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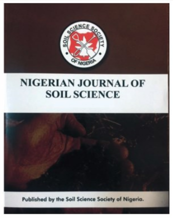

Mineralogical investigation of some imperfectly and poorly drained soils of the Nigerian Northern Guinea Savanna agroecology

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ABSTRACT

This study aimed to investigate the mineralogy of soils with impaired drainage formed within the northern guinea savanna of Nigeria. Soil survey procedure was carried out to identify the two soil individuals (polypedon) namely: imperfectly drained soil (IDS) and poorly drained soil (PDS) that occupied 6,407.68ha (90.96%) and 636.82 ha(9.04%) respectively. In each soil individual, a representative soil profile pit was dug, described, and sampled from genetic horizons. Soil samples collected were prepared and the <2 µm fractions were subjected to laboratory mineralogical analysis. Evaluation of the soil depth and topography indicate IDS was deep (124 – 151 cm) and situated on nearly level (1 – 2 %) to gently sloping (3 – 7 %) ground on a mid-slope to lower slope position and PDS was also deep (142 – 147 cm) on the lower slope to the floodplain. Kaolinite dominated the clay-sized mineral in PDS. The dominance of kaolinite/kaolinite polymorphs indicates that the soils are mature and highly weathered. However, it was believed to have been brought about partly by erosional and depositional processes which contributed to the variation in mineral composition. The occurrence and dominance of Zeolite in IDS were attributed to pedogenesis because of its polymorphic platy habit. The presence of Quartz in both soil individuals (IDS and PDS), though in low amount counts for its high resistance to weathering which is indicative of inheritance from the parent material (basement complex).

1.0 Introduction

Borys and Mills (1976) defined ecology about land as on the relationship between all of the various environmental factors which influence land and its capability and suitability for supporting the multitude of uses of interest to man; hence, agroecological can be viewed as of those characteristics of an environment that influence agriculture or that qualify an area on the earth's surface as an agricultural land resource (Ojanuga, 2006). The larger part of Nigeria's landmass is dominated by savanna vegetation, broadly classified into Sahel, Sudan, and guinea savanna (Ogundele, 2006). Soil types in Nigeria are influenced by and follow very broadly, climatic and vegetational zones of the country because the degree of available moisture in the soil is an important factor in soil reactions, fertility, and productivity (Aregheore, 2009).

Mostly within northern parts of Nigeria, the area under basement complex rocks is considerably large, covering over 50 % of the total land area (Olaniyan *et al*., 2010). Ande (2010) submitted that several studies have been carried out to explain the genesis of soils formed from rocks of basement complex in the country. The potentials of these soils partly depend on the mineralogical composition of the Basement complex. Identifying these minerals is a step to understanding the soil properties. The soil particles of which the clay fraction contains more mineral materials have a great influence on the development of soil physical and chemical properties. In most soil, properties of water retention, hydraulic conductivity, swelling and shrinking, and cation exchange are largely controlled by mineralogical composition. Identification and characterization of clay minerals are one of the basic requirements for classifying soils as well as for the better understanding of soil genesis (Islam and Husain, 2008). Among commonly used methods to accomplish mineralogical analysis is X-ray diffraction (XRD), which has proven to be indispensable (Deng *et al*., 2009).

Soil drainage evaluation of the study area identified the soils to be predominantly of imperfect drainage (IDS) and a contiguous land tract downslope adjoining the streams and river to be poorly drained (PDS). The soil drainage is associated with the water table level that defines the moisture regimes as udic and aquic (Soil Survey Staff, 2014). The moisture regimes have partly been used together with the soil mineralogy to classify the soils as UlticHaplustalfs fine-loamy, mixed, subactive, iso hyperthermic, and Aeric Endoaqualfs coarse-silty, mixed, active, iso hyperthermic respectively for IDS and PDS (Shobayo, 2019). This is because they affect soil genesis (formation), affect the use and management of soils, and can be used to group soils with similar properties and morphology. The soils under study have sufficient moisture for crops; however, management considerations vary. The latter (PDS) may need artificial drainage for some cropping practices. Moisture levels of the soils have influenced the soil color as it darkens the soils by increasing light absorption. Improperly drained soils may give a grayish matrix because iron oxides occur in the ferrous state (Jackson, 2014) while soils with blackish color may be attributed to staining by manganese oxides when organic material is lacking.

