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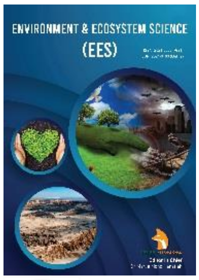

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RESEARCH ARTICLE

EVALUATION OF THE PHYSICO-CHEMICAL AND MORPHOLOGICAL PROPERTIES OF AN EXPOSED SOIL PROFILE IN AN EXCAVATED ACRISOL, SOUTHEAST NIGERIA

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ABSTRACT

Increased population density has led to a lot of pressure on the limited natural/land resources of south-eastern Nigeria. This includes the need for laterite, sand, kaolin, gravel and clay for buildings, backfills and road construction. This has led to extensive unmoderated excavation of these resources, particularly in Anambra state. The excavation has in turns, culminated in increased intensity of land degradation in the state, underscoring the need to characterize and evaluate the land use potentials of such sites to better understand the nature of the soils and the impacts of the attendant land use. Samples were collected from the different horizons of the profile to evaluate the physical, chemical and morphological properties of the soils. Coefficient of variation was used to measure the soil variability within the profile. Land capability class was determined, which informed the land use and management recommendations. The results show that the soil is very deep (>21.5m). The soil texture ranged from sandy clay loam to sandy. Infiltration rate and saturated hydraulic conductivity decreased by up to 300 to 560 % with excavation. The soils were strongly acidic; organic carbon and total nitrogen was low but highly variable; Al, H, Ca, Mg, K, Na, and phosphorus were moderately variable while pH, CEC and base saturation (BS) were the least variable. The land capability class was IIIes. Given the evidence of erosion and preponderance of erodible Nanka sands in the subsoil, the site should be reclaimed as soon as the mining activities are discontinued.

KEYWORDS

land degradation, soil excavation, soil profile, sand mining, open pit mining.

1. INTRODUCTION

Excavation of laterite, sand, kaolin, gravel, clay etc. for building purposes is common in many parts of Nigeria. The need for sand and laterite for building, backfills and road construction is on the increase due to massive infrastructural development in Anambra state, Nigeria. This has led to increased intensity of land degradation in the state. The environmental degradation extends beyond the excavation of both surface and subsurface areas of the soil. Disturbance such as excavation or land levelling would alter the soil profile by destroying vegetation, root channels and soil horizons which consequently would affect the sustainable use of the soil. The open pit system/method used in the mining has resulted to land degradation and interference with alteration of the soil profile. This method also generates material debris called overburden which reduces the quality of the land (Ladan, 2004).

Moreover, after excavation, most of the materials excavated are never replaced leaving the areas with hollows, thereby exposing the soil profile to further degradation. Land excavation, in itself, refers to a process whereby the soil is dug and removed usually with heavy machinery giving rise to, hollows or trenches (Suleiman, 2004). This has deleterious impacts on the land as it renders it unfit for sustainable use. Large mining operations disturb the land by directly removing materials in some areas and dumping waste in others thus changing the topography of the place (Botkin and Edward, 2006). Indeed, it ultimately results in the degradation of arable land, diversity and preponderance of natural flora and fauna, contamination of surface and underground water resources, soil erosion and landslide, landscape alteration and ecological instability (Nwadialor, 2011; Eni *et al.*, 2014). This underscores the need to take proactive measures to mitigate these deleterious impacts, even prior to the sanctioning of any laterite or soil mining operation. This has largely been ignored in Nigeria, resulting in rapid, and sometimes, monumental land degradation.

Furthermore, though a lot of data that underscore the impacts of the unsustainable mining operations are currently available (Nwadialor, 2011; Nwachukwu and Osoro, 2013; Eni *et al.*, 2014; Nwachukwu *et al.*, 2017; Ofunim-Omoruyi *et al.*, 2017; Okolo *et al.*, 2018), there is limited data dealing with an assessment of a soil profile exposed via these laterite mining activities. Similarly, no emphasis has been laid on the need to

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assess the nature of the deeper soil horizons to determine whether they could potentially predispose the land to further degradation if left unattended to. Furthermore, land capability assessment seems to be tied to agricultural land use. This study relates it directly to land evaluation for non-agricultural use.

