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Influence of Topography on Selected Pedological Properties of Soils Formed on Basement Complex in the Upland Areas of Rainforest Southwest Nigeria

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HIGHLIGHTS

- With the current reports of increased food insecurity in sub-Saharan Africa associated with improper and unconventional land use/ management practices among farmers that has adversely hindered food production, the study examined, classified and recommend various land management strategies that will improve soil health and enhance agricultural production in the studied area and in the areas with similar soil catena.

Abstract

The study investigates the impacts of topography on the formation and distribution of soils within the rainforest region of southwestern Nigeria, establishes their taxonomic classes (USDA & FAO/UNESCO), and recommends appropriate management practices that promote conservation. Five profile pits established and described at different physiographic positions were considered for this study. Soil samples were collected for physical, chemical, and mineralogical analysis, and rock samples were also collected for thin sectioning under a petrographic microscope. Fine sand fractions were separated into heavy and light minerals with bromoform. Correlation coefficients and simple regression analysis between the selected soil properties were calculated. The results revealed that the soils are derived from fined-grained biotite gneisses and schist; the clay content increased with increasing depth while the sand content decreased. Organic matter and available P content were relatively low, with values ranging from (0.2 – 1.35 %) and (1.29 – 5.40 ppm) respectively. The pH, exchangeable cations, and exchangeable acidity values fluctuate across the pedons. The crystalline oxides of Fe and Al were low, with no definite distribution pattern, indicating a highly weathered soil. The soils are predominantly ultisols and are placed in the ustults suborder (USDA), which was equated as Luvisols (FAO-UNESCO). The correlation between slope position and chemical properties showed that no singular property consistently showed the same significance level on the entire slope. For effective management of the soils, conservation management practices of economic importance, such as the usage of vegetal cover, should be adopted to assist in preventing rapid soil degradation across the landscape.

Keywords: Basement complex; taxonomic; mineralogy; bromoform; biotite gneisses

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1. Introduction

The weathering of rocks or other materials that have been deposited by water, gravity, or wind results in the formation of soil which qualities are determined by the interactions of climate and organisms acting on parent materials as conditioned by relief/ topography over time (Jenny 1941; Ukwuoma-Okolo 2021). One of the five primary soil-forming factors is topography which was described by Jenny (1941); Ben Mahmoud and Zurqani (2021) as an independent soil-forming factor which its contribution to soil formation can be considered on its own. Incidentally, most topographic information considers runoff and erosion to slope, which deals with soil removal and destruction. However, topography as a factor of soil formation on the other hand, influences radiation i.e., the amount of heat that penetrates the soil through sunlight and other objects that emits heat and the amount of water that penetrates the soil, resulting in leaching and the redistribution of elements and soil components (Hook and Burke 2000). It has a strong influence in determining the differences between soil types and their nutritional condition. Brandy and Weil (1999) define soil catena or topo sequence as soils developed as a result of topography in a specific area. They appear as a series of soils with close relationships to landscape positions that may differ in morphological, chemical, and fertility condition (Begna 2020). Topography is therefore essential in biogeochemical processes that influences important environmental, economic, and social activities (Griffiths et al. 2009; Bingqin et al. 2019).

Several studies reported changes in soil properties as a result of topographic local effects, which accounted for between 26 and 64% of overall variation in soil parameters and moisture Bockheim (2005), Cox et al. (2002), and Wilson et al. (2004). Moorman (1981) reported a strong relationship between topographic positions and soil genesis on basement complex in Southern Nigeria. However, topographic variability in crop production according to Dinaburga et al. (2010) is thus, a synthesis of soil attributes and factors influencing agricultural productivity via its effects on soil physicochemical characteristics, biomass production, incoming solar radiation, and precipitation, all of which have an impact on crop yield in the long run and hence confirms the facts that variation in crop production is a combined reflection of soil attributes and factors influencing agricultural productivity (Dinaburga *et* al. 2010). A soil therefore forms an integral part of the land surface and any variations in geomorphology which may influence hydrologic processes will affect the pedogenic processes through the effect of differential distribution of water, sediments and dissolved materials (Brunner *et* al. 2004 and Van der Meij et al. 2018).

The primary goal of agriculture is to produce enough food to feed the world's population, as well as enough raw materials to meet the demands of our industries and earn foreign exchange for the country through agricultural exports. In terms of food production, the soil thus represents everyone's hope. Given these facts, it becomes clear that the soil requires special care in terms of management in order to fulfil agricultural goals and ensure sustainability of the resources. Proper soil management, which entails managing a piece of land in such a way that it can be expected to yield at optimal level over time, is one of the pivots around which modern agriculture revolves.

Varied landforms may occur in a particular location with varied soils, and their capability/suitability potential for crop production may also vary, necessitating special land use management. This study is designed to aid in the provision of accurate information on the influence of topography in the study area's land quality. This will help soil users most especially farmers and the government to improve agricultural output in the study area and other areas with similar composition.

2. Materials and Methods

2.1. The Study Area

The studied area lies between latitudes 7° 32'N and 7° 33'N and longitudes 4° 39'E and 4° 40'E within southwestern Nigeria's schist belt (Rahaman 1988). The site is about 2.5 km away from Kajola village, a suburb of the Obafemi Awolowo University (O.A.U.) Teaching and Research Farm (T&R-F), located within the schist belt of southwestern Nigeria (Rahaman, 1988). The location is in the tropical rainforest agroecological zone, which has a hot, humid tropical climate with distinct dry and rainy seasons. The average annual rainfall is about 1527 mm, and the average monthly air temperature is around 31 °C, which is moderately high throughout the year, with a slight variation between the monthly mean minimum and maximum temperatures. The region also records the following average monthly data: humidity 73.8 %, and sunshine 6.6 hours. The wind speed was 114.6 km d^{-1} while potential evaporation was 4.36 mm d^{-1} (Meteorological data bank, T&R-F, O.A.U., Ile-Ife 2020). The site is an extensive farmland with many human activities, primarily farming and occasional overgrazing by animals, with some parts currently under fallow. According to Smyth and Montgomery (1962) and Rahaman (1988), the area is underlain by the Precambrian rocks which are part of what is collectively referred to as the basement complex of southwestern Nigeria. Previous research (Boesse and Ocan 1988) identified the underlying rock in the study region as fine-grained biotite gneisses and schist, which are part of the Precambrian basement complex rocks that are widespread in southwestern Nigeria.

2.2. Field Work (Sampling Procedure and Laboratory Analysis)

Soil sampling units was selected based on the physiographic positions of soils on the landscape. A slightly undulating toposequence that has relatively flat top was selected for the study with soil profile pits established at each physiographic position (Crest, upper slope, sedentary, hill-wash and valley bottom) as observed along the toposequence. Five soil profile pits were established along the toposequence, with a total of twenty four (24) soil samples collected from the identified genetic horizons. The repeated subsampling method was used to ensure that the samples taken from a given horizon for laboratory analyses were representative, starting with the lowest genetic horizon to the uppermost to avoid cross contamination from the horizons above (Smeck and Wilding 1980). Core samples were taken from each horizon for bulk density determination and rock samples were collected for thin section preparation and primary mineral identification.

