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CHARACTERIZATION AND CLASSIFICATION OF SOILS FORMED FROM AMPHIBOLITE COMPLEX ROCKS ORIGIN IN IFE-ILESA AREA OF SOUTHWESTERN NIGERIA

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ABSTRACT

The study characterized and classified soils formed from amphibolite complex rocks in Ife–Ilesa area of Southwestern Nigeria, with the view to understanding the soil genesis and providing scientific basis for appropriate land-use planning, soil fertility management, and sustainable agricultural development. Ten soil profile pits were established on identified physiographic positions of a selected landscape. The profiles were described using the FAO guidelines, while genetic horizons were identified and sampled accordingly. The soil samples were analysed for some physical and chemical properties. The results showed that the soils were well-drained as indicated by their reddish-brown hues in the A-horizon and redder hues in the B- and C-horizons (2.5YR - 7.5R). It was observed that the soil texture for both topsoil and subsoil varied from sandy clay loam to clay reflecting the influence of parent material and topography. The soils were slightly acid to very strongly acid (pH (H_2O) = 6.50 - 4.75). The exchangeable bases ranged between 0.18 and 27.03 $cmol_{(+)}kg^{-1}$, while exchangeable acidity values varied between 0.45 and 1.90 $cmol_{(+)}kg^{-1}$. Effective cation exchange capacity values ranged between 1.16 and 28.13 $cmol_{(+)}kg^{-1}$. Base saturation, organic carbon, total nitrogen, amorphous iron ($Fe_{(o)}$) and aluminium ($Al_{(o)}$) values varied from 14.11% - 96%; 0% - 7.62%; 0.04% - 0.79%; 0.95% - 3.36% and 0% - 0.70% respectively, while the available phosphorus values varied between 3.88 and 38.89 mg kg^{-1}. In conclusion, the soils were classified as Ultisols and Alfisols according to USDA Soil Taxonomy. However, according to IUSS/WRB the soils were correlated as Leptosols, Ferralsols and Acrisols, while locally, the soils were classified under Itagumodi Association and they belonged to Owena series, Ibule series, Ijare series, Araromi series, Gambari series and Jago series respectively. Soil management practices such as liming and organic amendment should be encouraged for sustainable crop production.

Keywords: ***Amphibolite, , Characterization, Classification, Ife-Ijesa, Nigeria***

INTRODUCTION

Soil is an important natural resource that supports agricultural productivity, ecosystem functioning and sustainable land-use planning (Tahat *et al*., 2020). Its properties and behaviour are largely controlled by the nature of parent materials, climate, topography, organisms and time. Among these factors, parent material plays a crucial role in establishing the mineralogical composition, physical and chemical characteristics of soils, particularly in tropical environments where intense weathering prevails (Zhang *et al*., 2024). In Southwestern Nigeria, variations in basement complex lithology have resulted in the development of soils with contrasting characteristics and management requirements.

According to Salawu *et al*. (2021), the Ife-Ilesa area of southwestern Nigeria lies within the Precambrian basement complex and is geologically dominated by amphibolite complex rocks, alongside gneisses, schists and quartzites. It has been reported that amphibolite rocks are typically rich in basic minerals such as hornblende and plagioclase feldspar, which, upon decomposition, may produce soils with distinctive physical and chemical properties, including relatively higher base status and clay activity compared to soils formed from more acidic parent materials. However, prolonged weathering under humid tropical climatic conditions often leads to significant leaching of bases, mineral transformation, and profile differentiation, making it necessary to evaluate the current status of such soils (Nzeukou *et al*., 2025).

Although, knowledge of the characteristics of soils of Southwestern Nigeria is increasing, their genesis so far has been controversial. Some pedologists and geomorphologists have reported that soil development in Southwestern Nigeria had been considerably influenced by past climatic conditions, especially those of the three erosional phases (Smyth and Montgomery, 1962; Salawu *et al*., 2021). On the other hand, Ojanuga (1978) ascribed the formation of soils in the metamorphic forest region of Southwestern Nigeria to the interaction of geomorphic and pedogenic processes. Amusan and Ashaye (1991) noted that hydrolytic weathering appears to be the predominant pedogenetic process with lessivation, braunification, induration, floral and faunal pedoturbation, mobilization and immobilization of iron and cyclic change of climate as other dominant pedogenetic processes in the soils of the area.

Logical assumptions can be made that the physical and chemical nature and behaviour of soil materials depend on the size, shape, and arrangement of soil constituents. These characteristics result from modifications of the properties of the parent rock or parent materials by soil-forming processes (Moore *et al*., 2022). Soil formation however, causes the reorganization of the constituents into patterns that diverge widely from the pattern of normal random packing.

Despite the agricultural importance of the Ife–Ilesa area, detailed information on the characteristics and classification of soils derived specifically from amphibolite complex rocks remains limited. Accurate soil characterization provides essential data on morphology and chemical composition which are indispensable for soil classification, land evaluation, and sustainable soil management. Proper classification using internationally recognized systems, such as the USDA Soil Taxonomy and the World Reference Base for Soil Resources (WRB), also facilitates comparison with similar soils in other regions and enhances the applicability of research findings.

Therefore, this study aimed to characterize and classify soils formed from amphibolite complex rocks in Ife–Ilesa area of Southwestern Nigeria, by examining their physical, chemical and mineralogical properties. The study seeks to improve understanding of soil genesis in the Basement Complex terrain and provide a scientific basis for appropriate land-use planning, soil fertility management, and sustainable agricultural development in the region.

MATERIALS AND METHODS

Study Area

The study site is situated within latitudes 7° 32´N and 7° 33´N and longitudes 4° 39´E and 4° 40´E (Fig. 1). The sample site is about 20 km Southwest of Ilesa, off the Ife-Ilesa-

Akure road, and is located within the lands that belong to Itagunmodi and Imoo villages in the Ife-Ilesa area of Osun State. The area is within the same ecological zone (tropical rainforest) as Ile-Ife, with a hot, humid tropical climate having distinct dry and bimodal rainy seasons. The mean annual rainfall is 1527 mm, and the mean monthly air temperature is 31℃ (Table 1).

The natural vegetation was initially rainforest, consisting of very tall and big trees as well as thick shrubs. However, consequent upon cultivation, the vegetation is now dominated by a mixture of perennial plants, annual crop farms, and permanent crop plantations. The crest (summit) and the shoulder are currently under annual cropping (Cassava, *Manihot spp.*; Yam, *Dioscorea spp*.; Maize, *Zea mays*; Okra, *Abelmoschus esculentus*; Tomato, *Solanum lycopersicum;* etc.). The end of the upper slope position was planted to cacao (*Theobroma cacao*) but has now been abandoned and has grown into a secondary forest. The middle slope is a fallow land overgrown with weeds (*Chromolaena odorata*) and dispersed palm trees (*Elaeis guineensis*). The lower slope supports cacao inter-cropped with cassava (*Manihot esculenta*) and Banana or Plantain (*Musa spp.*), while the valley bottom supports plantain and banana (*Musa spp.*) as well as cocoa trees (*T. cacao*). The area had an undulating topography marked by ridges and hills of amphibolites and meta-ultramafites, as well as non-extensive plains. The river valleys were "V-shaped" and very deep. They were found in some places to suddenly fall steeply away from the sides of the hills (Smyth and Montgomery, 1962).

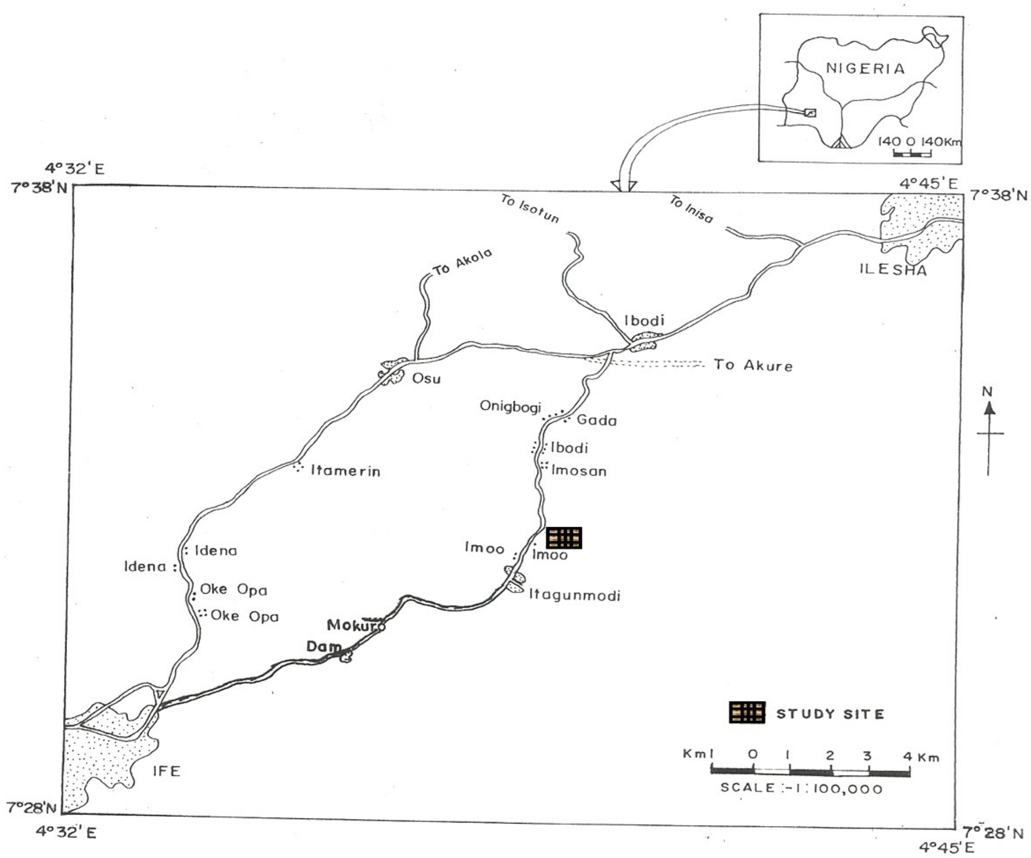

Figure 1: Location map of the study site

TABLE 1: Mean monthly rainfall and temperature data at Obafemi Awolowo University Teaching and Research Farm, Ile-Ife.

