sommers, 1982) was used to analyse soil organic carbon (SOC). Total Nitrogen was determined using the micro-Kjeldahl digestion method (Bremner and Mulvaney, 1982). Available phosphorus was assessed using the Bray II Method (Olsen and Somers, 1982).

2.5 Soil Classification

The soils were classified in accordance with the USDA Soil Taxonomy (Soil Survey Staff, 2014) and the World Reference Base (WRB) for Soil Resources (FAO, 2001; IUSS Working Group WRB, 2015). The soils were further classified based on the USDA and the USBR Land Capability Classification (Klingebiel and Montgomery, 1961; USBR [United States Bureau of Land Reclamation], 1953; Landon, 2013). The land use recommendations were then made with respect to these classifications and the physico-chemical properties of the soils.

2.6 Data Analysis

The coefficient of variation (CV), which is defined as $\text{Standard Deviation} / \text{Mean} \times 100$, was determined for various physico-chemical properties across the study area. It gave an estimate of the degree of

variability of the soil properties within and across the soil profiles of the study area. According to reported estimates, soils with a CV of < 20 % were said to have low variability, 20 – 50 % were moderately variable, while ≥ 50 % were regarded as highly variable (Aweto, 1982). 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. RESULTS AND DISCUSSION

3.1 The Geo-References of the Study Area

The geographic information of the soils is shown in Table 2, while the soil profiles and schematic diagrams showing the sequence of horizonation are shown in Figure 2.

Study area	Landscape position	Geology	Latitude	Longitude	Altitude
Umungwa	Foot Slope	Benin Formation	N 05° 33' 39.1"	E 007° 24' 19.7"	100 m
Umuawa Ogii	Foot Slope	Nsukka Formation	N 05° 47' 14.6"	E 007° 21' 11.7"	120 m
Ikpem	Foot Slope	Igbaku Sandstones	N 05° 44' 43.0"	E 007° 17' 00.7"	126 m
Amuro	Foot Slope	Imo Clay Shale	N 05° 47' 09.7"	E 007° 16' 27.4"	89 m

Figure 2: Soil profiles on the Benin Formation (a), Nsukka Formation (b), Igbaku Sandstone (c) and Imo Clay Shale (d)

3.2 Variability of the Morphological and Physical Properties

The physical properties of soils are shown in Table 3. Figure 2 shows the soil profiles and schematic diagrams depicting the sequence of horizonation, horizon depths, colour and texture. The soil was generally deep (> 200cm). Soil colour ranged from dull brown (7.5 YR 5/3) to brown (7.5 YR 4/3) in the topsoil; and from Dull yellow orange (10 YR 6/4) to orange (5 YR 6/6) in the subsoil. While for all pedons, the soil colour varied

with depth from brownish in the topsoil to reddish in the subsoil, Amuro on the Imo Clay Shale had a relatively uniform dull orange colour (7.5YR6/4) throughout the profile. Conversely, Ikpem on the Igbaku Sandstones and Umuawa Ogii on the Nsukka Formation had mottled subsoil horizons. This is an indicator of the preponderance of periodic/seasonal hydromorphic conditions in both pedons. Soil colour consequently varied considerably from soil to soil (Figure 2), relative to the nature and properties of the underlying geologic formation.