In Agu Awka, soil is put to many uses driven by the demand for industrialization, urbanization, and social developments, hence, the incessant excavation of soil within the study area. Due to inadequate land evaluation and land use planning, this has resulted in unfavourable soil and environmental conditions, especially the development of very deep pits. The extent of physical, chemical and morphological degradation caused by the indiscriminate excavation and deposition of soil / sediments has not been fully explored. Soil properties show great variations across various regions and these variations are essential for assessing the state of soil resources, dynamics and needs of the best management practices which mitigates land degradation and improves soil productivity (Dessalegn *et al.,* 2014). Therefore, the major objective of this study is to characterize and evaluate the physical, chemical and morphological properties of an exposed soil profile in an already excavated *Acrisol* in Agu Awka for sustainable and proactive land use planning. The specific objectives were to:

- Evaluate the physical and chemical properties of an existing soil profile in the excavated site.
- Evaluate the morphological properties of the soil profile.
- Assess the land capability and make land use recommendations.

2. Materials and Methods

2.1 Definition of Experimental Area / Plan

This study was conducted in August 2020 at Tipper Park, Agu Awka, Anambra state, Nigeria. The site is located on latitude 6°13'46.04"N and longitude 7°06'1.77"E (Fig. 1, Table 1). The soil profile was a pre-existing profile exposed through unregulated soil mining activity. This enabled the description and sampling of the soil to a depth of up to 21.5 m below the soil surface. To assess the impact of the excavation on soil hydrological properties (saturated hydraulic conductivity and infiltration rate), which directly influences the rate and extent of land degradation, a sampling point was defined within the excavated region and another sampling site adjacent to the site. This enabled the extrapolation of the negative impacts of the excavation on soil quality. The land capability was subsequently determined for the adjacent region, which gave insight into the capability of the land prior to excavation.

Table 1: Site Characterization

S/N	FEATURES	VALUE	REMARK
1.	Longitude	7°06' 1.77" E	
2.	Latitude	6°13' 46.04" N	
3.	Altitude	90 – 140 m asl	asl = above sea level
4.	Slope	1 – 10°	Equivalent to 1.75 – 17.63 %
5.	Infiltration Rate	37.5 cm/hr	6.7 cm/hr within the excavated site
6.	Hydraulic Conductivity	21.6 cm/hr	6.7 cm/hr within the excavated site
7.	Geologic Formation	Imo Shale Group	Partially underlain by Nanka Sands
8.	Dominant Plant Species	Grasses, bamboo, mimosa plant, goat weed, etc.	Mostly bare
9.	Land Cover / Land Use	Soil excavation / burrow pit	Adjacent to an abandoned farmland, within a commercial setting.
10.	Agro-ecological Zone	Tropical Rainforest	Annual rainfall range of 1,750 to 2,500mm distributed within the rainy season (April to October), with double-maxima rainfall, with a break in July or August

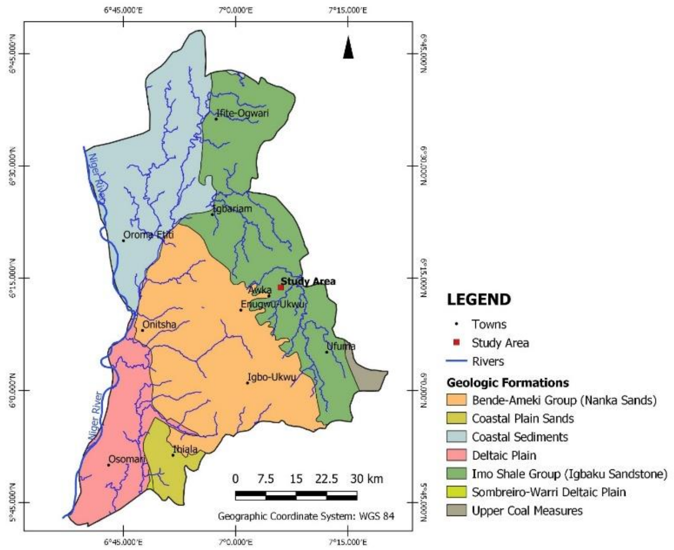

Figure 1: Geologic map of Anambra showing the study area

2.2 Description of the Excavated Site

Awka has two seasonal climatic conditions, the rainy season (April to October) and the dry season (November to March) (Ezeigwe, 2015). The rainy season is characterized by wet, humid and sometimes cold weather condition while the dry season has a short extreme and cold weather condition often designated '*the harmattan period'.* Awka has a humid tropical climate with annual rainfall range of 1,750 to 2,500mm and an annual temperature range of 28°C to 34°C (Ubuoh *et al.*, 2013).