Month	Mean rainfall (mm)	Mean temperature (℃)
January	6.7	32.4
February	24.7	34.3
March	71.1	33.8
April	136.2	32.2
May	199.1	31.0
June	182.9	29.5
July	210.3	27.7
August	184.2	27.3
September	245.8	28.2
October	229.7	30.6
November	27.2	33.0
December	8.9	31.5

Total annual rainfall = 1526.8mm, Mean annual temperature = 31℃

The study area is underlain by Precambrian rocks, which are part of what is collectively referred to as the Basement Complex of Southwestern Nigeria. The rocks were divided into two major groups: migmatite-gneiss-quartz complex and the Ife-Ilesa schist belt (Rahaman, 1976; 1988). The study area falls within the latter. The most important rock types present in this group (the schist belt) are the amphibolites, amphibole schist, talc-tremolite-schists, and metamorphosed basic to ultrabasic rocks (Rahaman, 1976; 1988).

Field experiment

A transect method of soil survey was used for this study. The transect was established on a hilly slope with a relatively flat top (more of a tableland) approximately 2 km northeast of Itagunmodi village. It runs almost parallel to the only access road in a north-easterly direction, cutting across arable farmland, secondary forest, fallow land, and cocoa plantation. The transect is approximately 585 metres long from the top of the hill to the valley bottom, positioned at 342.6 m (1124ft) above sea level at the valley bottom and 447.1 m (1467 ft) above sea level at the crest. It exhibits a complex toposequence with varying slope directions. Ten (10) profile pits (pedons) were established along the toposequence, each in a different physiographic position. The profile pits were named OKP-01, -02, -03, -04, -05, -06, -07, -08, -09, and -10 from the crest (summit) to the valley bottom, respectively. The pits were described and designated using FAO (2006) and Soil Survey Staff (2022) guidelines for soil profile description. Representative soil samples were taken from identified horizons for laboratory analyses. Elevation (height) of individual pedon was taken using surveying Micro Altimeter model M-1 with calibrations ranging from -304.8 m to 1524 m (-1000 to +5000 feet).

Laboratory Analysis

The collected samples were air-dried at room temperature, crushed, and passed through a 2 mm (10 mesh) sieve to separate the fine earth fraction (<2 mm), which was later subjected to physical, chemical, and mineralogical analyses. The bulk density was determined using the core method as described by Black and Hartge (1986). The soil was oven-dried at 105 ℃ until constant weight was attained. Particle size analysis was determined using the hydrometer method of Bouyoucos (1962) as described by Gee and Or (2002). Soil pH was determined in both distilled water and 1.0 M KCl (1:1 Soil-Solution ratio) using a glass electrode pH meter (Kent Model 720). Exchangeable bases (Ca, Mg, K, and Na) were extracted with 1.0 M NH_4OAc solution at pH 7.0 (Thomas, 1982). Calcium (Ca^{2+}) and Magnesium (Mg^{2}+) ions were determined using AAS (Perkin-Elmer Model 703), while Sodium (Na^+) and Potassium (K^+) ions were determined with a flame photometer (Gallenkamp Model FH500). Exchangeable acidity was determined by the titration method using 1.0 M KCl for extraction (McLean, 1965; Sims, 1996). Effective cation exchange capacity (ECEC) was determined by the summation of NH_4OAc extractable bases (Ca^{2+}, Mg^{2+}, $Na^{+,}$ and K^+) and KCl extractable aluminium (Al^{3+}) (Soil Survey Staff, 2022). Organic carbon was determined by the Walkley-Black method (Allison, 1965; Nelson and Sommers, 1996). Total Nitrogen was determined by the macro-Kjeldahl method (Bremner, 1996). Available phosphorus was determined by the Bray No 1 method (Bray and Kurtz, 1945; Kuo, 1996). Tamm's reagent (acidified ammonium oxalate under darkness at pH 3.0) and the extraction procedure of McKeague and Day (1966) were used for amorphous iron (Fe) and Aluminium (Al) extraction. The Fe extracted was determined by the colorimetric Ortho phenanthroline method, while the Al extracted was determined colourimetrically by the modified Aluminon method (IITA, 1979) using a spectrophotometer (B. & L. Spectronic 20 Model). Particle separation was done by wet and dry sieving, sedimentation, and the decantation procedure of Jackson (1956).

RESULTS AND DISCUSSION

Soil morphology and landform relationships

Pedons OKP-01 and OKP-02 were confined to the hilltop positions that are relatively flat. The pedons were shallow because the soils were formed over a hard, continuous iron pan. The soil's colour varied from dark reddish brown (5YR 3/2 moist) to dark red (10R 3/6 moist), while the texture ranged from sandy clay loam to clay. Ironstone and concretions occurred very frequently throughout the profiles. Pedon OKP-03 was confined to the steep slopes immediately below the summit of the toposequence (Fig 2). The subsoil, especially the B-horizons, has a matrix colour of red (10R 4/8 moist) with clay texture (Tables 2a & 2b). The soils have frequent ironstone materials. Soils of pedon OKP-04 occur at a steeply sloping position of the toposequence in the upper slope. The soils are characterized by fine-textured (clay) surface and subsoil horizons. The B-horizon has a soil matrix colour of red (10R 4/8 moist) with many distinct sharp reddish yellow (2.5YR 7/8 moist) mottled clays. Pieces of weathered (rotten) rocks were seen within the profile, especially at the lower horizons. Soils of pedon OKP-05 occur on a gentle slope to a sloping section (middle slope position) of the toposequence. The soils have a clay texture, and the colour ranged from dark reddish brown (2.5YR 3/4 moist) to red (10R 5/8 moist) matrix in the B-horizons with many distinct sharp brownish yellow and yellow mottles (10YR 6/8 and 10YR 7/8 moist). There is a well-developed gravel layer made almost entirely of quartz. Pedon OKP-06 occurs at the break of slope on a gentle slope to a sloping section of the middle slope. The soils have a clay texture in the subsoil just before the hard, continuous layer. The pedon is shallow with soil colour varying from dark reddish brown (5YR 3/2 moist) to red (10R 4/8 moist) and yellowish-brown mottles (10YR 5/8 moist). Soils of pedons OKP-07, -08, and -09 (Fig. 2) occur on the lower slope section of the toposequence. The soils have a clay texture with soil colour varying from dark reddish brown (2.5 YR 2.5/4 moist) to red (7.5R 4/8 moist) in the B-horizon. The soils have a friable consistence and almost uniform morphology. The pedons have well-developed gravel layers almost entirely made of concretions. Pedon OKP-10 occupies the valley bottom position of the toposequence, and the soils are poorly drained. The soil texture varied from sandy loam to clay, and the colour varied from dark reddish brown (2.5YR 3/4 moist) to reddish yellow (7.5YR 6/6 moist) with grey (5YR 6/1 moist) mottles in the B-horizon.

The reddish hues (10R) of the subsoils of the profiles at the crest, upper, middle, and lower slopes of the toposequence suggest good drainage. This red colouration may be due to the presence of hematite as explained by the previous authors (Bigham *et al*.,1978; Jiang *et al*., 2022). As the moisture condition increased and drainage became poorer down the slope (valley bottom), hues became greyish. Similar colour changes from summit to valley bottom were observed by Okusami and Oyediran (1985) and Gou *et al*. (2022). Lower redox potential and iron reduction may be responsible for the decreased redness in poorly drained soils (Zhang *et al*, 2021). The clayey nature of the soils may have resulted from the rapid weathering of the bedrock, which was highly susceptible to weathering (Bamjoko and Ogunwale, 1980; Guo *et al*., 2023). Pedons OKP-01, -02, and -06 were shallow due to underlying hard, continuous ironstone material, while pedon OKP-10 was poorly drained with the water table at 90 cm from the soil surface. All other pedons examined were deep (>180 cm), and they had indistinct horizon boundaries, with a wide transition between diffuse or gradual and an uneven topography (Table 2). This is an indication of a good degree of relationship between one horizon and the next. The subsoils have probably undergone a process of transformation, homogenization, and eluviation-illuviation process, which has led to the development of stable soil structure and well-defined subsoil horizons (B-horizons).

Physical properties of the soils

Tables 3a & 3b show the particle size analysis and bulk density data of the soils. The gravel content (size greater than 2 mm) varied from 0.0% to 76.0%, with profiles (pedons) from the summit, upper and middle slopes having relatively higher values, while the lower slope and valley bottom profiles have lower values. Generally, the gravel content increased from the A-horizon to the B-horizon and then decreased from the B-horizon to the C-horizon, except at lithologic breaks. The increase in gravel content from A to B-horizons is characteristic of the shallow upland profiles. The gravel content decreased with depth in slope positions, except for the lower slope, which had no pattern of distribution.

Textures varied from sandy loam to sandy clay loam for surface horizons, except pedon OKP-08, which had clay texture. The B and C-horizons had clay texture except pedon OKP-10, which had clay loam texture in the Btg-horizon. The sand content ranged from 2% to 62% and decreased with depth, except at lithologic discontinuities (e.g., pedon OKP-05). The silt content ranged from 8% to 31%; the values decreased with depth. Generally, the silt content is low, a characteristic that it shares with most Nigerian soils (Ojanuga, 1975; Gambo *et al*., 2025). The clay content generally increased with depth to a maximum and then decreased in the BC and C-horizons. A similar trend was observed by Ojanuga (1975) in soils of the Ife and Ondo areas of Southwestern Nigeria. The clay values ranged from 19% in the Ap horizon to 82% in the Bt horizon. Generally, soils in the middle and lower slope positions had higher clay content than soils that occupy the summit, upper slope, and valley bottom positions.