Table 3: Physical properties of soils of the study area

Hor.	Depth (cm)	Moisture Content (%)	Particle Size Distribution				Bulk Density (Mg/m³)	Porosity	Ksat (cm/s)
			Sand (%)	Silt (%)	Clay (%)	Textural Class			
Umungwa – Benin Formation									
Ap	0-16	0.85	91	1	8	S	1.49	43.66	4.00
A ₂	16-65	0.89	92	1	8	S	1.51	42.87	2.59
BA	65-94	0.92	89	1	10	LS	1.52	42.79	2.27
B ₁	94-140	0.93	89	1	10	LS	1.52	42.53	1.73
B ₂	140-175	1.87	88	1	11	LS	1.53	42.43	1.41
B ₃	175-200	1.79	88	1	11	LS	1.59	39.85	1.19
Umuawa Ogii – Nsukka Formation									
Ap	0-23	10.78	59	9	33	SCL	1.26	52.49	0.04
A ₂	23-45	8.74	53	6	41	SC	1.30	50.98	0.02
ABg	45-83	9.17	53	7	41	SC	1.31	50.57	0.04
BgA	83-97	8.74	51	8	41	C	1.55	41.70	0.01
Bgt ₁	97-107	9.80	49	9	48	C	1.60	39.58	0.01
Bgt ₂	107-143	5.88	52	7	42	SC	1.37	48.30	0.01
Cg	143-168	6.80	50	8	43	SC	1.40	44.25	0.01
2Cg	168-200	10.20	75	8	18	SL	1.60	39.74	0.08
Ikpem – Igbaku Sandstone									
Ap	0-19	3.77	86	3	11	LS	1.43	46.23	2.16
A ₂	19-26	7.14	81	3	16	SL	1.46	44.79	0.22
A ₃	26-40	6.86	79	3	18	SL	1.46	44.75	0.04
BA	40-51	7.07	75	3	22	SCL	1.52	42.91	0.01
Bgt ₁	51-82	9.09	71	3	26	SCL	1.52	42.72	0.01
Bgt ₂	82-140	9.70	71	3	26	SCL	1.52	42.68	0.01
Cg	140-200	10.10	57	7	36	SC	1.65	37.82	0.01
Amuro – Imo Clay Shale									
A ₁	0-26	8.82	59	9	32	SCL	1.23	53.74	0.04
AB	26-72	10.42	59	9	32	SCL	1.23	53.74	0.04
B ₁	72-111	11.11	56	11	34	SCL	1.31	50.42	0.13
B ₂	111-150	10.10	58	10	32	SCL	1.34	49.51	0.13
BC	150-200	9.26	59	11	30	SCL	1.38	44.72	0.39

Hor. = Horizon, Ksat = Saturated Hydraulic Conductivity, S = Sand, LS = Loamy Sand, SL = Sandy Loam, SCL = Sandy Clay Loam, SC = Sandy Clay, C = Clay

The texture of the topsoil ranged from sand at Umungwa (Benin Formation) to sandy clay at Umuawa Ogii (Nsukka Formation). Clay content generally tended to increase down the profile (Figure 3). It has been reported that this is diagnostic of the existence of argillic horizons in these soils (Chikezie et al., 2010). Nevertheless, while the vertical variability was moderate at Umuawa Ogii (Nsukka Formation) and Ikpem (Igbaku Sandstones), it was low at Umungwa (Benin Formation) and Amuro (Imo Clay Shales) (Table 4). The low vertical variability of clay at Umungwa and Amuro precludes the existence of well-developed argillic horizons.

Table 4: Vertical variation of clay down the profiles

Pedon	Geologic Formation	Statistics			
		Mean	Std. Dev.	Coeff. of Var. (CV)	Variability
Umungwa	Benin Formation	9.67	1.37	14.17	Low
Umuawa Ogii	Nsukka Formation	38.38	9.20	23.97	Moderate
Ikpem	Igbaku Sandstones	22.14	8.17	36.90	Moderate
Amuro	Imo Clay Shale	32.00	1.41	4.41	Low

Nevertheless, the generally clayey texture of both the top- and subsoils of Umuawa Ogii (Nsukka Formation) and Amuro (Imo Clay Shale) belies the impression that soils of Southeastern Nigeria are generally coarse-textured (Osuji et al., 2002). Moreover, since soil texture influences soil

chemical and biological fertility (Igboji and Onyibe, 2019; Kayode et al., 2019), the soils of the region will vary considerably in their physical, chemical and biological properties, and can thus, not be treated alike.

Figure 3: Depth function of clay on the Benin Formation (Umungwa) (a), the Nsukka Formation (Umuawa Ogii) (b), the Igbaku Sandstone (Ikpem) (c) and the Imo Clay Shale (Amuro) (d)

The variability of sand, silt and clay across the study area were moderate, high and high respectively in the topsoil and moderate, high and moderate respectively in the subsoil (Figure 4 (a), (b), (c), Table 5). Similar results have also been reported by other researchers (Nkwopara, 2018). 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 a study reported low silt content for the soils of Southeastern Nigeria, which was attributed to intense weathering and leaching inherent in the region (Akamigbo, 1984), the relatively higher silt content of Umuawa Ogii and Amuro may be attributed to the nature of their respective geologic formations.