Comprehensive knowledge of soil mineralogy in Africa is lacking due to poorly and fragmentally coordinated scientific investigations coupled with the limitations in the traditional analytical techniques (Kamau, 2013). Therefore, the study was conducted to characterize the mineralogical composition of the less than 2 μm fraction within a soil profile of the selected drainage impaired soils.

2.0 Materials and methods

2.1 Location of the sampling site

The study area lies on latitude 11°25'N to 11°34'N and lon-

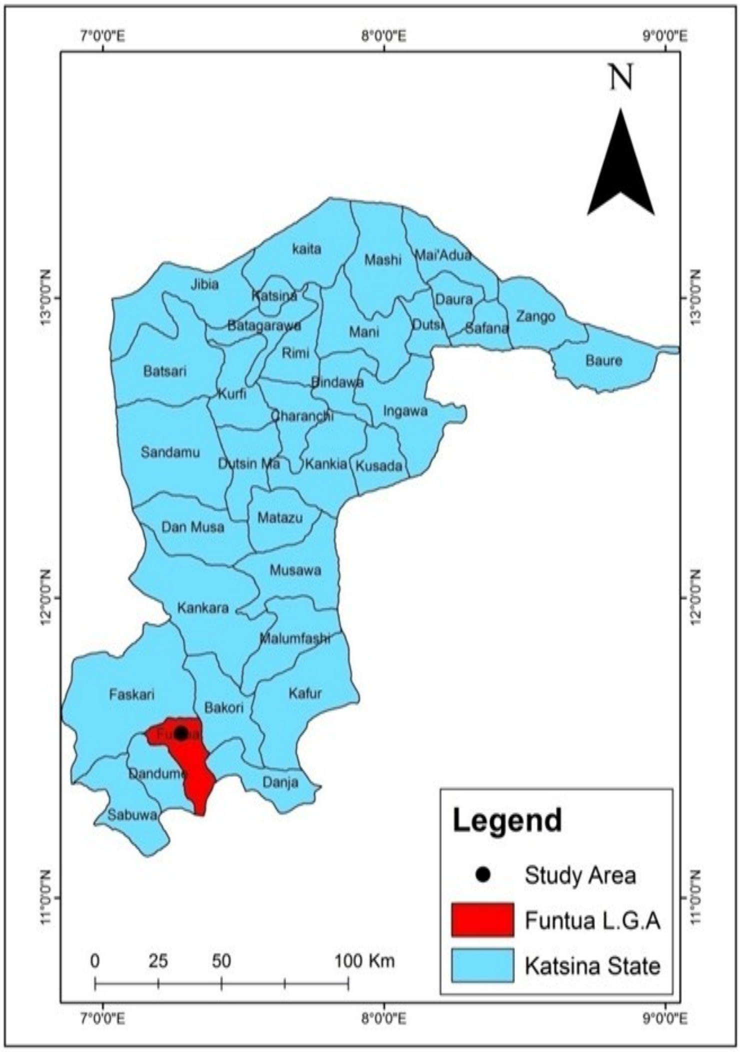


Figure 1: Location map of the study area

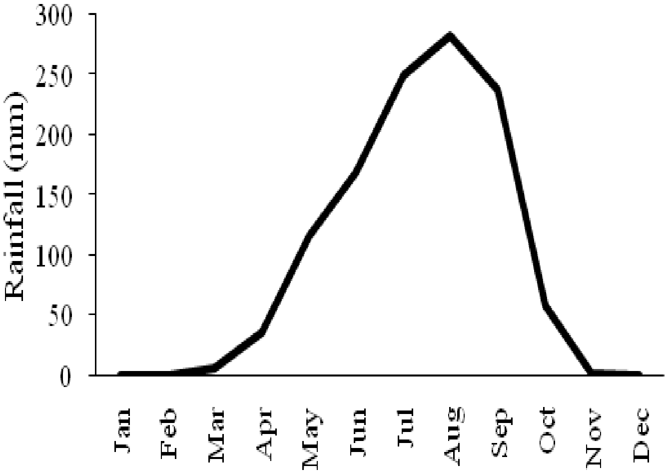


Figure 2:Rainfall data of study area

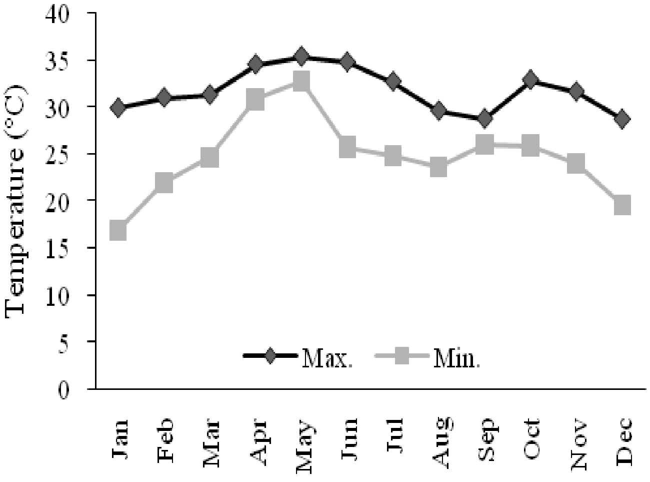


Figure 3:Temperature data of study area

gitude 7°16'E to 7°22'E, located in Funtua, Funtua Local Government Area (LGA) of Katsina State, Nigeria. It is bordered by Faskari LGA to the north, Bakori and Danja LGAs to the east, and Dandume LGA to the west (Fig. 1).

2.2 *Climate*

The climate of the study area is typical of that of the northern guinea savanna of Nigeria. It is characterized by a long dry season and a shorter but very conspicuous wet season. It has total annual rainfall figures ranging from 800 mm to over 1000 mm. The mean monthly maximum range of temperature was between 28.70 and 35.40°C; while the minimum range between 16.89 °C and 32.70 °C (Abaje *et al*., 2016). Figures 2 and 3 show the rainfall and temperature data of the study area.

The area has a land coverage of 7,044.5 ha.

2.3 Method of sample collection

A reconnaissance soil survey was carried out in the study area. This was undertaken to obtain preliminary information as well as the actual land area that was studied (7,044.5 ha); thus, the study enabled for detailed soil survey (Soil Science Division Staff, 2017). The conventional method of a survey involving GPS assisted procedure was adopted and the soil survey work identified two soil individuals (namely: IDS and PDS). The concept of the soil individual was based on soils that shared similar morphological, topographical, and physical characteristics of depth, drainage, the colour of soil matrix and mottles, texture, and structure identified. In each soil individual that was identified, one soil profile pit was dug, described, and sampled from the bottom-up, to minimize contamination by falling debris across a horizon's full depth and breadth according to the occurrence of the genetic (natural) horizon for soil mineralogical characterization. The soil samples were air-dried in the laboratory, crushed with porcelain pestle and mortar, and sieved to remove materials greater than 2 mm (gravel). The clay mineralogical analysis of the less than 2 mm soil particles was carried out.