Geologically, Awka lies within the Anambra Basin. The outcropping stratigraphic units overlying the Anambra Basin are comprised of the Imo Shale Group, the Ameki Group (including Nanka Sands), the Ogwashi Formation, and the Benin Formation (Ekwenye *et al*., 2015; Ogbe and Osokpo, 2021). The study site is underlain by the Imo Shale Group (Fig. 1), which is closely associated with the Nanka Sands due to its proximity to the borderline between both formations. The Imo Shale Group is composed of blue-grey shales with sand lenses, marl and fossiliferous limestones (Nwajide, 2013; Madueke *et al*., 2021a). On the other hand, the Nanka Sands is mainly composed of sands and minor calcareous clay/mud with heterolithic bedding (Nwajide, 2013; Ekwenye *et al*., 2014). The soils of the study location are characterized by very deep well-drained soils. The soils are generally highly weathered or undergoing weathering which is evident from the rock materials lying around on the site. According to the SoilGrids online directory (https://soilgrids.org/), the soils of the area are predominantly Acrisols.

The study area has an undulating topography with gentle to steep slopes. It is located in the tropical rainforest but the predominant vegetation on the site are mainly grasses, bamboo and weeds like mimosa plant, goat weed etc.

2.3 Characterization of the Excavated Site

The geographic coordinates and other site features of the study area are shown in Table 1**.** The altitude and the slope range from 90 to 140 m above sea level and 1 to 10° respectively. While the altitude is not high, the differential elevation provides room for sand / laterite mining. According to the specification of Engelen and Dijkshoorn (2013) the slope class ranges from level (0 – 10 %) to sloping (10 – 30 %). The sloping nature of part of the terrain makes it susceptible to increased / concentrated runoff and soil erosion. This situation is compounded by the fact that the vegetation of the area has been largely removed, leaving behind only sparse stands of grasses, bamboo and mimosa plants. As such, the area has been highly degraded (Fig. 2), with unproductive subsoil materials exposed to the surface. The organic matter-rich topsoil having been lost; makes the reclamation of this site, more difficult. Furthermore, the area has become so compacted that a section of the site is submerged by a stagnant water pond throughout the rainy season (Fig. 3). Fig. 4 shows a schematic diagram depicting the configuration of the study area.

Figure 2: Evidence of On-site Degradation of the Study Site

Figure 3: Water Pond Developed as a Result of Excessive and Unmoderated Excavation

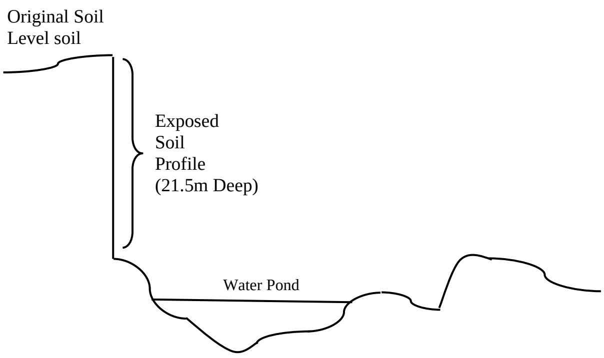

Figure 4: Schematic Diagram Depicting the Configuration of the Study Area

2.4 Site and Soil Profile Description of the Excavated Site

The existing soil profile that was exposed in the course of soil excavation was cleaned and characterized prior to soil sample collection. The site and the soil profile were described following the guidelines of soil profile description (FAO, 1999). Soil samples were subsequently collected from the horizons, observed and subjected to routine laboratory analysis to determine the physical, chemical and morphological properties of the soils of the profile.

2.5 Laboratory Analysis of Soil Samples

Particle size distribution of the soils was determined using Bouyoucous hydrometer method (Gee and Bauder, 1986), using 0.1 N sodium hexametaphoshate $(NaPO_3)_6$ as dispersant.

Soil pH was determined electrometrically using glass electrode pH meter in a soil-liquid ratio of 1:2.5 (Hendershot *et al,* 1993).

Soil organic carbon was determined by the modified wet oxidation method (Walkey and Black, 1934; Nelson and Somners, 1982).

Total nitrogen was determined by Microkjeldahl distillation method (Bremner and Mulvaney, 1982).

Available phosphorous was determined by Bray I method using spectrophotometer (Anderson and Ingram, 1993).

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 (Jackson, 1962). Exchangeable potassium and sodium were analysed using flame photometry (Jackson, 1962).

Exchangeable acidity was extracted with KCl (1 N) and determined by titration 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 (PBS) was calculated as a percentage of the sum of the base-forming cations (Ca, Mg, Na and K) to the CEC of the soil (Agbugba, 2018).

Infiltration rate of the soil was determined using the double ring infiltrometer (Anderson and Ingram, 1993). Infiltration rate (cm/hr) against cumulative time (min) was shown on a bar chart (Fig 5).