The bulk density ranged from 1.23 Mg/m³ in the topsoil of Amuro [Imo Clay Shales] (0 – 72 cm) to 1.65 Mg/m³ in the Cg horizon (140 – 200 cm) of Ikpem [Igbaku Sandstones]. In all the constituent horizons, bulk density was below the baseline value at which root penetration becomes

problematic on sandy loam soils (1.75 – 1.80 Mg/m³), sand (1.6 Mg/m³) and clay (1.4 Mg/m³) (USDA Natural Resources Conservation Service, 2001; Donahue et al., 1990), except in the BgA and Bt₁ horizons of Umuawa Ogii (Nsukka Formation) where it was 1.55 Mg/m³ and 1.60 Mg/m³ respectively. The generally low bulk density showed that the soils were not compacted (Esu and Ojanuga, 1986).

Saturated hydraulic conductivity ranged from 0.01 cm/s in the subsoil of Umuawa Ogii (Nsukka Formation) and Ikpem (Igbaku Sandstones) to 4.0 cm/s in the Ap horizon (0 – 16 cm) of Umungwa (Benin Formation). Generally, the maximum value was recorded in the topsoil, decreasing with increasing depth, except at Umuawa Ogii (Nsukka Formation) and Amuro (Imo Clay Shale), where it was relatively irregular. The variability of saturated hydraulic conductivity across the study area was however very high in both the topsoil and the subsoil (Figure 4 (d), Table 5), indicating that it was greatly influenced by variation in geologic formation.

Figure 4: Variability of sand (a), silt (b), clay (c) and saturated hydraulic conductivity (d) across the study area

Table 5: Spatial variability of some physical properties across the study area

Soils	Statistics	Sand	Silt	Clay	Hydr. Conductivity
Topsoil	Mean	72.13	5.13	23.00	1.05
	Std. Dev.	15.04	3.25	11.90	1.34
	CV (%)	21	63	52	128
	Variability	Moderate	High	High	Very High
Subsoil	Mean	67.42	5.88	27.21	0.48
	Std. Dev.	13.18	3.68	10.46	0.69
	CV (%)	20	63	34	144
	Variability	Moderate	High	Moderate	Very High

(a)

(c)

(b)

(d)

Figure 5: Variability of soil pH (a), ECEC (b), base saturation (c) and aluminium saturation (d) across the study area

Table 6: Chemical properties of the study area

Hor.	Depth	pH	Org. C (%)	Tot. N (%)	Ava. P (ppm)	Exchangeable Bases (cmol/kg)				Ex. Acidity		ECEC (cmol/kg)	Base Sat. (%)	Al Sat. (%)
						Ca	Mg	K	Na	Al	H			
Benin Formation (Umungwa)														
Ap	0-16	6.51	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	175-200	5.09	0.55	0.05	2.80	0.13	0.07	0.39	0.10	0.20	0.90	1.79	39	11
Nsukka Formation (Umuawa Ogii)														
Ap	0-23	5.00	3.99	0.28	2.80	0.78	0.66	0.55	0.22	4.84	1.04	8.09	27	60
A ₂	23-45	4.82	0.85	0.06	3.73	0.80	0.69	0.56	0.19	5.56	3.18	10.98	20	51
ABg	45-83	4.88	0.85	0.07	1.87	0.87	0.70	0.56	0.16	8.18	0.16	10.63	22	77
BgA	83-97	4.89	0.55	0.04	2.80	0.62	0.69	0.52	0.16	3.40	0.60	5.99	33	57
Bgt ₁	97-108	4.97	0.70	0.06	1.87	0.58	0.69	0.56	0.16	3.74	2.22	7.95	25	47
Bgt ₂	108-143	4.86	0.45	0.04	2.80	0.64	0.89	0.51	0.16	6.72	0.08	9.00	24	75
Cg	143-168	4.82	0.65	0.06	1.87	0.96	0.66	0.41	0.16	6.48	0.72	9.39	23	69
2Cg	168-200	4.80	1.65	0.14	1.87	0.40	0.66	0.40	0.18	1.64	0.94	4.22	39	39
Igbaku Sandstone (Ikpeem)														
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	140-200	6.04	0.45	0.04	1.87	0.40	2.18	0.39	0.19	1.09	1.01	5.26	60	21
Imo Clay Shale (Amuro)														
A ₁	0-26	7.92	1.75	0.14	18.65	9.35	9.30	0.47	0.15	0.00	0.24	19.51	99	Trace
AB	26-72	8.52	1.25	0.10	22.38	8.90	9.30	0.31	0.15	0.00	0.22	18.88	99	Trace
B ₁	72-111	8.82	1.05	0.09	15.86	9.00	9.22	0.36	0.16	0.00	0.20	18.94	99	Trace
B ₂	111-150	9.06	0.90	0.08	13.06	8.46	9.10	0.33	0.16	0.00	0.18	18.23	99	Trace
BC	150-200	8.30	0.75	0.07	9.33	9.80	9.06	0.31	0.61	0.00	0.18	19.96	99	Trace