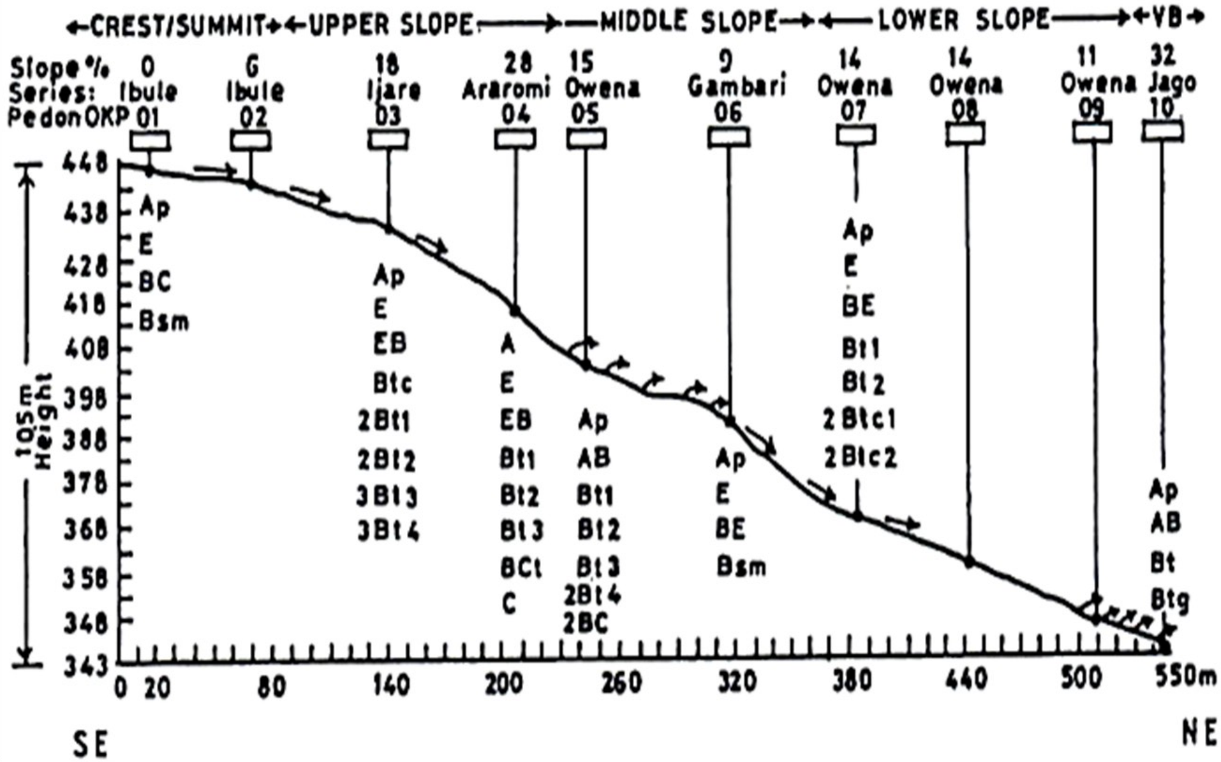

Figure 2: Landform/Landscape of the Study Site

TABLE 2a: Morphological properties of the soils

Horizon	Depth (cm)	Colour (moist)	Texture [t]	Structure [x]	Consistence [y]	Concretions [b]	Boundary [z]	Notes
				PEDON OKP-01: IBULE SERIES				
Ap	0-12	5YR 3/2	grsc	2mcr	mvfr wnstnpl	frgrrd	cs	few, medium frequent fine roots
E	12-22	2.5YR 2.5/4	vgrsc	2msbk	mfr wnstnpl	frstgrrd	gw	few, medium, frequent fine roots
BE	22-37	10R3/4	vgrc	2msbk	mfr wsstspl	fr st gr rd	gw	few fine and medium roots.
Bsm	37-69	10R 3/6	vgrc	2msbk	mfr wsstspl	fr st gr rd	ND	very few fine roots,

Horizon	Depth (cm)	Colour (moist)	Texture [t]	Structure [x]	Consistence [y]	Concretions [b]	Boundary [z]	Notes
								merging into an
								impenetrable sheet of
								ironstone.
PEDON OKP- 02 IBULE SERIES								
Ap	0-10	2.5YR 2.5/4	grsc	2mcr	mfr wnstnpl	fr gr rd	cs	frequent very fine and few
E	10-28	2.5YR 3/6	vgrc	2msbk	mfr wnstspl	fr gr strd	gw	medium roots
BE	28-45	2.5YR 4/6	vgrc	2fsbk	mfr wsstspl	fr gr rd	gs	common very fine and
Bsm	45-97	10R 4/6	vgrc	2fsbk	mfr wsstspl	frst bd fgr rd	ND	few medium roots
								few fine roots
								merges into an
								impenetrable sheet of
								ironstone
PEDON OKP-03 IJARE SERIES								
Ap	0-15	2.5YR 2.5/4	grsc	2mcr	mvfr wnstnpl	f gr rd	cw	frequent very fine roots.
E	15-32	2.5YR 3/6	vgrc	2mcr	mfr wnstnpl	fr gr rd	gw	frequent fine roots.
EB	32-50	2.5YR 3/6	vgrc	2fcr	mfr wsstspl	vfr gr rd	cs	few medium, common
Btc	50-81	10R 4/6	vgrc	2msbk	mfm wsstspl	fst vfrgr rd	cs	fine roots
2Bt1	81-116	10R 4/8 &	grc	2msbk	mfm wstpl	vfr gr st rd	gs	very few medium roots
2Bt2	116-146	10YR 6/8	grc	2msbk	mfm wstpl	vfr gr rd	cs	few fine prominent
		10R 4/8 &						sharp/brownish yellow
3Bt3	146-187	10YR 6/8	vgrc	3msbk	mfm wstpl	fr st gr rd	cs	mottles
3Bt4	187-220		sgrc	3msbk	mfm wstpl	-	ND	common coarse and
		10R 4/8 &						medium prominent, sharp
		10YR 6/8						brownish yellow mottles
		10R 4/8						few medium and fine
								prominent, sharp
								brownish yellow mottles
								few fine mica flakes.
PEDON OKP-04 ARAROMI SERIES								
Ao	0-7	10YR 3/2	grsc	2mcr	mfr wnstnpl	fr gr rd	cw	Abundant very fine, fine
E	7-15	2.5YR 3/6	vgrc	2mcr	mfr wnstnpl	fr gr rd	gw	and few medium roots.
EB	15-40	2.5YR 4/6	grc	2mcr	mfm wsstspl	vfr gr fst rd	gw	Abundant fine and
Bt1	40-60	10R 4/8	grc	2mcr	mfm wsstspl	vfr gr fst rd	dw	medium roots
		&7.5YR 6/8						Abundant fine and
Bt2	60-110		grc	2msbk	mvfr wsstspl	fr gr rd	dw	medium roots
		10R4/8 &						few medium distinct sharp
Bt3	110-145	7.5YR7/8	grc	2msbk	mfr wsstspl	fgr rd	dw	reddish, yellow mottles:
								frequent fine and few

Horizon	Depth (cm)	Colour (moist)	Texture t	Structure x	Consistence y	Concretions b	Boundary z	Notes
Bct	145-172	10YR4/8 & 7.5YR7/8	sgrc	2msbk	mfr wsstspl	fgr rd	ds	medium roots. few medium distinct sharp
C	172-205	2.5YR4/8 &7.5YR7/8 2.5YR4/8 &7.5YR7/8	sgrc	massive	mfr wstpl	fgr rd	ND	reddish yellow mottles few fine and common medium roots few medium prominent sharp reddish yellow mottles few fine roots Many coarse prominent sharp reddish yellow mottles, very few medium roots many medium prominent sharp reddish yellow mottles and weathered minerals.

t Texture: vgr = very gravelly, gr = gravelly, sgr = slightly gravelly, c = clay, l = loam or loamy s = sandy or sand;
x Structure: 1 = weak, 2 = moderate, 3 = strong, cr = crumb, sbk = subangular blocky, abk = angular blocky, vf = very fine, f = fine, m = medium, c = coarse;
y Consistence: m = moist, w = wet, vfr = very friable, fr = friable, fm = firm, vfm = very firm, nst = non sticky, sst = slightly sticky, st = sticky, vst = very sticky, npl = non plastic, pl = plastic, vpl = very plastic.
z Boundary: A = abrupt, C = clear, g = gradual, d = diffuse, s = smooth, w = wavy, ir = irregular, b = broken, ND = Not determined
b Concretions: vf = very few, f = few, fr = frequent, vfr = very frequent, gr = gravel, st = stone, rd = rounded, bd = boulder.