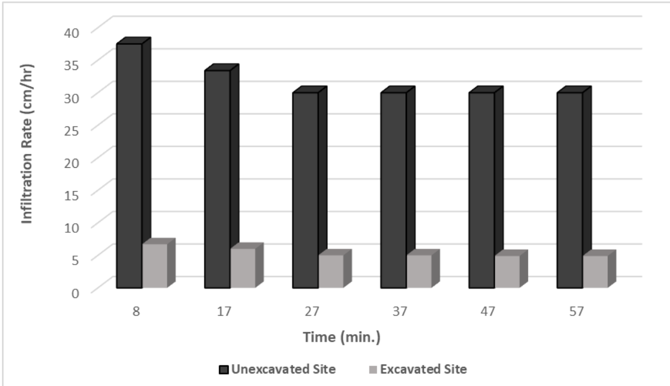

Figure 5: Bar chart of cumulative time and infiltration rate of the excavated and unexcavated sites

Saturated hydraulic conductivity (Ksat) was analysed using the constant-head permeameter method (Klute and Dirsksen, 1986). It was subsequently computed using the transposed Darcy's equation as follows:

$$Ks = \frac{Q \times L}{At \times \Delta H}$$

Where Ks is saturated hydraulic conductivity (cm/h), Q is steady-state volume of outflow from the soil core (cm^3), L is length of soil core (cm), A is cross sectional area of the soil core (cm^2), t is time interval (h), and ΔH is hydraulic head change (cm).

2.6 United States Department of Agriculture (USDA) Land Capability Classification

The soils were classified based on the USDA Land Capability Classification (Klingbiel and Montgomery, 1961). The land use recommendations were then made with particular reference to the Land Capability Classifications, and the soil and site characterization.

2.7 Statistical Analysis of Site and Soil Characteristics

Coefficient of variation (CV) was computed as a measure of the vertical variability of selected soil properties in the existing profile on the excavated site. The CV was estimated using the equation:

$$CV = \frac{S}{Z} \times 100$$

Where:

S= Standard deviation which is the square root of the sample variance

Z= Mean of the measured values

Properties with larger CV values were deemed to be more variable than those with smaller CV values. CV values of 0-15%, 16-35% and ≥ 36% are indicative of low (least), moderate and high soil variability respectively (Oku *et al.*, 2010).

3. Results and Discussion

3.1 Characterization of Excavated and Unexcavated Sites at Agu Awka, Anambra State, Nigeria

Infiltration rate generally decreased with time, prior to attaining the steady state (Fig. 5). This is because as more water replaces the air spaces, the water from the soil surface infiltrates more slowly and eventually reaches a steady state (FAO, 1985). The unexcavated site generally had considerably higher infiltration rate than the excavated site (Fig. 5). The highest value of 37.5 cm/hr was recorded on the unexcavated section of the site. For a corresponding time interval, a value as low as 6.7 cm/hr was recorded for the excavated site. Similarly, the saturated hydraulic conductivity was 21.6 cm/hr and 6.7 cm/hr for the undisturbed and the disturbed sections respectively. It has been reported that reduced infiltration rate and soil conductivity results in increased and concentrated runoff (Huang *et al*., 2017; Lei *et al.,* 2020). Increased runoff, in turn, predisposes the soil to more intense erosion (Huang *et al*., 2017; Madueke *et al*., 2019; Madueke *et al*., 2021b). This underscores the extent of degradation on the site and how it can rapidly degrade further if necessary actions are not taken promptly.

Given the extent and magnitude of gully erosion, and the prevailing high rainfall amount and intensity in Anambra state, the operations of excavation sites need to be supervised by government. Unfortunately, this is currently not the case as the excavated sites are usually abandoned as soon as the resources are exhausted (Okolo *et al*., 2018; Nwachukwu *et al*., 2017). This has resulted in the contamination of soils, underground water, rivers, streams and lakes with heavy metals (Ezeh 2007; Ezeh and Anike 2009; Nnabo 2015, 2016); landslides, gully erosion and road failure (Nwachukwu and Osoro, 2013); and silting of rivers, streams, lakes and reservoirs. As such, there is a consensus that burrow pits need to be reclaimed and restored at the end of the burrow pit operation (Nwachukwu *et al*., 2017).

Furthermore, to proactively conserve the soils and prevent further degradation of the soils, certain steps may need to be taken prior to the approval of any burrow pit / sand / soil excavation / stone quarrying / mining operation. In conjunction with the Nigerian Institute of Soil Science (NISS) and other allied agencies, the government should require that soil and site assessment be conducted to determine the inherent features, the exploratory potentials and the environmental impacts of the proposed activity, as part of its contractual obligations.