Similarly, it has been reported that the spatial variability of soil pH on any site is largely dependent on the parent material (Zhang et al., 2019). Furthermore, the alkaline reaction of Amuro (Imo Clay Shale) contradicts the generally held opinion as reported by several researchers that the soils of Southeastern Nigeria are acidic (Osuji et al., 2002; Gideon et al., 2016). As such, if based on the general view, Amuro soils are treated with lime, the already existing alkalinity problem will be exacerbated, with disastrous consequences on soil productivity and ecosystem functions. The soil organic carbon content ranged from 0.45 % in the Bgt₂ horizon (108 - 143 cm) of Umuawa Ogii (Nsukka Formation) and the Cg (140 - 200) horizon of Ikpem (Igbaku Sandstones) to 3.99 % in the Ap horizon (0 - 23 cm) of Umuawa Ogii. This is in line with reports that most cultivable soils contain 1 - 6 % organic matter, which is mostly within the top 25 cm of the soil; and this relatively small proportion influences the physical, chemical and biological properties of the soil (Brady and Weil, 2016).

Total Nitrogen ranged from 0.04 % in the subsoil to 0.28 % in the topsoil of the study area, and correlated positively with organic carbon, as also reported by other researchers (Uquetan et al., 2016). The low nitrogen content is inherently preponderant in the soils of Southeastern Nigeria. It may be attributed to excessive leaching of nitrates due to high rainfall and the rapid decomposition of organic matter as a result of the high temperatures of the humid tropics (Eshett et al., 1990; Onwuka and Mang, 2018). The soils were acutely deficient in available phosphorus (< 3.0 ppm), except for the topsoil of Umungwa [Benin Formation] (0 - 65 cm) and the entire profile at Amuro (Imo Clay Shale). The moderate to low available phosphorus is, however, a widespread occurrence in the humid tropics of Southeastern Nigeria, and is attributable to the high phosphate fixation capacity of humid tropical soils (Eshett et al., 1990; Olander and Vitousek, 2004; Wurzbürger et al., 2012). The ECEC of the soils ranged from 1.69 cmol/kg in the Ap horizon (0 - 16 cm) of Umungwa (Benin Formation) to 19.96 cmol/kg in the BC horizon (150 - 200 cm) of Amuro (Imo Clay Shale).

The low ECEC in much of the study area is in line with the assertion by Osuji et al. (2002) that soils overlying the Coastal Plain Sands and sandstones are acidic, have low CEC, base saturation and fertility levels. It was however higher at Amuro (Imo Clay Shale) because of the nature of the geologic formation. Similarly, the variability of ECEC across the study area was high in the topsoil and the subsoil (Figure 5 (b), Table 7), showing that variation in geologic formation affects the nature, properties and potential use of the soils. Base saturation generally ranged from as low as 20 % in the A₂ horizon (23 - 45 cm) of Umuawa Ogii (Nsukka Formation) to 99 % at Amuro (Imo Clay Shale). Base saturation was generally highest in the topsoil, except for Amuro (Imo Clay Shale), where it was relatively uniform throughout the profile. It has been reported that pH correlates positively with base saturation (Foth, 1990; Kabala and Abaz, 2018). As such, the decrease of base saturation with increasing depth can be attributed to pH, which tended to decrease with increasing depth.

Soils	Statistics	Soil pH	ECEC	Base Saturation	Aluminium Saturation
Topsoil	Mean	6.24	8.92	55.54	27.08
	Std. Dev.	1.22	6.55	27.43	19.64
	CV (%)	20	73	49	73
	Variability	Moderate	High	Moderate	High
Subsoil	Mean	6.14	8.90	52.54	29.54
	Std. Dev.	1.54	6.25	27.97	22.66
	CV (%)	25	70	53	77
	Variability	Moderate	High	High	High

Juo (1984) attributed the low base saturation of the soils of Southeastern Nigeria to the coarse texture of the soils and/or the heavy precipitation and leaching that characterize the soils of the region. This assertion, as well as the contention of that soils of Southeastern Nigeria have low base saturation, proved erroneous for Amuro (Imo Clay Shale) and Ikpem (Igbaku Sandstones) because both geologic formations yielded soils with a relatively higher concentration of clay and basic cations. This is in line with the variability of base saturation across the study area, which was moderate in the topsoil and high in the subsoil (Figure 5 (c), Table 7), showing that base saturation is affected by the nature of the geologic formation from which the soil was formed.