TABLE 2b: Morphological properties of the soils

Horizon	Depth (cm)	Colour (moist)	Texture[t]	Structure[x]	Consistence[y]	Concretions[b]	Boundary[z]	Notes
			PEDON OKP- 05 OWENA SERIES Quartz gravelly variation)					
AP	0-11	2.5YR3/6	vgrsc	2mcr	mfr wnstmpl	vfr gr rd	cw	abundant very fine, fine
AB	11-22	2.5YR3/6	grc	2mcr	mvfr wnstnpl	vfr gr rd	gw	and few medium roots.
Bt1	22-68	2.5YR5/8	grc	2msbk	mfr wsstspl	vfr gr f st rd	ds	abundant very fine, fine
Bt2	68-90	2.5YR5/8	grc	2msbk	mfr wssrspl	vfr gr rd	cw	and few medium roots
Bt3	90-140	10R5/8	sgrc	2msbk	mfr wsstspl	fr gr rd	as	frequent very fine, fine
2Bt4	140-185	&7.5YR5/8	grc	2msbk	mfr wsstspl	-	cw	and few medium roots
2BC	185-205	2.5YR5/8 &10YR7/8 2.5YR5/8 &10YR8/8	sgrc	2fsbk	mfr wsstspl	-	ND	common fine and very few medium roots very few medium roots. few fine distinct strong

Horizon	Depth (cm)	Colour (moist)	Texture[t]	Structure[x]	Consistence[y]	Concretions[b]	Boundary[z]	Notes
								brown mottles many angular gravel and stone size layers of quartz stones many medium & fine, prominent, sharp brownish yellow & yellow mottles
PEDON OKP 06 GAMBARI SERIES								
AP	0-12	5YR3/2	vgrsc	2mcr	mfr wnstnpl	fr gr rd	gw	abundant fine and very fine roots
E	12-27	5YR4/3	vgrsc	2fcr	mfr wnstnpl	vfrgr st rd	gs	abundant fine and very fine roots
BE	27-40	2.5YR4/6	vgrc	2fcr	mfr wsstspl	vfr gr rd	cs	few fine roots
Bsm	40-90	10R4/8 & 10YR5/8	vgrc	2fgr	mfm wstpl	frgr vfr st rd	ND	many coarse prominent sharp yellowish-brown mottles, merging into an impenetrable sheet of iron stone.
PEDON OKP-07 OWENA SERIES								
AP	0-11	2.5YR 2.5/4	sgrsc	2fcr	mvfr wnstnpl	vf gr rd	aw	frequent fine, medium and few coarse roots.
E	11-23	2.5YR 3/6	grsc	2mcr	mfr wsstspl	vfr gr rd	cs	common fine and medium roots
BE	23-48	2.5YR 4/6	vgrc	2msbk	mfr wstpl	vfrgr vf st rd	cw	common fine and medium roots
Bt1	48-88	10R 4/8	sgrc	2msbk	mfr wstpl	fr gr vfst rd	gs	common medium roots.
Bt2	88-122	10R 4/8	sgrc	2msbk	mfr wstpl	fgr rd	cs	common medium and few fine roots
2Btc1	122-152	10R 4/8	grc	2msbk	mfr wstpl	vfrgr fst rd	gs	few medium and fine roots
2Btc2	152-193	10R 4/6	vgrc	2msbk	mfr wstpl	vfrgr fst rd	ND	few fine roots. many rounded iron stone.
PEDON OKP-08 OWENA SERIES								
AP	0-10	2.5YR3/4	c	2mcr	mfr wsstspl	-	as	common fine and very fine roots
AB	10-22	10R3/4	sgrc	2msbk	mfr wsstspl	-	gs	common fine and very fine roots
Bt1	22-60	7.5YR4/6	c	2msbk	mfr wsstspl	vfgr rd	ds	few fine and medium roots.
Bt2	60-128	7.5R4/8	c	2msbk	mfr wstpl	-	cs	
2Bt3	128-173	7.5R4/8	grc	2msbk	mfr wst pl	fr gr rd	cs	
2Bt4	173-200	7.5R4/8	grc	2msbk	mfr wst pl	fr gr rd	ND	

Horizon	Depth (cm)	Colour (moist)	Texture[t]	Structure[x]	Consistence[y]	Concretions[b]	Boundary[z]	Notes
								common fine and medium roots many gravel and stone size rounded iron stone as layer.
				PEDON OKP - 09 OWENA SERIES				
AP	0-8	10R3/4	scl	2msbk	mfr wnstnpl	fgr rd	cs	common coarse, medium and fine roots.
AB	8-19	10R3/6	grc	2msbk	mfr wsstspl	frgr rd	cw	common coarse, medium and fine roots.
Bt1	19-42	10R4/6	grc	2msbk	mfr wstpl	frgr rd	gw	common medium and coarse roots
2Bt2	42-82	10R4/8	grc	2msbk	mfr wstpl	frgr rd	gw	few medium roots.
2Bt3	82-153	10R4/8	grc	2msbk	mfr wstpl	vfr gr rd	gw	frequent gravel and stone size concretionary and quartz materials
2Bt4	153-205	10R4/8	grc	2msbk	mfr wstpl	-	ND	
				PEDON OKP - 10 JAGO SERIES				
AP	0-8	2.5YR3/4	grsl	2mcr	mfr wnstnpl	f gr rd	cw	common medium frequent fine roots
AB	8-30	2.5YR 3/6	sgrc	2msbk	mfr wsstspl	vf gr rd	gw	common medium frequent fine roots
Bt	30-77	2.5YR 4/6	sgrc	3msbk	mfm wst pl	vf gr rd	gw	frequent medium and few fine roots
Btg	77-90	7.5YR6/6 & 5YR 6/1	grcl	2msbk	mfm wvstvpl	fr gr rd	ND	common medium roots. merging into a water saturated layer.

[t] *Texture: vgr = very gravelly, gr = gravelly, sgr = slightly gravelly, c = clay, l = loam or loamy s = sandy or sand;*
[x] *Structure: 1 = weak, 2 = moderate, 3 = strong, cr = crumb, sbk = subangular blocky, abk = angular blocky, vf = very fine, f = fine, m = medium, c = coarse;*
[y] *Consistence: m = moist, w = wet, vfr = very friable, fr = friable, fm = firm, vfm = very firm, nst = non sticky, sst = slightly sticky, st = sticky, vst = very sticky, npl = non plastic, pl = plastic, vpl = very plastic.*
[z] *Boundary: A = abrupt, C = clear, g = gradual, d = diffuse, s = smooth, w = wavy, ir = irregular, b = broken, ND = Not determined*
[b] *Concretions: vf = very few, f = few, fr = frequent, vfr = very frequent, gr = gravel, st = stone, rd = rounded, bd = boulder.*

TABLE 3a: Physical properties of the soils

Horizon	Depth (cm)	Gravel Content (>2mm)	VCS (2.00–1.00 mm)	CS (1.00–0.50 mm)	MS (0.50 – 0.25 mm)	FS (0.25–0.10 mm)	VFS (0.10–0.05 mm)	Total sand (2.0-0.05mm)	Silt (0.05-0.002 mm)	Clay <0.002 mm	Silt/ silt+clay Ratio	Bulk Density (g/cm^3)	Textural class
			←			(%)			→				
OKP 01 IBULE SERIES													
Ap	0-12	30.0	11.1	16.6	13.3	9.0	8.0	58	17	25	0.40	1.09	gr Sandy
E	12-22	66.1	14.9	15.3	10.3	6.1	5.4	52	14	34	0.29	1.58	clay Loam
BE	22-37	73.5	11.0	10.4	6.8	4.7	5.1	38	10	52	0.16	1.60	vgr Sandy
Bsm	37-69	65.1	7.6	7.9	4.0	2.8	3.7	26	10	64	0.14	1.59	Clay Loam
													vgr clay
													vgr clay
OKP 02 IBULE SERIES													
Ap	0-10	36.5	8.6	14.-9	12.0	9.3	9.2	54	20	26	0.43	1.01	gr Sandy
E	10-28	59.1	7.8	11.2	9.3	6.7	7.0	42	17	41	0.29	1.66	clay loam,
BE	28-45	69.4	8.4	10.0	6.5	4.9	6.2	36	11	53	0.17	1.65	vgr clay
Bsm	45-97	62.8	6.7	9.2	4.2	3.1	4.8	28	08	64	0.11	1.68	vgr clay
													vgr clay
OKP 03 IJARE SERIES													
Ap	0-15	45.2	8.5	12.6	11.5	9.2	10.2	52	18	30	0.38	1.01	gr Sandy
E	15-32	75.1	10.0	11.1	8.5	5.9	6.5	42	16	42	0.28	1.64	clay loam
EB	32-50	76.0	9.1	8.3	5.4	3.9	5.3	32	15	53	0.22	1.56	vgr Clay
Btc	50-81	62.7	7.9	4.8	2.1	1.7	3.5	20	11	69	0.14	1.57	vgr Clay
2Bt1	81-116	51.0	8.0	6.9	2.4	1.8	3.9	23	10	67	0.13	1.61	vgr Clay
2Bt2	116-146	47.4	7.6	7.9	3.7	3.0	5.8	28	10	62	0.14	1.71	vgr Clay
3Bt3	146-187	52.8	4.4	4.5	2.1	1.9	4.1	17	15	68	0.18	1.48	vgr Clay
3Bt4	187-220	21.8	1.6	2.1	1.6	1.7	4.0	11	22	67	0.25	1.34	vgr Clay
													vgr Clay
OKP 04 ARAROMI SERIES													
Ao	0-7	42.1	7.4	11.0	16.2	10.2	11.2	56	17	27	0.39	0.75	gr Sandy
E	7-15	53.7	5.2	8.2	7.9	5.2	5.5	32	16	52	0.24	0.86	clay loam
EB	15-40	45.9	2.8	4.3	3.3	2.6	3.0	16	18	66	0.21	1.26	vgr Clay
Bt1	40-60	51.3	1.2	2.7	2.1	1.6	2.4	10	21	69	0.23	1.35	vgr Clay
Bt2	60-110	38.7	2.6	3.5	3.3	1.5	5.1	16	16	68	0.19	1.23	vgr Clay
Bt3	110-145	29.5	1.8	2.1	1.7	1.9	3.5	11	22	67	0.25	1.18	vgr Clay
BCt	145-172	9.5	1.2	2.2	3.0	3.6	6.0	16	24	60	0.29	1.11	vgr Clay
C	172-205	5.3	0.8	1.1	2.0	2.5	3.6	10	27	63	0.30	1.08	vgr Clay
													vgr Clay
OKP 05 OWENA SERIES (gravelly variation)													
Ap	0-11	53.7	10.8	15.7	12.3	8.6	10.6	58	18	24	0.43	1.02	vgr Sandy
AB	11-22	46.6	2.9	4.8	3.8	3.1	3.4	18	24	58	0.29	1.32	clay loam
Bt1	22-68	49.0	1.4	2.5	1.1	0.8	1.2	07	15	78	0.16	1.37	gr clay
Bt2	68-90	49.4	0.4	0.6	0.3	0.5	0.4	02	16	82	0.16	1.26	gr clay