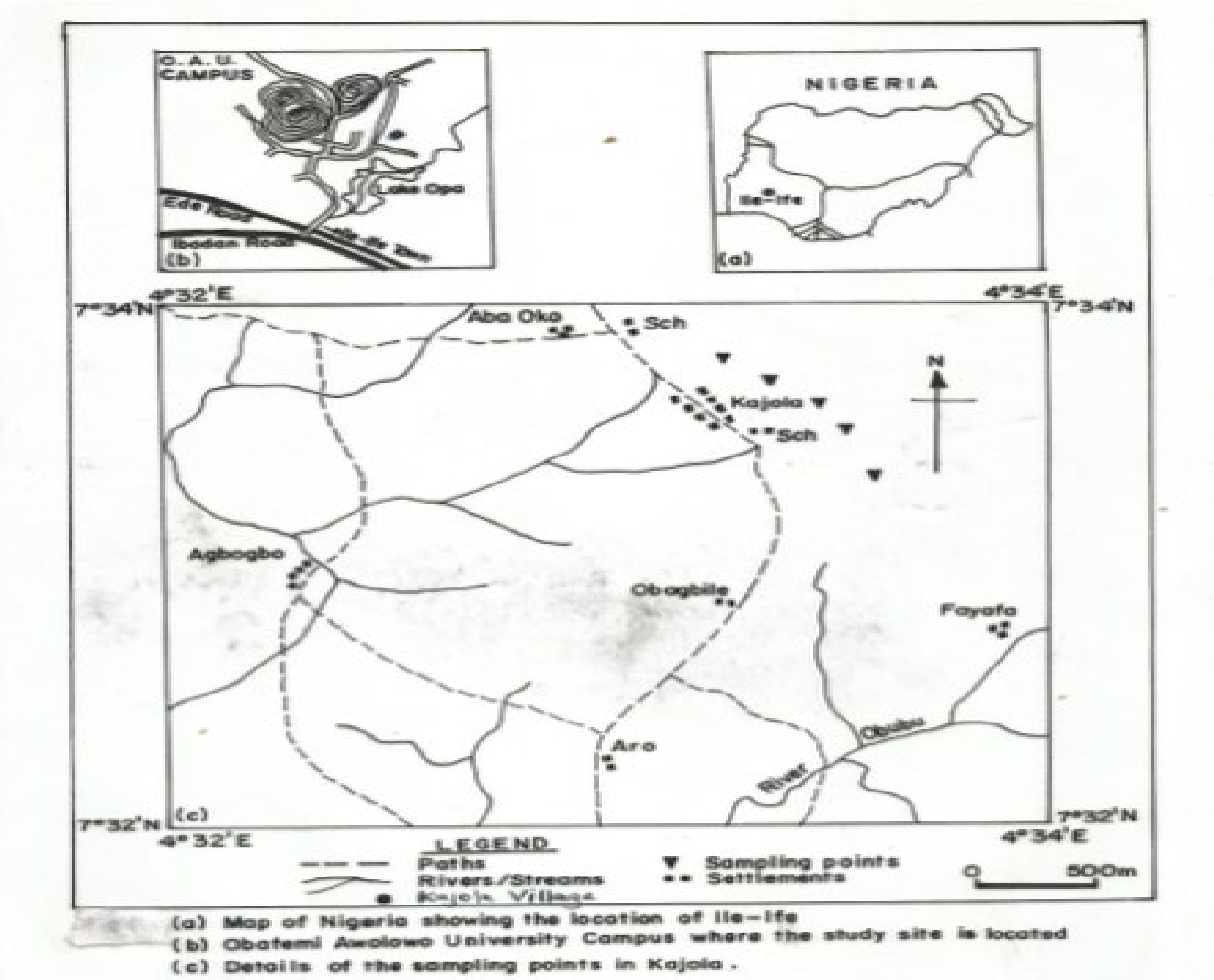

Figure 2. (**a**) Map of Nigeria showing the location of Ile Ife; (**b**) Obafemi Awolowo University Campus where the study site was located; (**c**) Details of the sampling site at Kajola.

The soil samples collected were air-dried, gently crushed with mortar and pestle and sieved with a 2 mm sieve to separate gravel content from the soil component. The less than 2 mm fraction was retained for physical, chemical and mineralogical analyses other than the bulk density determination.

2.3. Physical Parameters Assessed

The bulk density, gravel content, and particle-size distribution of the soil samples were examined. The percentage of soil retained by the 2 mm sieve, reported as a percentage of the total weight of the soil, was used to calculate the gravel content. The bulk density was determined by the core method as reported by (Blake and Hartge 1986), while the particle size distribution was evaluated by the modified Bouyoucos hydrometer method as reported by (Gee and Or,2002) using 5% w/v sodium hexametaphosphate (calgon) as the dispersing agent. Particle fractionation into very coarse sand (VCS), coarse sand (CS), medium sand (MS), fine sand (FS) and very fine sand (VFS) was carried out with the use of a set of sieves (1.0, 0.5, 0.25, 0.100 and 0.05 mm) representing 1000, 500, 250, 100 and 50 μm respectively arranged in decreasing order of sieve sizes as listed on the United State Department of Agriculture (USDA) particle size scale (Buol et al. 1997). Each of the sand fractions was weighed and expressed as a percentage of the total sand.

2.4. Chemical Parameters Assessed

The soil pH was determined in 1.0 M KCl (1:1 soil: solution ratio) with a glass electrode pH meter (Kent model 720) after equilibration for 30 minutes (Thomas, 1996). Exchangeable cations (Ca, Mg, K and Na) were extracted with 1.0 M ammonium acetate (NH_40AC) solution at pH 7.0 (Thomas and Throp 1985). Calcium (Ca^{2+}), sodium (Na^+), and potassium (K^+) ions in the extract were determined with the use of flame photometer (Gallenkamp Model FH 500), while magnesium (Mg^{2+}) ion in the extract was determined by titration. The exchangeable acidity was determined by extraction with 1.0 M KCl solution and titrated with NaOH and HCl solutions to measure total acidity (Al^{3+} and H^+) concentrations, respectively as reported by (Bertsch and Bloom, 1996). The available phosphorous was determined by Bray No. 1 method (Kuo, 1996). The organic carbon was determined by the Walkley Black method (Allison, 1965) as reported by (Darrell *et al.,* 1994). The effective cation exchange capacity (ECEC) was calculated as the summation of exchangeable cations and exchangeable Al (Sumner and Miller 1996). The free iron (Fe), aluminum (Al) and manganese (Mn) were determined by the dithionite citrate bicarbonate (DCB) method of Mehra and Jackson (1960). The ions extracted were determined with the use of atomic absorption spectrophotometer (AAS). The total elemental analysis was carried out by digesting the powdered soil samples with aqua regia and hydrofluoric acid under a fume chamber (Bernas 1968; Jackson 1958). Elements in the digest were determined by the atomic absorption spectrometer (AAS).