Aluminium saturation ranged from trace concentration at Amuro (Imo Clay Shale) to 75 % in the Bgt₂ horizon (108 - 143 cm) of Umuawa Ogii (Nsukka Formation). Sanchez (1976) reported that there is less than 1.0 ppm aluminium in the soil solution when aluminium saturation is less than 60 % but rises sharply when aluminium saturation increases beyond 60 %. As such, due to the low aluminium saturation (< 60%) in the soils, there is little risk of aluminium concentration attaining toxic levels, except at Umuawa Ogii. The variability of Aluminium saturation across the study area was high in the topsoil and the subsoil (Figure 5 (d), Table 7), showing that Aluminium saturation is affected by the nature of the geologic formation from which the soil was formed.

3.4 Soil Classification

The profile pits and the schematic diagrams of the horizon sequence are shown in Figure 2 (a) to (d). The taxonomic and WRB classifications of the study area are shown in Table 8.

Pedon	Geologic Formation	Taxonomic Classification	WRB Classification
Umungwa	Benin Formation	Typic Dystrudept	Dystric Cambisol
Umuawa Ogii	Nsukka Formation	Aeric Kandiaquult	Reductigleyic Gleysol
Ikpem	Igbaku Sandstone	Aeric Umbric Kandiaqualf	Gleyic Lixisol
Amuro	Imo Clay Shale	Chromic Hapludert	Chromic Vertisol

3.4.1 Taxonomic Classification

The soils belong to different taxonomic orders, irrespective of the location on similar physiographic positions in the tropical rainforest of Southeastern Nigeria (Table 8). The soils consequently reflect the difference in the nature and properties of the underlying geologic formation; a situation that should be taken into consideration in land use planning and land allocation.

Order: Due to the existence of minimal diagnostic features, including poor structural stability, minimal variation in soil colour and clay down the profile, the soil of Umungwa on the Benin Formation was classified as an Inceptisol. Umuawa Ogii on the Nsukka Formation was classified as an Ultisol because of the existence of a kandic horizon with percent base saturation less than 35% within 200cm below the mineral soil surface, as well as evidence of increasing clay content with increasing depth (Table 3). Ikpem on the Igbaku Sandstone was characterized by the presence of kandic horizons with percent base saturation greater than 35% (Table 6), and was thus classified as Alfisols. As a result of the generally high clay content of greater than 30% throughout the depth of the profile (Table 3), smoothly polished surfaces (slickensides) and the wide cracks that appear and disappear in tandem with fluctuation in soil moisture, the soils of Amuro on the Imo Clay Shale were classified as Vertisols.

Sub-order: Umungwa (Benin Formation) did not have aquic soil moisture regime, nor does it have gelic or cryic soil temperature regimes. It was therefore classified as an Udept due to the prevailing udic soil moisture regime. Due to the preponderance of reducing conditions as indicated by the mottled subsoil horizons (23 cm below the mineral soil surface) Umuawa Ogii (Nsukka Formation) was classified as an Aquult. Ikpem (Igbaku Sandstones) was classified as an Aqualf due to the preponderance of reducing conditions as indicated by the mottled subsoil horizons (16 cm from the soil surface) and chroma of 1 within 51 to 154 cm depth. Amuro (Imo Clay Shale) was classified as Uderts because of its udic soil moisture regime.

Great Group: Umungwa (Benin Formation) was classified as a Dystrudept due to an ECEC less than 15 cmol kg⁻¹ and a base saturation of less than 60 % in all horizons. Umuawa Ogii (Nsukka Formation) was classified as Kandiaquult because of the absence of a lithic, paralithic or petroferic contact; having an ECEC less than 12 cmol/kg (Table 6); and the absence of progressively lower clay content with depth of 20 % relative to the highest clay content within a depth of 150 cm. Similarly, Ikpem (Igbaku Sandstones) was classified as Kandiaqualf due to the presence of kandic features, which was also evident at Umuawa Ogii. With a pH value ranging from 7 to 9 and a base saturation that is as high as 99 %, Amuro on the Imo Clay Shale cannot be classified as a Dystrudert. It was therefore classified as a Hapludert.