3.2 Soil Morphology of the Excavated Site

The soil profile was very deep (Table 2, Figs 4 and 6), with a depth of up to 21.5m. An image of the soil profile is shown in Fig. 6. The profile has 3 master horizons (Ap, B, and C). This is typical of tropical soils (Johnson *et al.,* 2005). The horizons have a colour differentiation which ranged from dark red in A-horizon to yellow in the C-horizon. The yellowish colour evident in the C-horizons is diagnostic of the preponderance of Nanka Sands (Ogbe and Osokpo, 2021), which is closely associated to the Imo Shale Group on the site. The soils predominantly have a granular structure. Soil colour is influenced by soil organic matter hence, the darkness in the A-horizon decreased with depth. The A-horizon is thinner compared to the other horizons, which could be as a result of erosion, causing stripping of the soil, thus preventing materials from staying in place to develop into soil (Mulugeta and Sheleme, 2010). Dark coloured surface horizons are enriched with organic matter, offering many benefits to the soil, and the red colour of the surface horizons may be associated with the high (Iron) Fe oxide of the parent material (Demiss and Beyene, 2010). The pedon is well-drained, as indicated by the absence of mottles. The consistency ranged from non-sticky to slightly sticky when wet and loose to friable when moist. The variable consistence of the pedon could be as a result of the differential distribution of clay with depth. Indeed, many red coloured tropical soils has clay particles composed of mainly kaolinite and oxides of iron and aluminium, which has little capacity to develop stickiness and to expand and contract on wetting and drying (Foth and Ellis, 1990). The friable consistence observed at the surface horizons could be attributed to the higher organic matter in the layers (Mulugeta and Sheleme, 2010). The soils of the different horizons are non-plastic and the horizons have smooth to wavy boundaries.

Table 2: Morphological features of the Horizons within the profile pit

Horizon	Depth (cm)	Texture	Moist colour	Consistence	Structure	Horizon Boundary
Ap	0-80	SCL	dr (10YR3/6)	fr, ns and np	g	S
B	80-1100	SCL	dr (10YR 4/6)	ss and np	g	C
C1	1100-1500	S	y (10YR 8/8)	fr, ns, np, l	lc	W
C2	1500-1700	S	yr (5YR 5/6)	ns, np and vf	lc	W
C3	1700-1900	S	ry (5YR 7/6)	ns, np and vf	hc	S
C4	1900-2150	S	vpb (10YR	vf, ns and np	hc	C

SCL = Sandy Clay loam; S = Sandy; dr = dark red; y = yellow; yr = yellowish red; ry = reddish yellow; vpb = very pale brown; fr = friable; ns = non-sticky; np = non-plastic; ss = slightly sticky; l = loose; vf = very friable; g = granular; lc = loose crumbs; hc = hard crumbs; s = smooth; c = clear; W = wavy

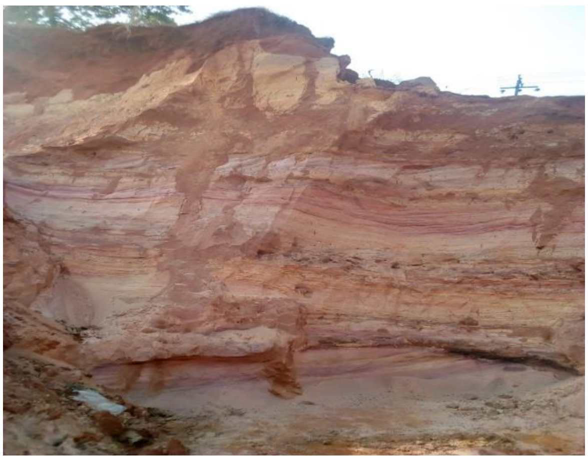

Figure 6: Exposed Soil Profile on the Excavated Site

3.2 Particle Size Distribution of the Soils in the Study Area

Table 3 presents the data on soil texture. The table revealed that sand content was moderately variable (16 ≥ CV ≤ 35%) while silt and clay content were highly variable (CV > 36%) as also reported by other researchers (Oku *et al.,* 2010). The soil texture was sandy clay loam in the first two horizons. This is a product of the impact of the Imo Shale Group which tends to yield more clayey soils (Madueke *et al*., 2021a). The subsequent four horizons had sandy textures. This may be attributed to the impacts of Nanka Sands, the geologic formation within those depths, which was also reported by Ogbe and Osokpo (2021). This trend may be attributed to the successive deposition of contrasting materials (Mulugeta and Sheleme, 2010). This agrees with the findings of other researchers (Ubuoh *et al*., 2013; Madueke *et al*., 2021a), who revealed that soil texture of south-eastern Nigeria is related to their parent materials. The coarse texture of the lower horizons controls the variability in nutrient storage capacity, limits the water holding capacity and allows roots to grow under sub-optimal soil water due to water deficits (Karuma *et al.,* 2015).