2.5. Mineralogical Analyses

2.5.1. Thin sectioning of the rock sample

A rectangular block small size of 3mm in diameter was cut from the rock sample collected from the field with a diamond saw, one side of this block was ground and polished to produce a flat, smooth surface free of scratches or imperfections, the block was carefully cleaned and cemented to a clean microscope slide with Canada balsam and a cover glass was cemented in place to produce the thin section (Cady et al. 1986). At this thickness (3mm diameter), it has been established that rocks behave like a transparent medium allowing the passage of light (Kerr 1977). Hence, the study of optical properties of mineral components of the rock was enhanced. This thin section of the rock samples was produced and mounted on a glass slide for mineralogical identification under a petrographic microscope as described by (Simpson 1986). Optical observations were made in both plane polarized light and cross nicol (Adetayo et al. 2013).

2.5.2. Sand mineralogy

The fine sand fraction was separated into light and heavy mineral fractions using bromoform (s.g. = 2.89). The light fraction in the sample stayed afloat while the heavy mineral fractions went down the separating funnel under the influence of gravity. The light and heavy mineral fractions were separated and the mineral constituents in each separate was examined with the use of a drop of Canada balsam (R.I. = 1.54) placed on a glass slide and enough sub-sample was taken with a micro spatula to ensure uniform coverage of an area about 22-mm square on a glass slide. This was then covered with a cover slip. Identification of mineral grains was made according to their optical properties under plain polarized light and in crossed polar. Mineral properties such as colour, relief, pleichroism, birefrigence, interference colour and extinction were used for the identification of the minerals. The relative amount of individual mineral present was determined by counting with the use of cross wire method (Wilding and Drees 1983).

Correlation coefficients and simple regression analysis between the selected soil properties were calculated to determine the relationships between the soil parameters assessed and the influence of topography on its distribution across the slope. All statistical analyses were carried out using SAS 9.1 version (2002-2004) software programme.

3. Results

3.1. Physical Properties of the Soils

Table 1 shows the particle size distribution and bulk density data of the soils along the toposequence under study. The gravel content varied from 8 to 68%, with pedons from the summit, upper, and middle slopes having relatively high values of 22 to 68%, while the lower slope and valley bottom pedons have lower values, 8 to 32%, probably owing to sorting. The gravel content generally increased from the A-horizon to the B-horizon and then decreased significantly from the B to the C-horizon, except at the lithologic break. This increase in gravel content from A to B horizon is a characteristic of the upland pedons (Fasina et al. 2005), which is as a result of several pedogenic and geomorphic processes, among which are eluviation, selective particle removal, the nature of the parent material, erosional processes, and landscape positioning (McAuliffe et al. 2018). These factors collectively shape the vertical distribution of soil particles, leading to the observed pattern of increasing gravel content with depth in the study area. However, in pedons at the lower slope position, there were no particular patterns of gravel distribution. This gravel accumulation was a characteristic property of soils formed in the upland portion of the landscapes derived from the granitic gneiss metamorphic rock complex of central western Nigeria (Smyth and Montgomery 1962; Okusami and Oyediran 1985). These have not obstruct root proliferation since roots are found beyond the gravel horizons.

The soil texture varied from sandy loam to sandy clay loam for surface horizons except in Pedon 05 which has clay texture. The B and C-horizons have clay loam texture except in Pedons 03 and 04 that were more clayey in the B and BC horizons. The sand content ranged from 29 to 67% and decreased with increasing depth except at certain depths where the BC-horizon contained more of sand, as encountered in Pedons 03 and 04. The silt content ranged from 11 to 25%, although the value fluctuated within all the pedons with increasing depth. The soils have low to moderate silt content at the surface irrespective of their location on the topography. A characteristic that distinguished the soils of granitic-gneiss rock complex origin from other sandy soils of southwestern Nigeria (Fasina 2001 and 2002; Fasina et al. 2007). The clay values ranged from 18 to 59%. The clay content increased generally with increasing depth to a maximum (probably due to illuviation/eluviation interplay or possibly clay migration) and then decreased in the BC horizons. Similar trend was observed by Ojanuga (1978) in soils of Ife and Ondo areas of southwestern Nigeria. Generally, soils in the middle and lower slope positions have higher clay content than those that occupy the valley bottom position. For Pedons 02, 03, and 04, the particle size distribution of the sub-soil horizon of the soils suggests that the B-horizons were influenced more by eluviation – illuviation processes. The high clay content in the deeper horizons of some of the soils occasioned by clay dispersion, translocation, and accumulation, coupled with some morphological properties such as the colour, texture, consistence and plasticity in the profile description (Fasina et al. 2005) formed the basis for the recognition of argillic horizons in some of the soils. The lower clay content in the surface horizons could be due to the sorting of soil materials by biological and/or agricultural activities, clay migration or surface erosion by run-off or a combination of these (Ojanuga 1978; Ogban et al. 1999).

The bulk density values obtained ranged from 0.74 g cm^{-3} in the Ap horizons to 1.73 g cm^{-3} in the Bt horizons. The higher values in surface soils (e.g. pedons 02 and 03) are due to compaction from grazing animals and occasional movement of machines such as tractors (Kumar et al. 2018). Usually, soils with low bulk density are known to be associated with high total porosity, while root penetration becomes a problem when bulk density exceeds 1.6 g cm^{-3} (Payne 1988). Generally, the bulk density value increased with increasing

Table 1. Physical properties of the soils on the toposequence that was studied.