Sub-group: Due to the absence of densic, lithic or paralithic contact, mollic or umbric epipedon, a network of cracks, aquic moisture regime, and soil properties, fragipans, argillic, kandic or natric horizon, human-transported materials or stratified alluvial sediments, Umungwa on the Benin Formation could not be classified as Humic, Lithic, Vertic, Aquic, Andic, Oxidic, Alfic, Ultic, Fragic, Fluventic or Lamellic Dystrudept. It was therefore classified as a Typic Dystrudept. With an ECEC that was generally greater than 1.5 cmol/kg, no sandy horizon and no plinthite, Umuawa Ogii on the Nsukka Formation was classified as Aerik Kandiaquult due to a chroma that was generally greater than 3 in all horizons within 25 to 100 cm soil depth. Due to 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, Ikpem on the Igbaku Sandstones was classified as an Aerik Umbric Kandiaqualf. Amuro on the Imo Clay Shale was classified as Chromic Hapludert due to a color value (dry) of 6 and a chroma of 4 (> 3).

3.4.2 WRB Classification

As was the case with the soil taxonomic classification, the soils also belonged to different world reference base soil groups, irrespective of the location on similar physiographic positions in the tropical rainforest of Southeastern Nigeria (Table 8). This buttresses the value of geology in determining soil variability and the attendant land use options.

Umungwa (Benin Formation): classified as a Cambisol as a result of the existence of cambic horizon as connoted by

1. soil texture ranging from sand to loamy sand
2. absence of rock fragments or structures in the entire profile
3. evidence of pedogenetic alteration, such as poor structural stability and minimal variation in soil colour down the profile and
4. a thickness of greater than 15 cm.

Furthermore, Umungwa soil met the requirement for classification as Eutric Cambisol, but for a base saturation of less than 50 % in all horizons at depths of higher than 16 cm (Table 6). It was therefore classified as a Dystric Cambisol.

Umuawa Ogii (Nsukka Formation): classified as a Gleysol because of the presence of,

- extensive mottling within a depth of 40 cm;
- no abrupt change in soil texture within a soil depth of 100 cm.

It was further classified as Reductigleyic Gleysol due to the absence of a

thick, dark, organic matter-rich topsoil that shows evidence of mottling within a depth of 40 cm below the soil surface.

Ikpem (Igbaku Sandstones): classified as Lixisols due to

- low ECEC (< 24 cmol/kg) and
- base saturation greater than 50 % in the argic horizon, starting within 100 cm soil depth.

Ikpem was further classified as Gleyic Lixisol due to extensive mottling within a soil depth of 75 cm as visible evidence of prolonged water-logging by shallow groundwater.

Amuro (Imo Clay Shale): classified as a Vertisols because of the presence of

- horizons with cracks and shiny structural units within a depth of 100 cm;
- a minimum of 30 percent clay in all horizons, and
- cracks – as wide as 1 - 3 cm and as deep as 160 cm – which open and close periodically.

It was classified as Chromic Vertisol for having in all horizons, a hue of 7.5YR and a colour value of 4.

3.4.3 USDA and USBR Land Capability Classification

The USDA and USBR land capability classifications, along with the attendant land use recommendations are shown in Table 9.

- 1) Umungwa on the Benin Formation (Figure 2a) had moderate susceptibility to erosion and subsoil permeability but was generally placed under USDA capability class IVs due to its sandy topsoil texture. It also met the minimum soil, topographic and drainage requirements to warrant placement in class 1 of irrigable lands, but for the textural limitation. Consequently, Umungwa, with a generally sandy topsoil texture, was placed under USBR capability class 3 (3v/C).
- 2) Umuawa Ogii on the Nsukka Formation (Figure 2b) had limitations related to moderate ongoing erosion, very slow subsoil permeability and poor drainage (grossly mottled horizons), warranting a placement in USDA capability class III with the classification IIIs_w. It also had limitations relating to texture, levelling and drainage. Though it required minimal expenses on grading and probable drainage, its placement in USBR capability class 3 was as a result of its sandy clay texture and low permeability. It was classified as 3hp/C.
- 3) Ikpem on the Igbaku Sandstones (Figure 2c). Its mottled subsoil and the sandy loam topsoil texture notwithstanding, was placed in USDA capability class III on account of its very slow subsoil permeability. It was thus classified as IIIs_w. It met all the requirements for placement in USBR capability class 1, but for the minimal need for some drainage as indicated by its mottled subsoil. It was thus placed in class 2 (2w/C).
- 4) Amuro on the Imo Clay Shale (Figure 2d) had a slope of 2 - 4 %, moderate susceptibility to erosion, moderate drainage, slow subsoil permeability and sandy clay loam texture, all warranting a placement in class II. However, in accordance with specifications (Landon, 2013), the pH of 8 - 9, necessitated its placement in USDA capability class III (IIIs). With regards to the USBR capability class, it was placed in Class 2 (2mu₂/C) due to its textural and levelling limitations (sandy clay loam topsoil texture and the need for levelling).