Horizon	Depth (cm)	Gravel Content (>2mm)	VCS (2.00–1.00 mm)	CS (1.00–0.50 mm)	MS (0.50 – 0.25 mm)	FS (0.25–0.10 mm) (%)	VFS (0.10–0.05 mm)	Total sand (2.0-0.05mm)	Silt (0.05-0.002 mm)	Clay <0.002 mm	Silt/ silt+clay Ratio	Bulk Density (g/cm^3)	Textural class
Bt3	90-140	17.5	0.8	1.2	0.7	0.3	0.8	04	16	80	0.17	1.24	gr clay
2Bt4	140-185	33.1	4.4	8.6	3.0	1.7	2.3	20	17	63	0.21	1.24	sgr clay
2BC	185-205	11.9	2.4	6.1	2.5	1.6	2.4	15	20	65	0.24	1.24	gr clay
													sgr clay

VCS = very coarse sand; CS = coarse sand; MS = medium sand; FS = fine sand; VFS = very fine sand, ngr = non gravelly; sgr = slightly gravelly; gr = gravelly; vgr = very gravelly

TABLE 3b: Physical properties of the soils

Horizon	Depth (cm)	Gravel Content (>2mm)	VCS (2.00–1.00 mm)	CS (1.00–0.50 mm)	MS (0.50 – 0.25 mm)	FS (0.25–0.10 mm) (%)	VFS (0.10–0.05 mm)	Total sand 2.0-0.05mm	Silt (0.05-0.002 mm)	Clay <0.002 mm	Silt/ silt+clay Ratio	Bulk Density (g/cm^3)	Textural class
						OKP 06 GAMBARI SERIE							
Ap	0-12	68.3	11.5	17.4	11.5	9.6	12.0	62	14	24	0.37	0.93	vgr Sandy
E	12-27	70.5	8.2	12.9	11.1	7.8	8.0	48	13	39	0.25	1.27	clay loam
BE	27-40	74.5	7.7	8.2	5.8	4.7	6.6	33	12	55	0.18	1.47	vgr Sandy
Bsm	40-90	70.3	15.5	8.7	4.4	4.0	7.4	40	12	48	0.20	1.45	clay
													vgr clay
													vgr clay
						OKP 07 OWENA SERIES							
Ap	0-11	3.8	3.5	12.3	12.1	9.8	11.3	49	22	29	0.43	1.01	sgr Sandy
E	11-23	42.9	5.4	12.9	11.5	7.3	7.9	45	17	38	0.31	1.45	clay loam
BE	23-48	52.8	6.5	10.4	7.5	4.7	4.9	34	12	54	0.18	1.42	gr Sandy
Bt1	48-88	14.5	3.3	7.0	6.4	4.6	4.7	26	12	62	0.16	1.38	clay
Bt2	88-122	9.4	2.5	6.1	6.3	4.5	4.6	24	13	63	0.17	1.37	vgr clay
2Btc1	122-152	48.5	3.5	5.3	4.9	3.5	3.8	21	12	67	0.15	1.61	sgr clay
2BtC2	152-193	57.9	5.9	7.2	4.8	3.3	3.8	25	11	64	0.15	1.69	sgr clay
													gr clay
													vgr clay
						OKP 08 OWENA SERIES							
Ap	0-10	1.0	2.2	7.5	10.6	8.9	8.8	38	17	45	0.27	1.04	ngr Clay
AB	10-22	12.4	1.3	4.2	5.8	5.0	4.7	21	14	65	0.18	1.14	sgr clay
Bt1	22-60	NS	1.6	4.0	5.4	4.5	4.5	20	18	62	0.23	1.25	ngr clay
Bt2	60-128	1.9	2.0	3.4	4.2	3.7	3.7	17	13	70	0.16	1.26	ngr clay
2Bt3	128-173	33.9	2.9	2.9	2.9	2.5	2.8	14	10	76	0.12	1.37	gr clay
2Bt4	173-200	40.9	6.2	3.9	3.5	3.0	3.4	20	16	64	0.20	1.19	gr clay
						OKP 09 OWENA SERIES							
Ap	0-8	3.8	4.2	10.2	12.3	11.8	11.5	50	21	29	0.42	0.95	ngr Sandy

Horizon	Depth (cm)	Gravel Content (>2mm)	VCS (2.00–1.00 mm)	CS (1.00–0.50 mm)	MS (0.50 – 0.25 mm)	FS (0.25–0.10 mm)	VFS (0.10–0.05 mm)	Total sand 2.0-0.05mm	Silt (0.05-0.002 mm)	Clay <0.002 mm	Silt/ silt+clay Ratio	Bulk Density (g/cm^3)	Textural class
		←				(%)				→			
AB	8-19	32.0	7.5	11.2	10.8	7.9	7.6	45	18	37	0.33	1.55	clay loam
Bt1	19-42	17.1	3.6	6.3	6.6	5.2	5.3	27	12	60	0.18	1.38	gr Sandy
2Bt2	42-82	26.9	2.9	6.0	5.7	4.2	4.2	23	16	61	0.21	1.46	clay
2Bt3	82-153	28.2	3.2	6.0	5.3	4.1	4.4	23	13	64	0.17	1.42	gr clay
2Bt4	153-205	16.7	2.1	4.4	3.8	2.6	3.1	16	12	72	0.14	1.25	gr clay
													gr clay
													gr clay
						OKP 10 JAGO SERIES							
Ap	0-8	16.4	4-2	11.6	14.9	13.0	14.3	58	23	19	0.55	0.76	gr Sandy
AB	8-30	9.4	2.6	6.7	10.1	7.6	8.0	35	18	47	0.28	1.23	loam
Bt	30-77	5.5	1.3	4.1	7.2	6.6	7.8	27	21	52	0.29	1.31	sgr clay
Btg	77-90	24.8	2.4	4.6	8.3	8.1	11.6	35	31	34	0.48	1.13	sgr clay
													gr clay
													loam

NS = Not significant; VCS = very coarse sand; CS = coarse sand; MS = medium sand; FS = fine sand; VFS = very fine sand, ngr = non gravelly; sgr = slightly gravelly; gr = gravelly; vgr = very gravelly

Chemical properties of the soils

The chemical properties of the pedons studied are shown in Tables 4a, 4b, and 5. The soils range from neutral to very strongly acidic (Mosley *et al*., 2024; Ojanuga, 1975), with pH (H_2O) values ranging from 4.75 to 6.80. In pedons OKP-01, -03, -06, -09, and -10, the pH values decreased with depth, while the pattern was erratic in the other pedons. Generally, the surface horizons of the pedons were medium to slightly acid (pH 5.5 - 6.50) except pedons OKP-01, -04, and -09. The B and C-horizons were very strong to strongly acidic with pH values ranging from 4.75 to 5.20 in the upland well-drained pedons. Soils of the humid tropics are inherently acidic due to heavy rainfall that leaches out essential basic nutrients, and the high intensity of weathering that has taken place in these soils. The pH in 1 M KCl is lower than the pH in water (H_2O). The difference in soil pH values (ΔpH) between the pH in KCl and H_2O (as expressed by ΔpH = pH (KCl) - pH(H_2O) is all negative in values ranging from -0.05 to -1.25. This suggests the dominance of silicate clay minerals over oxides and that the soil has a net negative electrical charge and, consequently, a high CEC (Hong *et al*., 2024).

The distribution of exchangeable cations is shown in Table 4. Generally, there is a high accumulation of bases in the surface horizon (7.42 to 27.03 $cmol_{(+)}$/kg of soil). This could have resulted from biogeochemical cycling through litter fall. The subsoil horizons have very low exchangeable cations with values that ranged between 0.18 and 10.58 $cmol_{(+)}$/kg soil. There was a decrease in total exchangeable bases with depth in all the pedons, though the trend is erratic in pedons OKP-03, -04, -05 and -10. This behaviour could be due to differential weathering that had occurred or due to plant uptake and leaching losses. Calcium ion (Ca^{2+}) had the highest values [0.10 $cmol_{(+)}$/kg soil to 20.21 $cmol_{(+)}$/kg soil] among the exchangeable bases, while magnesium was the next most abundant cation on the exchange sites with values ranging from 0.02 $cmol_{(+)}$/kg to 6.22 $cmol_{(+)}$/kg soil. The relatively high values of exchangeable calcium and magnesium could have resulted from the ferromagnesian nature of the parent rock. Exchangeable potassium (K^+) and sodium (Na^+) values were low (Table 4), with values ranging from 0.02 to 1.37 $cmol_{(+)}$/kg soil and 0.04 to 0.1g $cmol_{(+)}$/kg soil for K^+ and Na^+, respectively. These low values probably indicate that the soils examined developed from materials poor in Na^+ and K^+ minerals, or due to plant uptake and/or leaching losses as a result of their (Na^+ and K^+) mobility in soil. Exchangeable acidity values ranged from 0.45 $cmol_{(+)}$/kg to 1.90 $cmol_{(+)}$/kg soil (Table 4). Pedons OKP-04, -05, -06, and -08 showed high values of exchangeable acidity (Al^{3+} and H^+) with values ranging from 0.60 $cmol_{(+)}$/kg soil to 1.80 $cmol_{(+)}$/kg soil and relatively uniform with depth. Exchangeable Al^{3+} accounted for a greater percentage of the total acidity. Effective cation exchange capacity (ECEC) values were generally low, ranging from 0.83 $cmol_{(+)}$/kg soil to 27.33 $cmol_{(+)}$/kg soil. There were higher values in the surface horizons of all pedons examined than in the subsoil horizons. This observation is due to the influence of organic carbon on the exchange capacity of soil. Zhu *et al*. (2024) observed that low CEC values are consistent with low organic carbon content of soils especially in the B-horizon and probably with kaolinitic nature of the soils. In all the pedons examined, the ECEC values decreased with depth. However, the trend is erratic in pedons OKP-07 and -10.