Horizon	Depth (cm)	>2000mm (% of the whole soil)	Very coarse sand (1000-2000μm)	Coarse sand (500-1000μm)	Medium Sand (250-500μm)	Fine Sand (50-100μm)	Very fine sand (0.05-0.50 μm)	Total Sand	Silt	Clay	Bulk density g/cm^3	Textural class
		%										
Profile 01 Egbeda series												
Ap	0-18	35	10	13	10	9	7	49	21	30	1.06	Sandy loam
AB	18-24	61	10	12	10	8	7	47	25	28	1.54	Sandy clay loam
B	24-51	68	7	8	7	5	4	31	11	58	1.62	Sandy clay
BC	51-70	50	7	7	6	5	4	29	13	58	1.59	Sandy clay
Profile 02 Olorunda series												
Ap	0-18	41	10	13	12	10	10	55	17	28	1.01	Sandy clay loam
AB	18-28	68	10	12	11	10	8	51	11	38	1.57	Sandy clay loam
B21	28-72	64	10	8	7	7	6	39	13	48	1.63	sandy clay
B22	72-132	56	11	4	7	7	5	33	13	54	1.68	sandy clay
BC1	132-185	33	9	7	7	7	6	35	17	48	1.73	Sandy clay
BC2	185-210	22	9	9	9	8	8	43	15	42	1.48	Sandy clay
Profile 03 Makun series												
Ap	0-18	43	12	13	11	11	9	55	17	28	1.34	Sandy clay loam
BA	18-33	42	11	12	10	10	8	51	15	34	1.42	Clay loam
B21	33-65	39	12	8	7	4	3	34	13	53	1.45	Sandy clay
B22	65-120	47	12	6	6	4	2	30	11	59	1.65	Sandy clay
BC	120-200	23	11	8	10	5	5	39	15	46	1.40	Sandy clay
Profile 04 Oba series												
Ap	0-20	8	11	15	13	11	8	57	15	28	1.54	Sandy clay loam
BA	20-40	32	10	12	7	7	2	39	13	48	1.48	Sandy clay loam
B1	40-71	25	8	11	5	5	3	31	11	58	1.30	Sandy Clay
2BtC1	71-115	27	8	11	4	5	3	31	13	56	1.71	Sandy Clay
2BC2	115-170	15	10	13	7	7	2	39	13	48	1.40	Sandy clay
Profile 05 Jago series												
Ap	0-18	26	16	15	14	13	10	67	15	18	0.74	Sandy clay
AB	18-40	19	14	13	13	13	12	65	13	22	1.21	Sandy clay
B	40-60	18	14	17	15	12	10	67	11	22	1.31	Sandy clay
Btg	60-75	24	13	14	13	13	12	65	15	20	1.13	Sandy clay

depth to a maximum and then declined with increasing soil depth. The exception to this trend was observed in Pedon 04, where their values fluctuated. However, the higher values at depth have not hindered plant root penetration, as evidenced by the deep rooting of plants into greater depth in Pedon 02.

3.2. Chemical Properties of the Soils

Table 2 shows the chemical properties of the pedons studied. The soils fall within the neutral to very strongly acid class (Soil Survey Staff, 2003), with pH (H_2O) values ranging from 5.6 to 7.0. The pH decreased with increasing soil depth except in Pedon 03. The pH (1M KCl) ranged from 4.4 to 5.7. The value also decreased as the soil depth increased, except in Pedon 03, where no definite pattern was observed. Generally, the surface horizons of the pedons were medium to slightly acid (pH 5.2 - 5.7), while B and C-horizon were strong to very strong acid with pH values ranging from 4.4 - 5.7. The acid nature of the soil can be ascribed to high rate of leaching of bases which is prevalent in the humid tropics, and the acidic nature of the parent rock (granite-gneiss) (Ojetade et al. 2022). The higher pH values observed at the soil surface horizons might be due to liming effect of bush burning and bio cycling of nutrients (Fasina et al. 2005). The pH in 1M KCl was lower than the pH in water (H_20), thus the difference in soil pH values between the pH in KCl and H_20 (as expressed by ΔpH = pH (KCl) – pH (H_20)) were all negative ranging from -0.9 to -1.5. This suggests the dominance of silicate clay minerals over oxides (Van Raij and Michael 1972).

Generally, there was higher accumulation of bases in the surface horizons 6.59 - 12.57 cmol(+)kg^{-1} of the soil, and the total exchangeable bases decreased with soil depth except in some cases owing to nutrient biocycling (Ajiboye and Ogunwale 2010), and could also be due to differential weathering that had taken place or as a result of plant uptake and leaching losses. The exchangeable sites of the soils studied were dominated by exchangeable calcium and magnesium a common occurrence in most tropical soils. Exchangeable sodium (Na^+) and potassium (K^+) are low with values ranging from 0.08 to 0.26 cmol(+)kg^{-1} and 0.15 to 0.30 cmol(+)kg^{-1} soil respectively. These low values indicated that the soils under investigation developed from materials that are either low in K^+ and Na^+ content or have been exhausted by plant uptake or leaching due to their mobility within the soil. The higher values obtained at the surface horizon of the pedons could be attributed to higher organic matter content (Ano, 1991). However, the values fluctuated irregularly down the soil profile.

Exchangeable acidity values (Al^{3+} and H^+) ranged from 0.3 to 1.0 cmol (+) kg^{-1} soil. All the pedons examined showed little variation in the exchangeable acidity and the values were almost uniform with soil depth. Exchangeable Al^{3+} accounted for a greater percentage of the total acidity. Effective cations exchange capacity (ECEC) was generally low with values ranging from 3.73 to 14.26 cmol (+) kg^{-1} soil. There were higher values in the surface horizons of all the soils examined than in the sub-soil, probably due to the influence of organic carbon on the exchange sites of the soils. However, in those profiles where higher values were noticed in the sub-soil as in Pedons 02 (B22) and 03 (BC) with more of clay content, this could be due to the process of pedoturbation either by fauna or flora. Kadeba and Benjaminsen (1976) observed that low ECEC values were consistent with low organic carbon content of soils, especially in the B-horizons, and probably with the kaolinitic nature of the soils. The ECEC values decreased with increasing soil depth in all the pedons examined.

The organic matter content of the surface horizons of the pedons ranged from 1.54 to 2.55% and decreased with increasing soil depth. The sub-soil horizons were generally lower in organic carbon than the surface horizons of all the pedons examined, probably due to the fact that the surface horizons are the points where decomposition and humification of organic materials take place. The organic matter content of the entire soils studied was generally low, mostly less than 2%, except in the surface horizon of Pedon 01. The low organic matter obtained may be partly due to the effect of high temperature and relative humidity, which favor rapid mineralization of organic matter (Fasina et al. 2005), the degradative effect of cultivation, and other land use and management activities. In all the pedons examined, the exchangeable bases, ECEC, percent base saturation and organic matter contents were slightly higher in the surface horizons than in the sub-soils in general. Probable reason is that the surface horizons, although the most exposed to leaching and runoff, are indeed continuously recharged by phytocycling (Amusan and Ashaye 1991).

Available phosphorous (P) contents of the soils varied from 2.6 to 11.2 ppm in all the horizons in the profiles with the highest values at the surface horizons, The relatively high concentration of the available P and organic carbon in the surface horizons may imply significant organic or biocycled P in the soils and also an indication that organic matter contributes significantly to the available phosphorus in these soils. These values i.e. available phosphorous (2.6 to 11.2 ppm) and organic matter content (1.54 to 2.55%) were rated low to medium depending on the soil horizons (Esu et al. 1987). The available P values are considered low at some horizons as they were below or only slightly above the 10 ppm critical limit recommended for most commonly cultivated crops in the area (Uponi and Adeoye 2000; Aduayi et al. 2002; Obigbesan 2009). The values generally decreased with increasing depth, though the pattern is irregular in all the pedons that were examined. The low value of available P might be due to the fixation of phosphorus by iron and aluminum sesquioxides under well drained and acidic conditions of the soils (Onyekwere et al. 2001; Uzoho and Oti 2004). Further, Jubrin et al. (2000) noted that deficiency of P may occur in soils due to the strong adsorption of this nutrient by the soil colloids. Pedons 04 and 05 exhibit an unusually high concentration of available P in the sub-surface horizon, 8.4 and 8.9 ppm, respectively. This could probably be due to the effect of farming activities, especially decomposed cocoa pod residue, because the pedons are located within a cocoa farm or deposition of P in the valley bottom soils of the toposequence through erosion.