The land capability classes generally varied with variation in geologic formation. Similar results have also been reported for the soils of Southwestern Nigeria (Fasina et al., 2015).

Being of USDA capability classes III and IV, the soils were found to be suitable for grazing, forestry, wildlife, water supply, aesthetic purposes and different intensities of arable crop production. Irritability ranged from marginal to moderate due to USBR capability class of 2 to 3 respectively.

Table 9: Land Use Recommendations of Soils of the Study Area

Taxonomic / WRB Class	USDA Class	USBR Class	Land Use/Management Recommendations
Umungwa – Benin Formation			
Typic Dystrudept (Dystric Cambisol)	IVs	$\frac{3v}{C}$	<ul style="list-style-type: none"> - Marginally irrigable - Marginal suitability for cultivation - Adapted to the cultivation of all the upland crops of the region - They require high organic matter input/minimum tillage to improve soil porosity, curb water erosion and improve available water holding capacity (AWC).
Umuawa Ogii – Nsukka Formation			
Aeric Kandiaquult (Reductigleyic Gleysol)	IIIew	$\frac{3hp}{C}$	<ul style="list-style-type: none"> - Moderate suitability for cultivation and marginally irrigable - Adapted to the growth of wetland crops like rice - Requires levelling/grading for effective uniform irrigation - May require drainage or planting on large mounds if upland crop are to be grown - Deep ploughing and organic matter input are necessary to ameliorate the clayey texture, improve soil porosity and hydraulic conductivity thus reducing runoff and erosion.
Ikpem – Igbaku Sandstone			
Aeric Umbric Kandiaqualf (Gleyic Lixisol)	IIIsw	$\frac{2w}{C}$	<ul style="list-style-type: none"> - Moderate suitability for cultivation and moderately irrigable - It may require drainage as indicated by the mottled horizons and fluctuating water table. - The soil is adapted to wetland crops like rice during the rainy season or planting on large mounds. - It may require deep ploughing/subsoiling and organic matter input to improve soil porosity and drainage
Amuro – Imo Clay Shale			
Chromic Hapludert (Chromic Vertisol)	IIIs	$\frac{2mu_2}{C}$	<ul style="list-style-type: none"> - Moderate suitability for cultivation and moderately irrigable - Adapted to wetland crops and crops that thrive under conditions of high pH - Requires contour ridging, deep ploughing, drainage and organic matter input to improve soil porosity and permeability, reducing erosion and improving soil tilth. - Requires some levelling of the land surface to make for uniform irrigation and prevent erosion.

3.5 Land Use and Management Recommendations

The land use recommendations are outlined in Table 09. Umuawa Ogii on the Nsukka Formation (Figure 2b) and Ikpem on the Igbaku Sandstones (Figure 2c) are adapted to wetland farming like paddy rice cultivation because of their clayey texture and fluctuating water table, particularly for Umuawa Ogii. Deep ploughing/subsoiling and increased organic matter input may also be necessary to ameliorate the effects of the clayey texture, improve soil porosity, reduce runoff and curb the menace of water erosion. They are suitable for moderate cultivation due to their classification as Class III soils. The cultivation of yam, cassava, cocoyam and maize has been recommended for soils overlying Igbaku Sandstones and the Nsukka Formation (FDALR, 1985), but the hydromorphic condition of these pedons may be a limiting factor. Drainage or planting on large mounds during the height of the rainy season may be required if these upland crops are to be sustainably grown. Similarly, having been classified as Ultisols and/or Lixisols or Acrisols, it is recommended that being infertile soils, the use of adequate levels of fertilizers and lime will drastically raise the productive potentials of the soils (FAO, 2001; Brady and Weil, 2016).