TABLE 4a: Chemical properties of the soils

Horizon	Depth (cm)	pH (H_2O)	pH (KCl)	δpH	EXCHANGEABLE CATIONS						Sum of Cations	Exch acidity	ECEC	Base saturation	Aluminium Saturation	CEC ($cmol_{(+)}$ Kg^{-1} clay)
					Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	Al^{3+}	H^{+}						
					($cmol_{(+)}kg^{-1}$ soil)									(%)		
OKP 01 IBULE SERIES																
Ap	0-12	6.80	6.40	-0.40	17.22	5.60	1.37	0.15	0.30	0.60	24.34	0.90	24.64	98.78	1.22	98.56
E	12-22	6.60	6.20	-0.40	7.78	2.12	0.59	0.09	0.40	0.30	10.58	0.70	10.98	96.36	3.64	32.29
BE	22-37	6.45	5.90	-0.55	5.59	1.01	0.51	0.09	0.40	0.10	7.20	0.50	7.60	94.74	5.26	14.62
Bsm	37-69	6.15	5.50	-0.65	4.54	0.73	0.24	0.11	0.60	0.10	5.62	0.70	6.22	90.35	9.65	9.72
OKP 02 IBULE SERIES																
Ap	0-10	6.20	5.80	-0.40	12.97	3.99	0.24	0.14	0.40	0.30	17.34	0.70	17.74	97.75	2.25	68.23
E	10-28	6.30	5.70	-0.60	5.69	1.46	0.06	0.09	0.40	0.10	7.30	0.50	7.70	94.81	5.19	18.78
BE	28-45	6.30	5.40	-0.90	4.19	0.70	0.03	0.08	0.70	0.20	5.00	0.90	5.70	87.72	12.28	10.75
Bsm	45-97	6.00	5.60	-0.40	1.20	0.19	0.04	0.06	0.30	0.15	1.49	0.45	1.79	83.24	16.76	2.80
OKP 03 IJARE SERIES																
Ap	0-15	6.50	6.00	-0.50	11.98	4.80	0.24	0.12	0.40	0.20	17.14	0.60	17.54	97.72	2.28	58.47
E	15-32	6.50	5.90	-0.60	5.89	1.62	0.10	0.09	0.30	0.40	7.70	0.70	8.00	96.25	3.75	19.05
EB	32-50	6.50	5.80	-0.70	4.09	1.07	0.10	0.10	0.40	0.20	5.36	0.60	5.76	93.06	6.94	10.87
Btc	50-81	6.35	5.80	-0.55	3.09	0.66	0.04	0.09	0.30	0.20	3.88	0.50	4.18	92.82	7.18	6.06
2Bt1	81-116	5.90	5.70	-0.20	1.00	0.18	0.03	0.05	0.50	0.40	1.26	0.90	1.76	71.59	28.41	2.63
2Bt2	116-	5.60	5.50	-0.10	0.75	0.13	0.04	0.05	0.40	0.10	0.97	0.50	1.37	70.80	29.20	2.21
3Bt3	146	5.40	5.35	-0.05	0.85	0.13	0.06	0.05	0.30	0.30	1.09	0.60	1.39	78.42	21.58	2.04
3Bt4	146-	5.20	5.10	-0.10	0.60	0.08	0.04	0.05	1.00	0.60	0.77	1.60	1.77	43.50	56.50	2.64
	187															
	187-															
	220															
OKP 04 ARAROMI SERIES																
Ao	0-7	5.35	5.30	-0.05	12.48	5.06	0.39	0.15	0.50	0.70	18.08	1.20	18.58	97.31	2.69	68.81
E	7-15	4.90	4.45	-0.50	2.25	0.69	0.25	0.09	1.10	0.30	3.28	1.40	4.38	74.89	25.11	8.42
EB	15-40	4.80	4.10	-0.70	0.65	0.21	0.11	0.07	1.30	0.30	1.04	1.60	2.34	44.44	55.56	3.55
Bt1	40-60	4.80	4.30	-0.50	0.80	0.20	0.07	0.09	1.00	0.60	1.16	1.60	2.16	53.70	46.30	3.13
Bt2	60-110	4.80	4.35	-0.45	0.10	0.03	0.02	0.05	0.80	0.60	0.20	1.40	1.00	20.00	80.00	1.47
Bt3	110-	5.20	4.60	-0.60	0.15	0.03	0.03	0.05	0.70	0.30	0.26	1.00	0.96	27.08	72.92	1.43
BCt	145	5.00	4.70	-0.30	0.10	0.02	0.02	0.04	0.70	0.30	0.18	1.00	0.88	20.45	79.55	1.47
C	145-	5.10	4.80	-0.20	0.15	0.02	0.02	0.05	0.80	0.20	0.24	1.00	1.04	23.08	76.92	1.65
	172															
	172-															
	205															
OKP 05 OWENA SERIES (gravelly variation)																
Ap	0-11	5.45	5.20	-0.25	8.08	3.31	0.32	0.11	0.35	0.35	11.82	0.70	12.17	97.12	2.88	50.71
AB	11-22	5.20	4.60	-0.60	1.50	0.46	0.17	0.05	0.60	0.30	2.18	0.90	2.78	78.42	21.58	4.79
Bt1	22-68	4.75	4.20	-0.55	0.45	0.16	0.09	0.09	1.20	0.30	0.79	1.50	1.99	39.70	60.30	2.55
Bt2	68-90	4.90	4.45	-0.45	0.25	0.07	0.04	0.05	0.60	0.50	0.41	1.10	1.01	40.59	59.41	1.23
Bt3	90-140	5.10	4.70	-0.40	0.15	0.04	0.03	0.04	0.80	0.10	0.26	0.90	1.06	24.53	75.47	1.33
2Bt4	140-	5.10	4.90	-0.20	0.25	0.06	0.03	0.09	0.80	0.40	0.43	1.20	1.23	34.96	65.04	1.95
2BC	185	5.00	4.90	-0.10	0.10	0.03	0.03	0.07	0.60	0.80	0.23	1.40	0.83	27.71	72.29	1.27
	185-															
	205															

TABLE 4b: Chemical properties of the soils

Horizon	Depth (cm)	pH (H_2O)	pH (KCl)	δpH	Ca^{2+}	Mg^{2+}	K^+	Na^+	Al^{3+}	H^+	Sum of Cations	Exch acidity	ECEC	Base saturation	Aluminium Saturation	ECEC cmol $_{(+)}$ Kg^{-1} clay
					EXCHANGEABLE CATIONS ($cmol_{(+)}kg^{-1}$ soil)									%		
								OKP 06 GAMBARI SERIES								
Ap	0-12	6.10	5.80	-0.30	20.21	6.22	0.41	0.19	0.30	0.80	27.03	1.10	27.33	98.90	1.10	113.88
E	12-27	6.20	5.70	-0.50	9.53	2.47	0.22	0.12	0.40	0.50	12.34	0.90	12.74	96.86	3.14	32.67
BE	27-40	5.60	4.90	-0.70	4.49	0.78	0.23	0.09	0.30	0.40	5.59	0.70	5.89	94.91	5.09	10.70
Bsm	40-90	4.85	4.20	-0.65	0.70	0.12	0.08	0.05	1.20	0.60	0.95	1.80	2.15	44.19	55.81	4.48
								OKP 07 OWENA SERIES								
Ap	0-11	6.00	5.70	-0.30	8.78	3.60	0.32	0.16	0.30	0.20	12.86	0.50	13.16	97.72	2.28	45.38
E	11-23	6.45	5.75	-0.70	6.09	1.71	0.20	0.13	0.30	0.20	8.13	0.50	8.43	96.44	3.56	22.18
BE	23-48	6.60	5.75	-0.85	3.89	1.04	0.15	0.11	0.30	0.50	5.19	0.80	5.49	94.54	5.46	10.17
Bt1	48-88	6.40	5.60	-0.80	2.40	0.54	0.13	0.11	0.25	0.35	3.18	0.60	3.43	92.71	7.29	5.53
Bt2	88-122	5.70	5.00	-0.70	1.30	0.24	0.10	0.09	0.40	0.45	1.73	0.85	2.13	81.22	18.78	3.38
2Btc1	122-	5.10	4.10	-1.00	1.00	0.17	0.07	0.09	1.40	0.50	1.33	1.90	2.73	48.72	51.28	4.07
2Btc2	152	5.20	4.80	-0.40	0.65	0.11	0.04	0.08	0.70	0.80	0.88	1.50	1.58	55.70	44.30	2.47
	152-															
	193															
								OKP 08 OWENA SERIES								
Ap	0-10	5.50	5.00	-0.50	4.69	2.08	0.54	0.11	0.40	0.30	7.42	0.70	7.82	94.88	5.12	17.38
AB	10-22	5.35	4.90	-0.45	2.99	0.86	0.14	0.11	0.40	0.60	4.10	1.00	4.50	91.11	8.89	6.92
Bt1	22-60	5.10	4.55	-0.55	2.69	0.73	0.10	0.11	0.40	0.20	3.63	0.60	4.03	90.07	9.93	6.50
Bt2	60-128	4.90	4.55	-0.35	0.90	0.23	0.11	0.10	0.70	0.50	1.34	1.20	2.04	65.69	34.31	2.91
2Bt3	128-	5.00	4.30	-0.70	0.40	0.10	0.11	0.10	0.90	0.50	0.71	1.40	1.61	44.10	55.90	2.12
2Bt4	173	5.10	4.30	-0.80	0.30	0.07	0.08	0.09	1.00	0.60	0.54	1.60	1.54	35.06	64.94	2.41
	173-															
	200															
								OKP 09 OWENA SERIES								
Ap	0-8	6.55	6.30	-0.25	8.63	3.65	0.62	0.13	0.40	0.40	13.03	0.80	13.43	97.02	2.98	46.31
AB	8-19	6.55	6.00	-0.55	4.99	1.39	0.17	0.08	0.40	0.10	6.63	0.50	7.03	94.31	5.69	19.00
Bt1	19-42	6.30	5.35	-0.95	2.50	0.67	0.07	0.06	0.25	0.35	3.25	0.60	3.50	92.86	7.14	5.83
2Bt2	42-82	5.50	4.90	-0.60	1.50	0.33	0.04	0.07	0.35	0.15	1.94	0.50	2.29	84.72	15.28	3.75
2Bt3	82-153	5.20	4.60	-0.60	0.80	0.15	0.03	0.08	0.40	0.40	1.06	0.80	1.46	72.60	27.40	2.28
2Bt4	153-	5.20	4.60	-0.60	0.65	0.11	0.03	0.07	0.40	0.65	0.86	1.05	1.26	68.25	31.75	1.75
	205															
								OKP 10 JAGO SERIES								
Ap	0-8	6.00	5.50	-0.50	6.54	2.69	0.26	0.12	0.35	0.45	9.61	0.80	9.96	96.49	3.51	52.42
AB	8-30	5.80	5.00	-0.80	2.00	0.58	0.10	0.08	0.35	0.55	2.76	0.90	3.11	88.75	11.25	6.62
Bt	30-77	5.50	4.60	-0.90	3.74	0.98	0.04	0.13	0.50	0.30	4.89	0.80	5.39	90.72	9.28	10.36
Btg	77-90	5.85	4.60	-1.25	2.50	0.54	0.05	0.10	0.40	0.60	3.19	1.00	3.59	88.86	11.14	10.56