Profile distribution of crystalline Fe and Al oxides values and weathering ratios shows the percentage of dithionite extractable Fe and Al in all the soil profiles examined. The value of DCB- Fe (Fe_d) ranged from 1.46 to 3.44% and did not follow any pattern as the soil depth increased. In all the soil profiles examined, the highest Fe_d value occurred in the B-horizon except in Profiles 3 and 5, where the highest value of Fe_d was observed at the lowest horizon. The quantity of Al_d, that is Al substitution in Fe oxides and organic matter-bound Al (Parfitt and Childs 1988) in the soil was lower than Fe_d and ranged from 0.09 to 0.70%. Its distribution pattern was like that of the Fe_d distribution, which does not follow any pattern as the soil depth increased.

The Fe_d/Clay ratios were calculated to determine whether the Fe_d was associated with the clay fraction (Blume and Schwertmann 1969; Rebertus and Buol 1985). This ratio ranged from 0.03 to 0.11 and did not follow any pattern as the soil depth increased. The same pattern was observed in the Al_d/clay ratio with values ranging from 0.003 to 0.022. There is no obvious regular pattern in the distribution of the free Fe in the profiles.

Generally, it could not be established that all the B-horizons have higher Fe_d. This may be since iron movement is partially independent of clay movement. A similar observation was reported by Ogunsola et al. (1989) in soils overlying limestone areas in Nigeria. The means of the Fe_d/Clay ratios were low and were less than unity at the top sequence under study, indicating that basement complex topo sequence could be highly weathered (Enya et al. 2011). There is high negative significant correlation between Fe_d/clay and clay content in the soils studied (r= -0.82) (Table 9). At the same time, it was not significant when Fe_d/clay was correlated with silt (r=0.31), indicating the probable nonexistence of co-migration of clay and silt with depth, respectively (Enya et al. 2011).

3.3. Total Elemental Analysis of the Soil Samples and Saprolites

The total element analytical results are presented in Table 3. The concentration of Fe and Cu ranged from 100.5 to 523.01 ppm and 307 to 528 ppm, respectively. The highest values were observed at the surface of all the pedons examined. The values, especially Fe, do not follow a particular trend except in Profile 02, where it seems to reduce with increasing soil depth. In Profile 01, the values were reduced with increasing depth except at the last horizon, where the value suddenly increased, which may be a result of illuviation, parent material composition, redox processes, lateralization, capillary rise, or residual accumulation of Fe minerals. The dominant process depends on factors like climate, drainage, and soil formation history. In other Profiles 03, 04, and 05, the values were erratic. This could be due to the mineral composition of the underlying rock and/ or the transported materials, uptake of essential nutrients by plants, leaching of exchangeable cations through heavy rainfall or by erosion, or a combination of these factors. The higher values observed could be responsible for the occlusion of some of the plant's nutrients, like phosphorus, thereby making it unavailable for plant uptake, and could also be responsible for the lower exchangeable cations recorded from the soil under examination. However, this can be taken care of with an adequate soil management system. Apart from these two elements, the soil is presumed to have an acceptable level of ZnO (0.11- 3.00 ppm), CaO (2.00- 19.00 ppm), MgO (0.73- 14.06 ppm) and MnO_2 (3.90- 14.66 ppm) for plant growth. However, human activities also influence the composition of the minerals such as copper and calcium in the soil surface as some of the profile pits are located within cocoa plantations, and the fungicides that are commonly used in disease control are rich in Cu and Ca, hence there higher content compared with the rest.

Table 2. Chemical properties of the soil studied.