2.4 Mineralogical analysis

The samples were prepared by first removing exchangeable cations, organic matter, and sesquioxides from the samples following the method described by Kunze and Dixon (1986). Particle size separation was determined by the method described by Gee and Or (2002). The gravel content was first removed by direct sieving. Sand, silt, and clay were determined by Bouyoucos hydrometer method, using sodium hexametaphosphate as a dispersant and determining sizes and amount of particles settling by employing progressive time intervals. After obtaining the clay samples, preparation for an oriented mount for presentation to x-rays continued. About 5 - 10 g of clay sample was put into a clean test tube with the aid of a spatula. Distilled water was added to dissolve the sample and subsequently placed inside the centrifuge machine. This was allowed to run at 5 rpm for 5 minutes after which it was removed and the floating material was decanted. Another distilled water was added, mixed thoroughly, and again placed inside the centrifuge machine and ran the second time. This process went on five times to be sure individual samples went into a clear suspension. After decanting severally, about 3 - 5 drops of 0.6 % sodium hexametaphosphate solution were added. At this point, a clear suspension of clay was formed above, while the unwanted settled at the bottom of the test tube. A dropper was used to take some quantity of the suspended clay, saturated with magnesium ions, and was applied on a clean labeled glass slide. This was allowed to dry overnight in an oven at 105 °C, and ready for XRD analysis. The x-ray diffraction (XRD) analysis of the clay fraction was done at the Department of Physics, Umaru Musa Yaradua University, Katsina State, Nigeria.

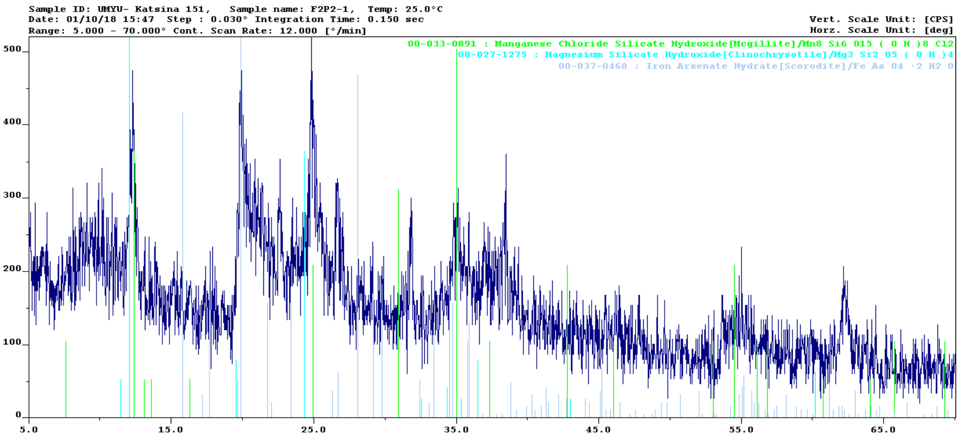
Horizon	**Depth (cm)**	**XRD Diffractograms of clay samples**
Ap	0-22	

Figure 4: X-ray diffractograms of clay-sized particle of IDS 0-22 cm

3.0 Results and Discusion

The mineralogy of clay fractions of the soils is discussed below and their various diffractograms are shown in Figures 4 - 9. Table 1 shows the summary of the mineralogical characteristics of the soil individuals.

X-ray diffractogram of clay fraction revealed three major minerals in surface soils (0 - 22 cm) of soil individual IDS as shown in Fig. 4. The major minerals as confirmed by the various peaks are scorodite (4.4720 Å, 3.1780 Å, 5.6090 Å, 3.0600 Å, 5.0180 Å), clinochrysotile (7.3500 Å, 3.6600 Å, 4.5400 Å, 2.4600 Å, 1.5370), and mcgillite (2.5600 Å, 7.1600 Å, 2.8880 Å, 3.5700 Å, 2.1120 Å). The predominance of clinochrysotile (a member of polytypes of chrysotile), a soft, fibrous silicate mineral in the serpentine subgroup of phyllosilicates indicates that the surface soils could be easily tilled because of their considerable tensile strength. Its high resistance to weathering had resulted in a low release of Mg to the soils and contributed to the soils' CEC. However, the selectively dissolved Mg ion might have contributed to the soils' incipient acidity.