Base saturation values were high (varying from 95% to 99%) in the A-horizons of all pedons. The values decrease with depth. Aluminium saturation, on the other hand, was low in the topsoil (A-horizons); however, it increased with depth, except in pedon OKP-05, which had an erratic trend. The organic carbon content of the surface horizons of the pedon studied ranged between 2.40% and 7.62% (Table 5) and decreased with depth. Organic carbon contents of the subsoil horizons were generally lower than the surface horizons of all pedons examined, except pedon OKP-10, which had an irregular decrease with depth. Total nitrogen content of the soil was generally low, ranging between 0.04% and 0.79% (Table 5). However, the surface horizons (A-horizons) had higher values than the subsoil horizons. The total nitrogen values decreased with depth in all the pedons examined. The relatively high total nitrogen values in the surface horizons are probably due to nutrient cycling through litter fall (Hoosbeek *et al.*, 2023). The carbon nitrogen ratio (C/N) was quite low (0.00 and 14.93). The ratio decreased with depth in pedons OKP-02, -03, -05, -07, and -10, while the pattern was erratic and irregular in pedons OKP--01, -08, and -09. However, the ratios increased with depth to a maximum and then decreased in pedons OKP-04 and -06. Horizons with relatively high C/N ratios showed an indication of low humification and hence, high litter accumulation and low rate of organic matter mineralization.

Available phosphorus (P) content of the soil varied from 3.88 mg/kg to 35.89 mg/kg and was generally highest in the surface horizons of all pedons. The available P values generally decreased irregularly with depth in all the pedons examined.

TABLE 5: The organic C, total N, available P and amorphous oxide content of the soils

HORIZON	Depth (cm)	O.M	Organic C	Total N	C/N	Avail. P (ppm)	Amorphous oxides Fe(o)	Al(o)
		←	(%)	→			← (%)	→
OKP 01 IBULE SERIES								
Ap	0-12	8.33	4.83	0.42	11.50	17.44	2.08	0.60
E	12-22	3.16	1.83	0.20	9.15	6.75	2.08	0.58
BE	22-37	1.75	1.01	0.09	11.22	7.88	2.14	0.61
Bsm	37-69	1.34	0.78	0.06	13.00	5.63	2.08	0.70
OKP 02 IBULE SERIES								
Ap	0-10	7.66	4.44	0.33	13.45	12.38	1.99	0.53
E	10-28	2.55	1.48	0.18	8.22	5.63	1.01	0.40
BE	28-45	1.81	1.05	0.13	8.08	6.19	1.95	0.70
Bsm	45-97	0.67	0.39	0.10	3.90	5.63	1.70	0.68
OKP 03 IJARE SERIES								
Ap	0-15	7.46	4.33	0.29	14.93	9.56	1.92	0.58
E	15-32	2.15	1.25	0.18	6.94	4.50	2.11	0.55
EB	32-50	1.41	0.82	0.11	7.45	4.50	1.90	0.51
Btc	50-81	1.01	0.58	0.11	5.27	4.50	0.96	0.43
2Bt1	81-116	0.34	0.20	0.06	3.33	4.50	1.50	0.55
2Bt2	116-146	0.20	0.12	0.06	2.00	7.88	3.36	0.60
3Bt3	146-187	0.07	0.04	0.04	1.00	3.88	2.40	0.51
3Bt4	187-220	**NS**	**NS**	0.05	0.00	3.88	1.34	0.40
OKP 04 ARAROMI SERIES								
Ao	0-7	8.93	5.18	0.51	10.16	19.13	1.82	0.56
E	7-15	4.23	2.46	0.24	10.25	6.19	2.02	0.51
EB	15-40	2.96	1.74	0.15	11.60	6.19	2.02	0.53
Bt1	40-60	2.15	1.25	0.10	12.50	6.75	1.86	0.52

HORIZON	Depth (cm)	O.M	Organic C (%)	Total N	C/N	Avail. P (ppm)	Amorphous oxides Fe(o) (%)	Al(o)
Bt2	60-110	1.08	0.62	0.07	8.86	7.88	1.23	0.36
Bt3	110.145	0.61	0.35	0.05	7.00	6.19	1.50	0.43
BCt	145-172	0.54	0.31	0.04	7.75	6.19	1.31	0.37
C	172-205	0.47	0.27	0.04	6.75	6.19	1.34	0.07
OKP 05 OWENA SERIES (Gravelly variation)								
Ap	0-11	8.06	4.68	0.41	11.41	12.38	1.92	0.26
AB	11-22	2.49	1.44	0.17	8.47	5.63	1.95	0.20
Bt1	22-68	1.48	0.86	0.10	8.60	7.31	1.70	0.15
Bt2	68-90	0.40	0.23	0.06	3.83	5.63	1.92	0.24
Bt3	90-140	0.27	0.16	0.06	2.67	5.06	1.92	0.17
2Bt4	140-185	0.13	0.08	0.05	1.60	5.63	1.41	0.04
2BC	185-205	0.13	0.08	0.04	2.00	7.31	1.50	0.09
OKP 06 GAMBARI SERIES								
Ap	0-12	13.13	7.62	0.79	9.65	24.56	1.70	0.37
E	12-27	5.81	3.37	0.34	9.91	11.25	1.92	0.43
BE	27-40	3.19	1.85	0.18	10.26	9.00	1.95	0.35
Bsm	40-90	1.31	0.76	0.10	7.60	7.88	1.70	0.26
OKP 07 OWENA SERIES								
Ap	0-11	7.29	4.23	0.39	10.85	35.89	2.48	0.32
E	11-23	3.29	1.91	0.21	9.10	31.17	2.69	0.63
BE	23-48	1.51	0.88	0.12	7.33	24.56	2.72	0.32
Bt1	48-88	0.77	0.45	0.08	5.63	7.31	3.20	0.26
Bt2	88-122	0.64	0.37	0.07	5.25	7.88	3.07	0.37
2Btc1	122-152	0.57	0.33	0.07	4.71	7.88	3.07	0.32
2Btc2	152-193	0.37	0.21	0.06	3.50	7.88	3.20	0.26
OKP 08 OWENA SERIES								
Ap	0-10	4.13	2.40	0.21	11.43	10.13	2.08	0.15
AB	10-22	1.78	1.03	0.13	7.92	9.56	2.85	0.19
Bt1	22-60	1.18	0.68	0.10	6.80	4.50	2.66	0.26
Bt2	60-128	0.54	0.31	0.07	4.43	4.50	3.12	0.28
2Bt3	128-173	0.47	0.27	0.05	5.40	5.06	2.98	0.22
2Bt4	173-200	0.40	0.23	0.05	4.60	7.31	2.85	0.24
OKP 09 OWENA SERIES								
Ap	0-8	6.15	3.57	0.29	12.31	10.69	1.47	**tr**
AB	8-19	2.79	1.62	0.13	12.46	5.06	1.76	**tr**
Bt1	19-42	1.18	0.68	0.09	7.56	7.88	2.22	0.11
2Bt2	42-82	0.91	0.53	0.08	6.63	4.00	2.14	0.13
2Bt3	82-153	0.77	0.45	0.05	9.00	5.63	2.02	0.22
2Bt4	153-205	0.64	0.37	0.05	7.40	4.50	2.18	0.19
OKP 10 JAGO SERIES								
Ap	0-8	7.22	4.19	0.31	13.52	6.19	1.70	0.09
AB	8-30	2.22	1.28	0.11	11.64	3.94	1.76	0.22
Bt	30-77	1.20	0.70	0.10	7.00	5.06	1.92	0.24
Btg	77-90	1.27	0.74	0.08	9.25	6.19	2.02	0.09

O.M = organic matter; Organic C = organic carbon; Total N = Total nitrogen; C/N = carbon: nitrogen ratio; Avail. P = available phosphorus.
NS = Not significant; tr = Traces

The relatively high concentration of available P and organic carbon in the surface horizons may imply significant organic or bio-cycled P in the soils. Pedon OKP-07 exhibits an unusually high concentration of available P in the next two horizons to the surface horizon (E;11-23 cm and BE; 23-48 cm) with available P values of 31.17 mg/kg and 24.56 mg/kg, respectively (Table 5).

Amorphous Fe and Al oxide values are shown in Table 5. This shows the percentage of oxalate extractable Fe and Al in the pedons examined. The oxalate Fe and Al ($Fe_{(o)}$ and $Al_{(o)}$) distribution with depth is almost uniform in all pedons examined except pedon OKP-03, which has an erratic pattern. Amorphous iron ($Fe_{(o)}$) contents between 1.01% and 3.20% and aluminium ($Al_{(o)}$) from traces to 0.70% in tropical rainforest soils indicate moderate-to-high levels of reactive, non-crystalline iron and aluminium oxides. These compounds are key to enhancing soil structural stability, binding organic matter, and adsorbing phosphorus, but they could also contribute to high nutrient fixation. The variations between the pedons, for example, OKP-07 OWENA showing consistently higher $Fe_{(o)}$ (>3.0%) compared to OKP-02 IBULE, suggest differences in the parent material or the intensity of the localized weathering process.