Horizon	Depth (cm)	pH (H_20)	pH KCl	ΔpH	Exchangeable Bases ($CmolKg^-$)				Exchangeable Acidity ($CmolKg^-$)		Sum of Bases	ECEC ($CmolKg^-$)	Base sat. (%)	Al. Sat. (%)	O.M. (%)	Avail. P. (ppm)	Crystalline oxide (%)		Fe_d/Clay	Al_d/Clay
					Ca^{2+}	Mg^{2+}	Na^+	K^+	Al^{3+}	H^+							$Fe_{(d)}$	$Al_{(d)}$		
Profile 01 Egbeda series																				
Ap	0-18	6.9	6.0	-0.9	7.2	4.86	0.21	0.30	0.4	0.2	12.57	12.97	97	3	2.55	11.2	2.08	0.58	0.07	0.019
AB	18-24	6.8	5.4	-1.4	6.6	4.86	0.26	0.26	0.2	0.3	11.98	12.18	98	2	1.61	7.4	2.14	0.61	0.08	0.022
B	24-51	6.5	5.0	-1.5	6.7	4.10	0.25	0.30	0.3	0.3	11.30	11.60	97	3	1.21	3.4	1.95	0.70	0.03	0.012
BC	51-70	6.0	4.6	-1.4	5.8	3.20	0.20	0.24	0.7	0.3	9.44	10.10	93	7	1.07	3.2	1.70	0.68	0.03	0.012
Profile 02 Olorunda series																				
Ap	0-18	6.5	5.3	-1.2	5.3	4.86	0.19	0.24	0.4	0.2	10.58	10.98	96	4	1.68	6.3	1.92	0.58	0.07	0.021
AB	18-28	6.4	5.0	-1.4	4.9	4.05	0.19	0.22	0.4	0.3	9.35	9.75	96	4	1.14	8.2	2.10	0.51	0.06	0.013
B21	28-72	6.2	5.0	-1.2	5.5	1.62	0.21	0.28	0.1	0.4	7.69	7.79	99	1	0.87	4.1	1.46	0.44	0.03	0.009
B22	72-132	6.1	5.0	-1.1	5.3	5.67	0.19	0.26	0.4	0.3	11.42	11.82	97	3	0.67	3.3	3.44	0.60	0.07	0.011
BC1	132-185	5.9	4.9	-1.0	5.3	4.05	0.20	0.26	0.1	0.3	9.81	9.91	99	1	0.60	3.0	2.40	0.51	0.05	0.011
BC2	185-210	5.6	4.8	-0.8	5.0	4.86	0.17	0.26	0.2	0.2	10.29	10.49	98	2	0.07	2.6	1.86	0.40	0.04	0.011
Profile 03 Makun series																				
Ap	0-18	6.8	5.6	-1.2	4.0	7.29	0.14	0.22	0.4	0.3	11.64	12.04	97	3	1.54	8.4	2.08	0.32	0.07	0.011
BA	18-33	6.7	5.5	-1.2	4.9	4.05	0.19	0.24	0.3	0.3	9.38	9.68	97	3	0.94	10.5	2.85	0.63	0.08	0.019
B21	33-65	6.6	5.5	-1.1	5.3	1.62	0.21	0.30	0.2	0.2	7.44	7.64	97	3	0.94	7.0	2.66	0.37	0.05	0.007
B22	65-120	6.4	5.5	-0.9	4.1	6.48	0.14	0.20	0.2	0.3	10.91	11.11	98	2	0.87	5.8	3.12	0.28	0.05	0.005
BC	120-200	6.7	5.7	-1.0	3.1	10.53	0.11	0.22	0.3	0.2	13.96	14.26	95	2	0.40	3.2	3.20	0.24	0.07	0.005
Profile 04 Oba series																				
Ap	0-20	6.4	5.2	-1.2	4.7	4.05	0.23	0.24	0.2	9.22	0.9	9.92	93	7	1.74	7.7	3.07	0.09	0.11	0.003
BA	20-40	6.2	4.8	-1.4	3.2	5.67	0.12	0.22	0.2	9.21	0.3	9.31	99	1	0.93	8.4	3.20	0.19	0.07	0.004
BC1	40-71	6.0	4.8	-1.2	2.2	5.67	0.08	0.24	0.2	8.19	0.3	8.29	99	1	0.67	5.8	3.07	0.26	0.05	0.004
2BtC1	71-115	5.8	4.6	-1.2	2.1	4.05	0.10	0.24	0.3	6.49	0.4	6.59	99	2	0.60	6.2	2.02	0.37	0.04	0.007
2BC2	115-170	5.6	4.4	-1.2	2.8	3.24	0.16	0.26	0.2	6.46	0.3	6.56	99	2	0.40	4.5	2.28	0.35	0.05	0.007
Profile 05 Jago series																				
Ap	0-18	7.0	6.7	-1.3	1.5	4.86	0.08	0.15	0.2	6.59	0.6	6.99	94	6	1.74	6.9	1.84	0.09	0.10	0.005
AB	18-40	6.6	5.2	-1.4	1.9	4.86	0.08	0.24	0.3	7.08	0.6	7.38	96	4	0.74	8.9	1.76	0.22	0.08	0.010
B	40-60	6.5	5.0	-1.5	0.6	2.43	0.08	0.22	0.2	3.33	0.6	3.73	89	11	0.40	5.4	2.01	0.24	0.09	0.010
Btg	60-75	6.3	5.0	-1.3	1.5	2.43	0.08	0.21	0.2	4.22	0.6	4.62	91	9	0.13	5.2	2.02	0.09	0.10	0.005

Table 3. Total elemental analysis of the soils studied.

Horizon	Depth (cm)	(Fe_2O_3)	(CaO)	(MgO)	(MnO_2)	(ZnO)	(CuO)
		ppm					
Profile 01 Egbeda series							
Ap	0-8	396.12	19.00	14.06	12.60	1.80	393.05
AB	8-24	296.48	17.00	12.32	8.70	3.00	436.06
B	24-51	292.02	3.00	5.34	9.66	1.20	517.27
BC	51-70	342.02	14.00	5.68	10.21	3.00	500.61
R	Above 70	396.95	10.00	1.19	13.11	ND	474.38
Profile 02 Olorunda series							
Ap	0-18	523.01	10.00	4.71	14.66	0.60	399.82
AB	18-28	506.81	14.00	4.41	16.49	1.70	528.1
B21	28-72	298.59	8.00	2.65	9.68	1.30	456.88
B22	72-132	274.69	6.00	2.44	7.64	0.40	448.77
BC1	132-185	179.70	1.00	1.36	6.20	0.30	457.3
BC2	185-210	100.50	1.00	2.50	3.90	1.20	449.8
Profile 03 Makun series							
Ap	0-20	322.64	10.00	3.00	12.11	2.00	333.15
BA	20-40	329.81	8.00	2.22	11.90	3.00	432.73
B21	40-71	288.22	6.00	2.32	9.21	1.10	422.73
B22	71-115	216.43	4.00	2.40	7.08	1.50	516.86
BC	115-170	124.00	2.00	1.21	5.33	ND	452.3
Profile 04 Oba series							
Ap	0-20	338.26	19.00	5.78	11.89	0.50	383.58
BA	20-40	332.22	11.00	4.21	10.24	0.22	398.34
B1	40-71	298.72	11.00	3.00	9.24	0.32	444.24
2BtC1	71-115	226.12	5.00	1.22	10.1	0.11	498.22
2BC2	115-170	308.92	1.00	2.08	10.98	ND	504.78
Profile 05 Jago series							
Ap	0-18	257.28	18.00	5.45	9.56	ND	332.36
AB	18-40	212.44	18.00	5.55	6.22	ND	311.22
B	40-60	135.40	18.00	6.29	4.39	0.80	307.37
Btg	60-75	190.60	2.00	0.73	6.11	0.20	459.80

3.4. Bedrock of the Soils Studied

Thin section of the rock sample was prepared for examination under the petrographic microscope to determine the mineralogical composition of the rock. Viewing the plates under the microscope, garnets and biotite were the major minerals observed under the plain polarized light (PPL), while quartz and plagioclase (feldspar) were the major elements observed under the cross polar (CP). These minerals were also accompanied by others identified as follow: staurolite, andalusite, kyanite, graphite, hornblende, tourmaline, rutile, ilmenite, haematite and pyrites, although in smaller quantities. However, considering the mineralogical composition of the fine sand fraction of the soils studied with the rock samples thin section under petrographic examination, it can actually be concluded that the soils along the toposequence studied were derived from the weathering of the fine grained biotite gneisses and mica schist. It had earlier been reported that mica schist was the common rock mineral found in the area (Smyth and Montgomery 1962).

3.5. Fine Sand Mineralogy

Table 4 shows the results of the mineralogical analysis of the soil's fine sand fraction (100 – 250 µm). Heavy liquid analysis showed that the light mineral fraction (specific gravity < 2.89) ranged from 23 to 84% while 16 to 77% constituted the proportion of the heavy mineral (s.g. > 2.89) fraction in the fine sand fraction. In majority of the pedons examined, the percentage of light mineral was greater than that of the heavy mineral fraction. This can be attributed to several pedogenic, geologic, and environmental factors, among which are parent material composition, intense weathering, selective transport, and deposition, leaching, and soil texture characteristics**.** These factors collectively influence the mineralogical composition of the soil, favoring the accumulation of more resistant light minerals over time. However, the composition did not follow a specific trend in all the soil profiles. In some, the percentages of both light and heavy minerals increased with an increase in soil depth, while in some, the values fluctuated with soil depth. The dominant light minerals found in the fine sand fraction were quartz, with values ranging from 86 to 98%, and feldspar (plagioclase), with values ranging from 02 to 04%, as shown in Table 5. The dominant heavy minerals were opaque in all the pedons observed, and they were about 62 to 92%.