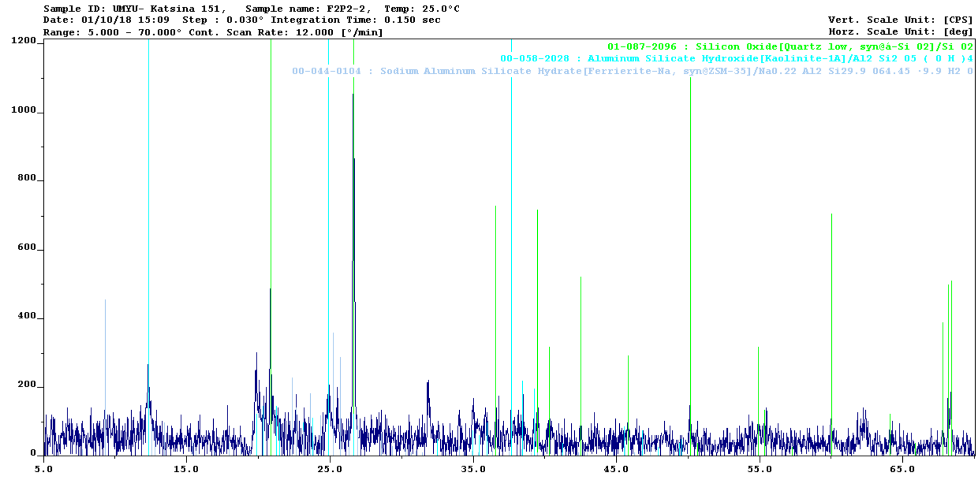
Horizon	Depth (cm)	XRD Diffractograms of clay samples
Bg	22-60	

Figure 5: X-ray diffractograms of clay-sized particle of IDS 22-60 cm

Scorodite, on the other hand, is an iron arsenate mineral commonly associated with arsenic-bearing ore deposits as a weathering product. It is metastable under most conditions and tends to dissolve incongruently, forming iron hydroxides and releasing arsenate to a solution (Dove and Rimstidt, 1985). The varying hydroxides of iron formed had contributed to its brownish red to yellowish-brown coloration, its occurrence is suggested to be neoformed from the basement complex weathering. The occurrence of mcgillite in this soil unit appears to be largely inherited from the parent material rather than of pedological significance but may be quite susceptible to decomposition if the environment becomes very unstable (i.e. intensive leaching) as has been reported to form as fracture fillings in a manganese-rich portion of quartzite, a major make up of the basement complex.

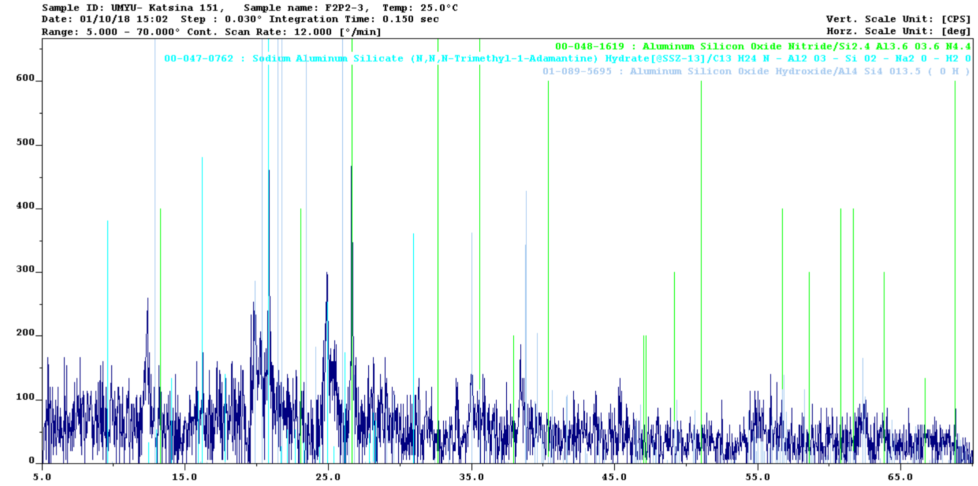
Horizon	Depth	XRD Diffractograms of clay samples
Btg	60-109 cm	