Classification of the soils: USDA Soil Taxonomy

The presence of Kandic horizons was established in most pedons because they meet the following requirements: a coarser-textured surface horizon over vertically continuous subsurface horizons; ECEC values within the subsurface B horizons that are less than 12 $cmol_{(+)}$/kg clay; a regular decrease in organic carbon content with depth (Tables 3 and 4) (Soil Survey Staff, 2022). The generally low base saturation of less than 35% (by sum of cations) at the appropriate depth of 125 cm below the upper boundary of the kandic horizon (but no deeper than 200 cm below the mineral soil surface) or 180 cm below the mineral soil surface (Juo *et al* 1976; Soil Survey Staff, 2022), placed pedons OKP-04 and -05 into the Ultisols whereas other pedons (OKP 01, -02, -03, -06, -07, 08, -09 and -10) would classify as Alfisols due to high base saturation of greater than 35% (by sum of cations).

The moisture regime of the soil is ustic because the climate of the area is hot humid tropical, with well distributed bimodal rainfall (Table 1). The soils in the study area support and sustain tree crops. Therefore, pedons OKP 01, -02, -03, -06, -07, 08, -09, and -10 were classified as Ustalfs, whereas all other pedons were Ustults.

Pedons OKP-01 and -02 were classified as Kanhaplustalfs because they have an ECEC value less than 12 $cmol_{(+)}$/kg clay and no clay decrease of 20% or more from the maximum clay content with depth. They are Lithic Kanhaplustalfs because of the presence of lithic contact (i.e., hard continuous Iron stone layer which limits the depth of the pedons).

Pedons OKP-03, -07, -08, and -09 were classified as Kandiustalfs because they satisfy the following conditions: no lithic, paralithic or petroferric contact within 150 cm of the mineral soil surface; ECEC values of less than 12 $cmol_{(+)}$/kg clay; no clay decrease with depth of 20% or more from the maximum clay content within 150 cm of the mineral soil surface. They are Typic Kandiustalfs because they satisfy the following requirements: no redox depletion accompanied by redox concentration; no aquic condition, no plinthite within 150 cm of mineral soil surface; no sandy particle size at depth of 50-100cm; presence of a hue of 2.5YR and redder with colour value (moist) of 3 and more throughout the kandic horizons (must be 2.5 YR or redder, colour value moist of 3 or less).

Pedons OKP-04 and -05 were classified as Humults because both have more than 0.9% organic carbon in the upper 15 cm of the kandic horizon. They were Kandihumults for the reasons stated above (i.e., for pedons

OKP-03, -07, -08, and -09), and Typic Kandihumults for satisfying the requirements of no aquic conditions, no plinthite, and redox concentration with colour value (moist) greater than 4 and a constant hue of 7.5YR (must be 10YR or yellower).

Pedons OKP-03, -07, -08, and -09 were classified as Kanhaplustalfs partly for the reasons stated above for pedons OKP-03, -07, -08, and -09, and because the clay increase has not peaked at the 150 cm stipulated depth. They are Typic Kanhaplustalfs for the reasons stated above (i.e., for pedons OKP-03, -07, -08, and -09). Pedon OKP-06 is classified as Haplustalfs and Lithic Haplustalfs because of the presence of lithic contact at 40 cm from the mineral soil surface and the absence of a well-developed kandic horizon within the pedon.

Pedon OKP-10 was classified as Aqualf because of an aquic moisture regime. At the great group level, it is classified as Kandiaqualfs because it has ECEC less than 12 cmol$_{(+)}$/kg clay in all the kandic horizon (Table 4) and it is Typic Kandiaqualfs because of the following: clay particle size throughout the layer from mineral soil surface to the top of kandic horizon at a depth of 50-100 cm; no plinthite within 150 cm of the mineral soil surface; and no redox concentration between Ap horizon and 75 cm from the mineral soil surface.

Classification of the soils: IUSS Working Group WRB

The presence of a depth-limiting continuous cemented layer, within 100 cm of the mineral soil surface, places pedons OKP -01, 02, and 06 into the Leptosols. Pedons OKP -03, -04, -05, -07, -08, and -09 were classified as Ferralsols because of the presence of ferralic B-horizon (characterised by low ECEC of less than 12 cmol$_{(+)}$/kg clay, less than 10% weatherable minerals, less than 10% water dispersible clay, a minimum of 30 cm thickness, and absence of rock structure). Pedon OKP -10 was classified as Acrisols because of the presence of argic B-horizon, which has base saturation less than 50% in some part of the B horizon. The IUSS Working Group WRB equivalent for pedons OKP -01 and -02 is Eutric Leptosols because the soils have base saturation of more than 50% throughout, while pedon OKP -06 is Dystric Leptosols because of the limited depth. They all belong to the Petroferric phase. Whereas pedons OKP-03, -04, and -05 classify as Haplic Ferralsols, pedons OKP-07, -08 and -09 classify as Rhodic Ferralsols because of the presence of dark red B-horizons in all the pedons. All the pedons have nitic properties in some parts of the ferralic B-horizon (i.e., a strong angular blocky structure with an acceptable clay content (30% or more clay), friable consistence, and oxalate extractable iron ($Fe_{(o)}$ greater than 0.2%). Pedons OKP-03, -04, and -05 are therefore classified as Niti-Haplic Ferralsols, while pedons OKP-07, -08, and -09 are classified as Niti-Rhodic Ferralsols. Pedon OKP-10 is influenced by groundwater at a depth not too shallow, has base saturation more than 50% (by NH_4OAc) (Juo *et al*., 1976) in at least some parts of the B-horizons within 125 cm, and shows gleyic properties within 100 cm of the soil surface. It was therefore classified as Gleyic Acrisols.

Soil Taxonomy classification system and the IUSS Working Group WRB are sometimes poorly correlated. This has been demonstrated in the classification of pedons OKP-03, -04, -05, -07, -08, and -09 as Ferralsols. Whereas the acceptable equivalent of Ferralsols in Soil Taxonomy is Oxisols (Soil Survey Staff, 1994; 2022), these soils were classified as Ultisols and Alfisols. This difference was brought about by the new definitions of ferralic and argic B-horizons, which have put at variance previously equivalent classification units at higher categories between Soil Taxonomy and IUSS Working Group WRB systems. Thus, the new definitions have made all those orders of Soil Taxonomy that depend on the identification of argillic/kandic horizon non-equivalent with those of IUSS Working Group WRB units, which depend on the presence of argic B-horizon (Okusami *et al*., 1997; IUSS-WRB, 2022).

Classification of the soils: Local Classification

The soils were correlated based on reports of survey work done by Smyth and Montgomery (1962). The parent materials, topographic positions, soil colour and presence or absence of mottles, soil texture, and general profile morphology were the main criteria used in correlating the soils. Pedons OKP-01 and -02 were confined to the hill top and formed over hard ironstone material. They are reddish-brown to dark red in colour and clay in texture. They are shallow and have frequent ironstone concretions occurring throughout the pedons. They are therefore classified as the Ibule series. Pedon OKP-03 is confined to the sloping section (shoulder) of the toposequence (Fig. 2). The soil is dark red to red in colour and clay in texture. It is characterized by a variable content of ironstone and fragments of ironpan. It is classified as the Ijare series. Pedon OKP-04 occurred at a steeply sloping site of the toposequence. The soil is red in colour and clay in texture close to the soil surface. Pieces of weathered/rotten rocks were seen within the profile. It is therefore classified as the Araromi series. Pedon OKP-05 occupied the middle slope of the toposequence. The soil is dark red to red in colour and clay in texture close to the soil surface. It has a well-developed gravelly layer which is composed almost entirely of quartz at 140cm depth. It is therefore classified as Owena series gravelly variation. Pedon OKP-06 occurred at the break of slope of the middle slope. The pedon is shallow, consisting of ironstone materials at 40cm depth, which is of the form of an impenetrable sheet. This pedon could not be classified as the Ibule series because of its position on the landscape (lower-middle slope). It therefore classifies as a Gambari series. Pedons OKP-07, -08, and -09 occupy the gentle to sloping section of the lower slope. They were clay in texture close to the soil surface, they were dark reddish brown to red in colour, and almost of uniform morphology. They have well-developed gravelly layers almost entirely made of concretions. They are therefore classified as the Owena series. Pedon OKP-10 occupied the valley bottom of the toposequence, and the soils were poorly drained. The texture is sandy loam to clay loam with a reddish yellow colour and saturated at 90cm from the soil surface. The pedon therefore classifies as the Jago series due to the texture and yellowish colour with gley mottles.

CONCLUSION

The morphology, physical, chemical, and mineralogical characteristics of some soils in landforms of ultrabasic rock origin in the Ife-Ilesha area of Southwestern Nigeria were studied to generate baseline data and understand their genesis. The soils were well-drained as shown by their reddish-brown colour in the surface A-horizon and redder hues in the sub-soil B- and C-horizons (2.5YR - 7.5R). The topsoil and subsoil textures of the pedons were quite variable, and these reflect the influence of parent material and slope/topography. Most of the chemical properties determined had very low values. It was concluded that the soils were predominantly Ultisols and Alfisols according to Soil Taxonomy, and nearly all pedons have ustic soil moisture regime except the OKP-10 with an aquic moisture regime. However, according to IUSS/WRB, the soils were correlated as Leptosols, Ferralsols, and Acrisols, while locally, the soils were classified under Itagumodi Association and they belonged to Owena series, Ibule series, Ijare series, Araromi series, Gambari series, and Jago series, respectively.

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