Table 3: Particle size distribution and textural class of the horizons within the profile pit

Horizon	Depth (cm)	% Sand	% Silt	% Clay	Textural class
Ap	0-80	65.60	13.6	20.80	SCL
B	80-1100	67.60	9.60	22.80	SCL
C1	1100-1500	95.60	2.00	2.40	S
C2	1500-1700	73.60	1.60	4.80	S
C3	1700-1900	89.60	5.60	4.80	S
C4	1900-2150	91.60	3.60	4.80	S
Mean	-	80.60	6.00	10.07	-
Std Dev	-	13.19	4.73	9.16	-
CV (%)	-	16.36	78.83	90.96	-
Variability	-	Moderate	High	High	-

Note: SCL: Sandy clay loam; S: Sand; Std Dev: Standard Deviation; CV: Coefficient of variation

Soil texture is the most stable physical characteristic of the soils which has influence on a number of other soil properties including structure, soil moisture availability, erodibility, root penetration and soil fertility (Karuma *et al.,* 2015). This is because texture is a composite of the coarse fraction (sand) and the finer fractions (silt and clay) and an increase or decrease in one component imparts the opposite effect on the other and hence, affects physico-chemical properties of the soils (Ubuoh *et al.*, 2013.). Clay for example has been reported to interact with organic matter and increased water and nutrient holding capacity (Agbugba, 2018). The observed reduction of clay content with depth may also be attributed to the nature of parent materials (Ubuoh *et al.*, 2013). Although silt content tended to fluctuate with increasing soil depth, it was generally much high (9.6 – 13.6 %) in the surface horizons formed from the Imo Shale Group, than in the sub-surface horizons formed from the Nanka Sands. The severe gully erosion on soils formed from the Nanka Sands may be traceable to the low clay content, high sand content, poor aggregation and low aggregate stability (Ocheli *et al*,. 2021). The exposure of the Nanka Sands formation through sand mining consequently predisposes the area to intense gullying.

3.3 Chemical Properties of the Soils in the Study Area

The chemical properties of soils in the exposed soil profile are shown in Table 4. The results show that pH, CEC and % base saturation had low variability (CV ≤ 15 %) down the profile, as also reported other researchers (Ezeaku *et al*., 2015). This could be attributed to the fact that soils of the humid tropics of south-eastern Nigeria are highly leached and acidic due to the high rainfall and the acidic nature of the parent materials. Al, H, Ca, Mg, K, Na, and available phosphorus were moderately variable (16 ≥CV≤35 %). This is in line with the findings of Ezeaku *et al*. (2015). Organic carbon and total nitrogen were highly variable (CV ≥ 36%). This aligns with the findings of Oku *et al.* (2010) and could be attributed to the fact that organic matter accumulates in the surface soil with a relatively small proportion getting illuviated down the profile.

Table 4: Some chemical properties of the Horizons within the profile pit at the excavation site

				EXCH. ACIDITY (cmolkg^{-1})			EXCH. CATIONS (cmolkg^{-1})						
Horizon	Depth (cm)	pH	OC (%)	Al^{3+}	H^+	TN (%)	Ca^{2+}	Mg^{2+}	K^+	Na^+	CEC	BS (%)	Avail. P (mg kg^{-1})
Ap	0-80	5.47	0.19	0.70	0.20	0.017	1.20	0.60	0.12	0.06	2.85	68.1	1.10
B	80-1100	5.16	0.13	0.80	0.40	0.012	1.00	0.40	0.07	0.05	2.74	56.2	0.84
C1	1100-1500	4.65	0.01	0.90	0.50	0.005	0.80	0.80	0.15	0.11	3.26	57.0	0.56
C2	1500-1700	4.36	0.25	1.00	0.40	0.020	1.00	0.80	0.08	0.05	3.33	57.9	0.52
C3	1700-1900	4.45	0.23	1.20	0.70	0.020	1.20	0.60	0.10	0.07	2.97	46.1	0.61
C4	1900-2150	4.32	0.23	1.20	0.50	0.020	1.20	0.40	0.12	0.09	3.11	58.2	0.57
Mean	-	4.74	0.17	0.97	0.45	0.016	1.07	0.60	0.11	0.07	3.04	57.3	0.70
Std Dev	-	0.47	0.09	0.21	0.16	0.006	0.16	0.18	0.03	0.02	0.23	6.99	0.23
CV (%)	-	9.92	53.28	21.65	35.56	38.12	17.12	30.00	27.27	28.57	7.57	12.20	32.86
Variability	-	Low	High	Moderate	Moderate	High	Moderate	Moderate	Moderate	Moderate	Low	Low	Moderate