Table 4. Percentage light and heavy mineral composition of the fine sand fraction of the pedons.

Horizon	Depth (cm)	Light mineral (s.g <2.89) ← %	→ Heavy mineral (s.g > 2.89)
		Profile 01 Egbeda series	
Ap	0-18	48	52
AB	18-24	51	49
B	24-51	53	47
BC	51-70	55	45
		Profile 02 Olorunda series	
Ap	0-18	58	42
AB	18-28	59	41
B21	28-72	63	37
B22	72-132	67	33
BC1	132-185	71	29
BC2	185-210	79	21
		Profile 03 Makun series	
Ap	0-18	28	72
BA	18-33	32	68
B21	33-65	29	71
B22	65-120	23	77
BC	120-200	41	59
		Profile 04 Oba series	
Ap	0-20	64	36
BA	20-40	66	34
B1	40-71	72	28
2BtC1	71-115	68	32
2BC2	115-170	67	33
		Profile 05 Jago series	
Ap	0-18	79	21
AB	18-40	77	23
B	40-60	82	18
Btg	60-75	84	16

Brown staurolite, pinkish andalusite and gray kyanite were the predominant heavy minerals. However, garnet, rutile, ilmenite, hematite, zircon and apatite also occurred in some of the pedons examined in varying proportion considering the richness of the parent rock in ferromagnesian minerals.

Table 5. Percentage of light and heavy mineral composition of the fine sand fraction of the soils studied.

Horizon	Depth (cm)	Quartz	Feldsper	Opaque	Staurolite	Andalusite	Kyanite	Garnet	Rutile	Zircon	Ilmenite	Apatite	Hematite
		Light mineral composition		**Heavy mineral composition**									
Profile 01 Egbeda series													
Ap	0-18	94	06	88	03	02	02	-	01	-	01	02	01
AB	18-24	96	04	92	01	02	01	01	-	-	02	01	-
B	24-51	95	05	78	05	05	02	02	02	01	-	-	05
BC	51-70	96	04	74	10	-	05	-	04	02	02	03	-
Profile 02 Olorunda series													
Ap	0-18	98	02	62	05	10	-	05	05	08	-	05	-
AB	18-28	98	02	88	02	-	-	02	02	04	01	-	01
B21	28-72	98	02	84	-	04	02	02	-	02	03	01	02
B22	72-132	96	04	66	10	02	03	05	02	02	-	05	05
BC1	132-185	94	06	78	05	05	05	-	01	-	02	02	01
BC2	185-210	88	12	75	05	-	05	03	02	05	-	-	05
Profile 03 Makun series													
Ap	0-18	86	14	84	04	02	-	-	02	03	01	-	04
BA	18-33	88	12	82	05	02	04	02	02	01	-	01	01
B21	33-65	88	12	78	05	02	03	05	-	-	03	03	01
B22	65-120	90	10	76	02	02	03	02	02	04	02	05	-
BC	120-200	90	10	88	-	-	04	-	-	-	04	-	04
Profile 04 Oba series													
Ap	0-20	98	02	88	02	02	-	-	02	02	-	02	02
BA	20-40	96	04	92	-	-	02	-	02	01	01	01	01
B1	40-71	92	08	90	04	02	-	-	01	-	02	01	-
2BtC1	71-115	98	02	64	05	05	04	02	-	05	04	05	06
2BC2	115-170	97	03	76	04	05	-	01	04	02	-	05	03
Profile 05 Jago series													
Ap	0-18	98	02	78	04	04	08	-	02	01	01	-	02
AB	18-40	98	02	78	03	05	08	-	02	01	-	01	02
B	40-60	98	02	88	-	02	02	-	02	02	-	02	02
Btg	60-75	98	02	90	01	-	02	04	-	01	02	-	-

The occurrence of staurolite, zircon and rutile in the heavy mineral fraction and the abundance of quartz in the light mineral fraction of the soils examined pointed to the possibility that the soils developed from metamorphosed argillaceous sedimentary rocks (staurolite-bearing schists). The presence of feldspars which are weatherable minerals in the soils indicated that the soils have some inherent nutrient reserve, while the presence of resistant minerals like zircon and staurolite attested to a highly weathered environment that had concentrated these resistant minerals into appreciable proportions within the soil (Adegbite and Ogunwale 1994).

3.6. Statistical Analyses

The results of correlation analysis of some selected soil physical and chemical properties are shown in the correlation matrix (Table 6). Clay content shows a significance positive correlation with pH (H_2O), Na and H^+ (r= 0.99, 0.93 and 0.96) which suggests that the contribution of clay to this parameters in the soils is high. Also, a positive correlation was observed between the clay content and the bulk density of the soils examined. This is an evidence of the prominent role that clay content plays in the soil bulk density compared with other parameters listed above.

The soils' pH (KCl) significantly correlated with the sum of bases (r= 0.82) and ECEC (r= 0.92). This indicated that the soil pH affected the cation exchange in the soils examined i.e. the higher the pH to a certain level, the greater the amount of bases exchanged within the soil solumn and the higher the nutrients available for plant uptake. The ECEC correlated positively and significantly at all levels with organic carbon (r= 0.88) and available P (r= 0.99). This observation is similar to the report of Kadeba and Benjaminsen (1976) that between 56 and 83% of the variation in CEC of tropical soils is accounted for by the organic matter content of the soil. Further, organic carbon content showed a good correlation with the available P (r= 0.83). This indicated the importance of organic matter to the process of ion exchange in soils, and shows that organic P is a major source of P in the soils.