Figure 6 X-ray diffractograms of clay-sized particle of IDS 60-109 cm

At the subsurface soils (22-60 cm), quartz (3.3430 Å, 4.2545 Å, 1.8176 Å, 2.4564 Å, 2.2810 Å, 1.5413 Å), kaolinite (3.5809 Å, 7.1697 Å, 2.3867 Å, 2.3409 Å, 2.2951 Å) and zeolite-ferrierite (9.5216 Å, 3.5296 Å, 3.4634 Å, 3.9796 Å, 3.7665 Å) dominated. Quartz is primarily of igneous rocks, it is resistant enough to weathering which counts for its presence in low amount; however, it is indicative of inheritance from the parent material and might be the product of neotransformation. The dominance of kaolinite is an indication that the soil had weathered considerably however they may not have been formed in-situ but brought about by erosional and depositional processes. Ferrierite on the other hand is a species of zeolite that may have also contributed to the Na level of the soil.

At the lower subsurface soil depth (60-109 cm), zeolite-chabazite (4.7000 Å, 5.4700 Å, 9.2300 Å, 2.8900 Å, 3.5700), Sialon (3.3420 Å, 2.7410 Å, 2.5250 Å, 2.2340 Å, 1.7890 Å, 1.3110 Å) and kaolinite-mullite (4.3626 Å, 6.8594 Å, 3.4297 Å, 4.0906 Å, 4.1396 Å, 3.7964 Å) dominated. The occurrence of zeolite-chabazite in this soil might be as veins in the clay mineral composition and dominance of zeolite in the clay fractions was attributed to pedogenesis because of its polymorphic platy habit. Sialon detected having complex chemistry presupposes they were not inherited from the parent material and might be the product of neo-transformation. The abundance of kaolinite indicates that an extensive pedogenic process has occurred and has contributed to the moderate and low cation exchange capacity of the soils.

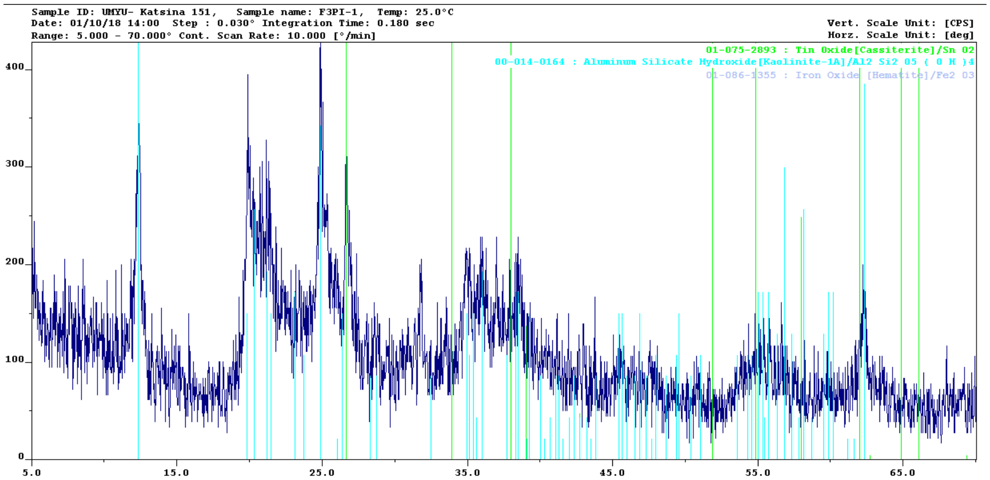
Horizon	**Depth (cm)**	**XRD Diffractograms of clay sample**
Ap	0-17	

Fig. 7 X-ray diffractograms of clay-sized particle of PDS 0-17 cm

X-ray diffractogram of clay fraction revealed two major minerals in surface soils (0 - 17 cm) of soil individual PDS as shown in Fig. 8. The minerals contained in PDS as confirmed by the various peaks against corresponding 2Theta Braggs angle were: cassiterite – SnO_2 (3.3468 Å, 2.6404 Å, 1.7623 Å, 2.3666 Å, 1.4135 Å, 1.6734 Å), and kaolinite (7.1700 Å, 1.6200 Å, 1.4890 Å, 3.5790 Å, 4.3660 Å, 1.5860 Å). Cassiterite imparted on the surface soil the characteristic brownish color (Dark yellowish brown -10YR4/6) and is commonly associated with alluvial deposits containing the resistant weathered grains of igneous rock.