Amuro on the Imo Clay Shale (Figure 2d) is also adapted to wetland crop production on account of its clayey texture and high-water holding capacity. This agrees with the recommendations that rice, sugarcane, plantain and vegetable can be cultivated on soils formed from the Imo Clay Shale (FDALR, 1985). Similarly, in tandem with the recommendation that vertisols can be used for small to large scale irrigated (dry) season crop production, particularly paddy rice farming (FAO, 2001), Amuro, having been classified as Vertisols, can also be used as such. The soils are not suitable for tree crops or plantations because the periodic expansion and contraction negate effective root establishment (FAO, 2001). Thus, conservation practices or reversion to rangeland are important management options to consider (Brady and Weil, 2016). The very high pH also limits the growth of acid-tolerant crops. Nitrate and ammonium sulphate fertilizers might be applied to improve fertility and to reduce soil alkalinity in the long run.

The periodic swelling and shrinking of soils is diagnostic of a high concentration of smectites. The movement in the soil might be sufficient to compromise building foundations, pipelines, pavements and roadbeds (Brady and Weil, 2016). As such, before roads and other structures are to be constructed at Amuro, the soils should be excavated to a specified depth and replaced with soils rich in kaolinite. However, the soils also have positive attributes as the smectites enable their use in pond, sewage/industrial waste lagoon and landfill construction (Brady and Weil, 2016). Increasingly, environmental scientists are using swelling-type clays for environmental monitoring as well as for the removal of organic chemicals from water by partitioning (Brady and Weil, 2016).

Umungwa on the Benin Formation (Figure 2a) was marginally suitable for arable crop production and irrigation due to its sandy texture. It can consequently only be suitable for a limited range of crops, even with careful management. However, it has been reported that although acidic Cambisols are not fertile, 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 (bambara) groundnuts. To ensure sustainability, the soil requires high organic matter input and conservation tillage to improve soil available water holding capacity and curb erosion by water. Due to the sandy texture, the soils of Umungwa on the Benin Formation are adapted to the use of drip irrigation system.

4. CONCLUSION

Soil variability across the study area ranged from moderate to very high. With regards to the physical properties, variability of sand across the study sites was moderate (CV ranging from 20 to 21 %), silt was high (CV of 63 %), clay ranged from moderate (CV of 34 %) to high (CV of 52 %), while hydraulic conductivity was very high (CV ranging from 128 to 144 %). Similarly, with regards to the chemical properties, soil pH and base saturation ranged from moderate (CV ranging from 20 to 49 %) to high

(CV of 52 %), while effective cation exchange capacity (ECEC) and aluminium saturation were high (CV ranging from 70 to 77 %).

Furthermore, the soils of Umungwa on the Benin Formation were classified as Typic Dystrudepts (Dystric Cambisols); Umuawa Ogii on the Nsukka Formation as Aeris Kandiaquults (Reductigleyic Gleysols); Ikpe on the Igba Sandstone as Aeris Umbric Kandiaqualf (Gleyic Lixisols); and Amuro on the Imo Clay Shale as Chromic Hapluclerts (Chromic Vertisols). Umungwa has a USDA and USBR capability class of IVs and 3v/C respectively; Umuawa Ogii has a USDA and USBR capability class of IIIs and 3hp/C respectively; Ikpe has a USDA and USBR capability class of IIIs and 2w/C respectively; while Amuro has a USDA and USBR capability class of IIIs and 2mu₂/C respectively.

The soils of the tropical rainforest belt of Southeastern Nigeria consequently differ significantly in their physico-chemical properties, taxonomic, WRB and land capability classes. As such, contrary to popular opinion, it is erroneous and dangerous to think that all the soils in the tropical rainforest of Southeastern Nigeria are coarse-grained, porous and acidic Ultisols and Oxisols of low base saturation, CEC and fertility. Similarly, their USDA and USBR land capability classes vary significantly, as does their potential uses and adoptable site-specific management practices. It can consequently be concluded that site geology plays a fundamental in determining the soil type and the sustainable use types. As such, treating the soils of Amuro on the Imo Clay Shale – whose pH ranges from 8 to 9 – with lime just because the soils of Southeastern Nigeria are thought to be acidic can be counterproductive, if not disastrous. Each soil needs to be taken on the strength of its properties and those of its parent materials, dispensing with undue generalizations.

Finally, since a single blanket soil management option cannot be implemented for the entire rainforest belt of Southeastern Nigeria, a semi-detailed or detailed soil survey of the region is a necessary prerequisite to sustainable land use planning and management. In the absence of that, in line with the assertion of that locally, soil variability is a product of variation in geology and topography, it may become necessary to characterize and classify the soil catena on each of the constituent geologic formations in the region. If the soils can be mapped using the soil catena-geologic formation approach, it may provide the necessary detail for sustainable land use planning, land husbandry and land allocation.

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