Note: OC: organic carbon; TN: total nitrogen; CEC: Cation exchange capacity; BS: base saturation; Avail P: Available phosphorus; Exch. Acidity: Exchangeable acidity; Exch. cations: Exchangeable cations: Std Dev: Standard Deviation; CV: Coefficient of variation; CV values of 0-15%, 16-35% and ≥ 36% indicate low (least), moderate and high variability respectively

It could also be deduced from the table that the soil is strongly acidic (4.32 - 5.47). Soil pH at the surface ranged from 5.16 to 5.47, while that at the sub-surface horizons ranged from 4.32 to 4.65. Similarly, several researchers have also observed that soils at the surface were strongly acidic (5.1-5.5) while soils at the sub-surface were very strongly acidic (4.5-5.0) (Karuma *et al*., 2015). Similar trends have been reported by many researchers while working on the humid tropical soils of south-eastern Nigeria (Ubuoh *et al*., 2013; Madueke *et al*., 2020, 2021a, 2021c). The values of the exchangeable acidity (Al^{3+} and H^+) increased as pH reduced in most horizons. The variations may be linked to the nature of the parent material and soil mineralogy (Okenmuo *et al.,* 2020). The resultant variability in the values of exchangeable acidity could be attributed to alumina-silicate clay minerals releasing Al^{3+} and H^+ into the soil solution via isomorphous substitution (Akamigbo and Nnaji, 2011). The basic element that usually influence aggregation gets easily lost when soil reaction is in extreme strong acidic range (Ubuoh *et al.*, 2013).

The low to very low level of the organic matter content is a common phenomenon in the humid tropics due to rapid mineralization of organic matter resulting from high temperature (Madueke *et al*., 2020, 2021a, 2021c). Another possible reason could be high leaching and severe sheet erosion, which are evident in the study area. Tillage operations and the depletion of nutrients elements by intensified arable farming accompanied by relatively low use of farm inputs could be another cause of low organic matter content in the area (Ubuoh *et al.*, 2013). The low nitrogen content of the soil could be as a result of the low organic carbon, rapid microbial activities and crop/vegetation removal leading to nitrate loss in the soil environment (Madueke *et al*., 2020, 2021a, 2021c). Prominent among these, is the positive correlation between organic matter and total nitrogen (Madueke *et al*., 2021c). The low level of exchangeable bases in the soil is an indication of heavy leaching of the soil nutrients. The leaching of calcium and magnesium are largely responsible for the acidity observed in the soil. High leaching rate is favoured by high rainfall, coupled with porous nature of the soils due to its texture and the parent materials. The cation exchange capacity (CEC) and the pH were low. The low CEC value could be as a result of the low organic matter in the profile. These soils were referred to as low activity clay (LAC) soils, probably as a result of their low CEC (Ubuoh *et al.*, 2013).

Base saturation was >20% but <70% (Table 4) which could be rated as medium fertility (Agbugba, 2018). Low base saturation levels may result in very acid soils and potentially toxic concentrations of cations such as Aluminium (Karuma *et al.,* 2015). They further stated that poor cultivation practices, poor soil and water conservation and inadequate supply of amendments to replenish nutrients removed by crops, among others, can contribute to low level bases in most soils. A relatively high base saturation of 70 to 80% should be maintained for good performance of most cropping systems (Karuma *et al.*, 2015). The moderate base saturation of the soils as shown in the Ap horizon (Table 4), could be attributed to properties inherited from the parent materials (Ubuoh *et al.*, 2013). The low value of available phosphorus recorded in all the soils could be attributed to strong weathering and low pH (Ubuoh *et al.*, 2013). The available phosphorus content decreased down the profile. Low available phosphorus in the surface and subsurface layers of the pedon may also be attributed to low soil pH (< 5.8) which could enhance phosphate fixation in humid tropical soils.

3.4 Land Capability Classification of the Excavated Site

The soils had less than 5 % surface and sub-surface stoniness, soil depth greater than 100 cm, well-drained soils rarely saturated (no mottles), sandy clay loam topsoil texture, no rock outcrops or boulders, and moderate topsoil and subsoil permeability, all of which would warrant placement in classes I or II. However, due to an average slope of approximately 10 %, moderate evidence of erosion and a soil pH ranging from 5 to 6, the soils were classified as class III soils. It was further classified as IIIes due to the moderate evidence of erosion and a soil pH that was generally below 6.