3.6. Taxonomic Classification

All the pedons observed showed increasing trend in clay content with soil depth to a certain level, a kind of trend that was indicative of argillic horizon. Low level of fertility as observed from the organic matter content and other soil mineral composition to the extent that they cannot be used to grow crops economically unless fertilizers are used to supply nutrients (Soil Survey Staff 2003). These are the two most important differentiating characteristics of the Ultisols. The pedons are mineral soils with ochric epipedon, low in organic matter, high in colour values and chromas. The soils are dry for more than 90 cumulative days but less than 180. The upland soils of southwestern Nigeria is primarily under ustic moisture regime (Periaswamy and Ashaye 1982), therefore, the soils are in Ustults suborder. Pedon 05 qualifies as Aqults because of the hydromorphic properties right from the soil surface and the gleyed subsurface horizons. The presence of Kandic horizons are established in most pedons because they meet the following requirements: coarse textured surface horizon over vertically continuous sub-surface horizons; ECEC values within the sub-surface B-horizons that are less than 12cmol (+)/kgclay; a regular decrease in organic carbon contents with increasing soil depth (Soil Survey Staff, 2003). Soils of Pedons 01, 02, 03 and 04 have no evidence of hydromorphic properties within 150 cm of the mineral soil surface but have clay distribution such that the percentage clay decreased from its maximum by 20% or more within 150 cm of the mineral soil surface. These soils therefore, classify as Typic Kanhaplustults, they have ECEC of less than 12 cmol/kg soil. Soils of pedon 05 show evidence of redox depletion within 75 cm of the mineral soil surface and therefore, qualify as Aquic Haplustults**.** In the FAO-UNESCO soil legend, all the pedons under consideration qualify as Luvisols because of the presence of argillic horizon and humus surface horizon that is separated from the mineral horizon (Bruand et al. 2004), a horizon eluviated of clay minerals and a horizon of at least 5 cm. thick with illuvial clays (Bruand et al. 2004). The soils of pedon 03 and 04 classify as Plinthic Luvisols because of the presence of indurated coherent plinthite within 100 cm of the soil mineral surface. Soil of pedon 05 classifies as Gleyic Luvisols because of evidence of gleyic properties within 100 cm of the soil surface. The soils of pedon 01 and 02 classify as Eutric Luvisols because of the high base saturation (IUSS 2006).

Table 6. Pearson correlation coefficients of the soils' physical and chemical properties at the studied area.

	Total sand (%)	Silt (%)	Clay (%)	Bd g/cm3	pH (H20)	pH KCl	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Al^{3+}	H^{+}	Sum of Bases	ECEC	Base sat. (%)	Al. sat (%)	O M (%)	Avail P. (ppm)	$Fe_{(d)}$	$Al_{(d)}$	$Fe_{(d)}$/Clay	$Al_{(d)}$/Clay
Total sand (%)	1																					
Silt (%)	0.97	1																				
Clay (%)	0.13	0.36	1																			
Bd g/cm3	0.03	0.94	0.99	1																		
pH (H20)	0.29	0.51	0.99	0.19	1																	
pH KCl	0.89	0.75	-0.34	0.93	-0.18	1																
Ca^{2+}	0.17	0.4	0.98	0.07	0.99	-0.3	1															
Mg^{2+}	0.99	0.99	0.28	0.97	0.43	0.808	0.317	1														
Na^{+}	0.49	0.69	0.93	0.4	0.98	0.034	0.942	0.62	1													
K^{+}	0.78	0.91	0.72	0.72	0.82	0.41	0.745	0.87	0.93	1												
Al^{3+}	-0.07	-0.31	-0.99	0.03	-0.97	0.398	-0.995	-0.2	-0.9	-0.67	1											
H^{+}	0.41	0.62	0.96	0.31	0.99	-0.05	0.968	0.54	0.99	0.89	-0.94	1										
Sum of Bases	0.99	0.99	0.25	0.97	0.41	0.82	0.293	0.99	0.6	0.86	-0.19	0.52	1									
ECEC	0.99	0.94	0.03	0.99	0.19	0.92	0.071	0.97	0.4	0.72	0.03	0.32	0.975	1								
Base sat. (%)	-0.85	-0.95	-0.63	-0.8	-0.75	-0.52	-0.659	-0.9	-0.87	-0.99	0.58	-0.83	-0.91	-0.8	1							
Al sat. (%)	-0.45	-0.65	-0.94	-0.4	-0.99	0.013	-0.957	-0.6	-0.99	-0.91	0.92	-1	-0.56	-0.36	0.85	1						
O M (%)	0.92	0.99	0.51	0.87	0.64	0.635	0.544	0.97	0.79	0.97	-0.46	0.74	0.962	0.876	-0.99	-0.76	1					
Avail P. (ppm)	0.98	0.91	-0.06	0.99	0.11	0.958	-0.017	0.94	0.32	0.65	0.12	0.23	0.951	0.996	-0.74	-0.27	0.83	1				
$Fe_{(d)}$	-0.32	-0.54	-0.98	-0.2	-0.99	0.152	-0.988	-0.5	-0.98	-0.84	0.97	-0.99	-0.44	-0.22	0.77	0.99	-0.67	-0.14	1			
$Al_{(d)}$	-0.34	-0.55	-0.98	-0.2	-0.99	0.133	-0.985	-0.5	-0.99	-0.85	0.96	-0.99	-0.45	-0.24	0.78	0.99	-0.68	-0.16	0.99	1		
$Fe_{(d)}$/Clay	0.06	-0.19	-0.98	0.16	-0.94	0.507	-0.975	-0.1	-0.84	-0.58	0.99	-0.89	-0.07	0.152	0.48	0.87	-0.34	0.24	0.93	0.92	1	
$Al_{(d)}$/Clay	-0.08	-0.32	-0.99	0.02	-0.98	0.389	-0.996	-0.2	-0.91	-0.68	0.99	-0.94	-0.2	0.02	0.59	0.93	-0.47	0.11	0.97	0.97	0.99	1

4. Conclusions

The soils under investigation are predominantly ultisols with sandy top and clayey subsoils and are placed in ustults suborder. Pedological properties of the soils examined together with a low silt/clay ratio (<1.0) pointed to the fact that the soils were highly-weathered and intensely-leached. The soils are generally deep and well drained except at the crest and valley bottom due to the peculiarity of their locations on the topography. Quartz constituted the major primary mineral composition in the light mineral fraction with smaller amount of feldspathic minerals while opaque minerals dominated the heavy mineral portion with other minerals such as staurolite, Andalusite, kyanite e.t.c. that are present in smaller proportions in the fine sand fractions. The properties of the soils studied down the toposequence do indicate that chemical weathering and therefore, mineralogical alteration have proceeded translocation or possibly comminution. This is equally true of pedons that demonstrates the clay distribution of an in situ formed soil, presumably because the colluvium materials on top of the saprolite belonged to the same parent rock as the saprolite.

This will definitely influence management requirements because of the differences in the intensity of the soil properties down the topography and hence requires different management practices such as contour farming, terracing, strip cropping, usage of vegetal cover of economic importance and other soil conservation practices that suit each soil type at the different physiographic positions as evidenced by the taxonomic classes, for maintenance of soil health, preventing erosion, and enhancing productivity thereby assist in preventing rapid soil degradation across the landscape. In general, more research is required over time to determine the effectiveness of the recommended strategies and its impact on crop yields and soil characteristics in field experiments.

Author Contribution: Fawole OA. The work is a sole authorship, carved out of my Doctoral thesis

Data Availability Statement: All the data presented in this work are from the results generated during the Field work, Laboratory and statistical analysis carried out during the research. They can only be found in my field data logbook.

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Conflicts of Interest: I therefore declare that there are no conflicts of interest associated to the manuscripts

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