As class III soils, according to Brady and Weil (2016), the soils are suitable for pastureland, forestry, wildlife conservation, water supply and aesthetic purposes. Furthermore, the soil is adapted to cultivation of most arable crops grown in the humid tropics. It is however, only suitable for moderate cultivation intensities. Erosion control measures and liming are essential prerequisites to sustainable use. The moderate evidence of erosion also buttresses the need for implementation of land reclamation measures as soon as soil excavation is terminated.

4. Conclusion and Recommendations

4.1 Conclusion

Anthropogenic activities such as excavation of laterite, sand, kaolin, gravel or clay for buildings, backfills and road construction are inevitable, but inadequate land evaluation and land use planning prior to such operations lead to extensive land degradation. It results in erosion, transportation and deposition of surface materials, which translates into both on-site and off-site land degradation. It also results in soil compaction and reduced infiltration, which in turns translates into increased runoff. This is evidenced in the assessment of infiltration rate and saturated hydraulic conductivity for both the excavated and the unexcavated sections of the site, which shows a decrease of up to 300 to 560 % with excavation. This, in turn, would increase runoff by up to 300 to 560 % in a region with very high rainfall amount and intensity. This ultimately, within a short time, results in extensive physical and chemical land degradation, particularly gully erosion and landslide, if land reclamation measures are not implemented promptly.

It is also noteworthy that the impacts of these gullies are not limited to the onsite loss of soil, organic matter, soil quality, growing plants, lives and properties. The offsite impacts, including the loss of downhill farms; silting of drainage channels, reservoirs, streams, rivers and lakes by eroded soils. In addition to facilitating erosion, it also results in the dissolution, translocation and deposition of pollutants in downstream sections of the landscape, as well as in surface and underground water reserves and habitats. This consequently affects the morphological and physico-chemical properties of the site and its environs, ultimately resulting in further loss of lives and properties.

The assessment of the soil profile shows that the soil was very deep (> 21.5 m); strongly acidic (pH 4.32 - 5.47); and has sandy clay loam topsoil texture. It was low in organic matter, cation exchange capacity and exchangeable bases. Morphologically, there are three master horizons (Ap, B, and C). Colour differentiation ranged from dark red to yellow, with a predominantly granular structure. The consistency of the soils of the profile ranged from non-sticky to slightly sticky when wet and loose to friable when moist. Physically, sand content was moderately variable while silt and clay content were highly variable. Chemically, organic carbon and total nitrogen were low but highly variable; Al, H, Ca, Mg, K, Na, and available phosphorus were moderately variable, while pH, CEC and base saturation were the least variable. The low cation exchange capacity and base saturation are diagnostic of the low fertility status of the soil.

In terms of the USDA land capability, the soil was classified as IIIes due to the moderate evidence of erosion and a soil pH that was generally below 6. These soils are suitable for pastureland, forestry, wildlife conservation, water supply and aesthetic purposes. Furthermore, the soil is adapted to cultivation of most arable crops grown in the humid tropics. It is however, only suitable for moderate cultivation intensities. Erosion control measures and liming are essential prerequisites to sustainable agricultural use. The moderate evidence of erosion also buttresses the need for the implementation of land reclamation measures as soon as soil excavation is terminated.

4.2 Recommendations

There is the need for regulated sand/laterite mining and quarrying activities and implementation of proactive soil conservation practices/regulations to improve the soil quality and ensure sustainable use. Given the importance of mining to the survival and sustainable development of human societies, it cannot be banned outrightly; it needs to be moderated and effectively supervised. In conjunction with the Nigerian Institute of Soil Science (NISS) and other allied agencies, the government should require that soil and site assessment be conducted to determine the inherent features, the exploratory potentials and the environmental impacts of the proposed activity. As part of its contractual obligations, it should be required that

- The land should be partitioned into different parcels, with excavation activities focussed on one parcel at a time;
- The existing topsoil on a particular parcel should be scraped off and retained onsite, protected from the direct impact of rainfall and runoff;
- Excavation should not go beyond the soil approved vertical and spatial limits;
- As soon as the limits are reached, deep-ploughing of the soil should be conducted to ameliorate compaction and improve soil drainage and infiltration;
- The retained topsoil should be spread all over the soil;
- Large quantity of organic amendments should be incorporated into the soil;
- Rows of vetiver grass should be planted at intervals;
- Carpet grass should be planted in-between, interspersed with tree seedlings;
- The site should be maintained to ensure sustainability;
- While this is ongoing, excavation may now be focussed on a different parcel.

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