At the subsurface soils (17 – 40 cm), amphibole (7.6300 Å, 3.5020 Å, 3.8100 Å, 1.4840 Å, 2.5360 Å) and kaolinite (7.1538 Å, 3.5769 Å, 4.3612 Å, 4.1809 Å, 3.8430 Å, 4.1289 Å) dominated. Amphibole found in this soil is an indication of the soil unit being less tensely weathered, however the presence of kaolinite in appreciable abundance implies the soil had been subjected to a high degree of weathering. The presence of amphibole may have also contributed to the enrichment of calcium in the soil being the most abundant among the exchangeable bases. Yagodin (1984) observed that the exchange capacity decreases with an abundance of kaolinite in the inorganic portion of the soil and when the

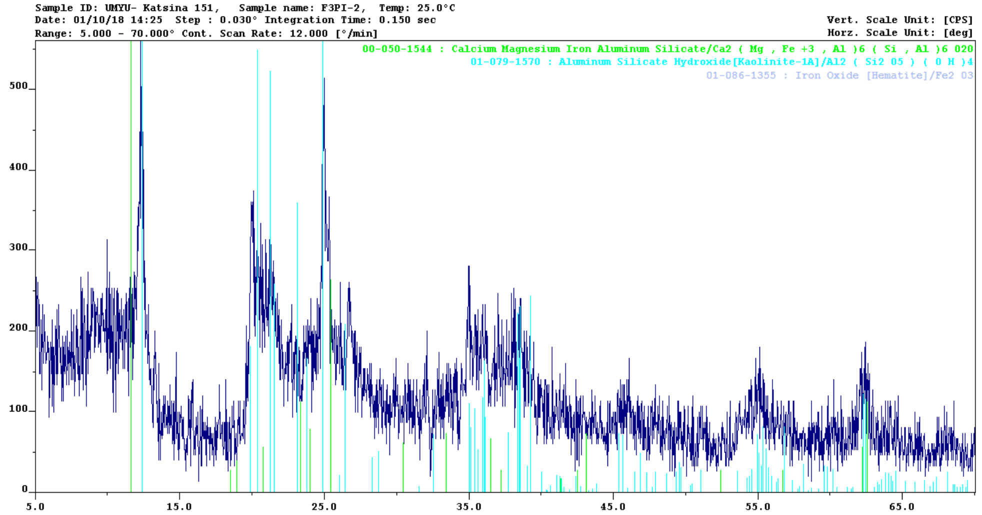
Horizon	**Depth**	**XRD Diffractograms of clay sample**
Bg1	17-40 cm	

Fig. 8 X-ray diffractograms of clay-sized particle of PDS 17-40 cm

fine fraction contains great amounts of amorphous ferric and aluminum hydroxides.

At the lower subsurface soil depth (40 - 142 cm), sericite (4.5000 Å, 4.4100 Å, 13.8000 Å, 4.3300 Å, 4.0000 Å), greenalite (2.5700 Å, 7.1200 Å, 3.5600 Å, 1.5900 Å, 2.1800 Å, 1.5500 Å) and magnetite-high (2.5406 Å, 1.4895 Å, 2.9790 Å, 1.6216 Å, 2.1065 Å, 4.8648 Å) dominated with low quartz (3.3430 Å, 4.2545 Å, 1.8176 Å, 2.4564 Å, 2.2810 Å, 1.5413 Å). Sericite, a fine-grained mica contributed significantly to the soil's CEC. Its presence in the subsurface soils provides useful information on the geochemical origin of the soil parent material and the stage of weathering. It has also contributed to the K level of the soil. However, sericite is resistant enough to weathering which counts for its presence in a low amount. Since some mica are known to persist in the clay fraction even in highly weathered soils, this probably accounts for the small amount of K found in this soil.

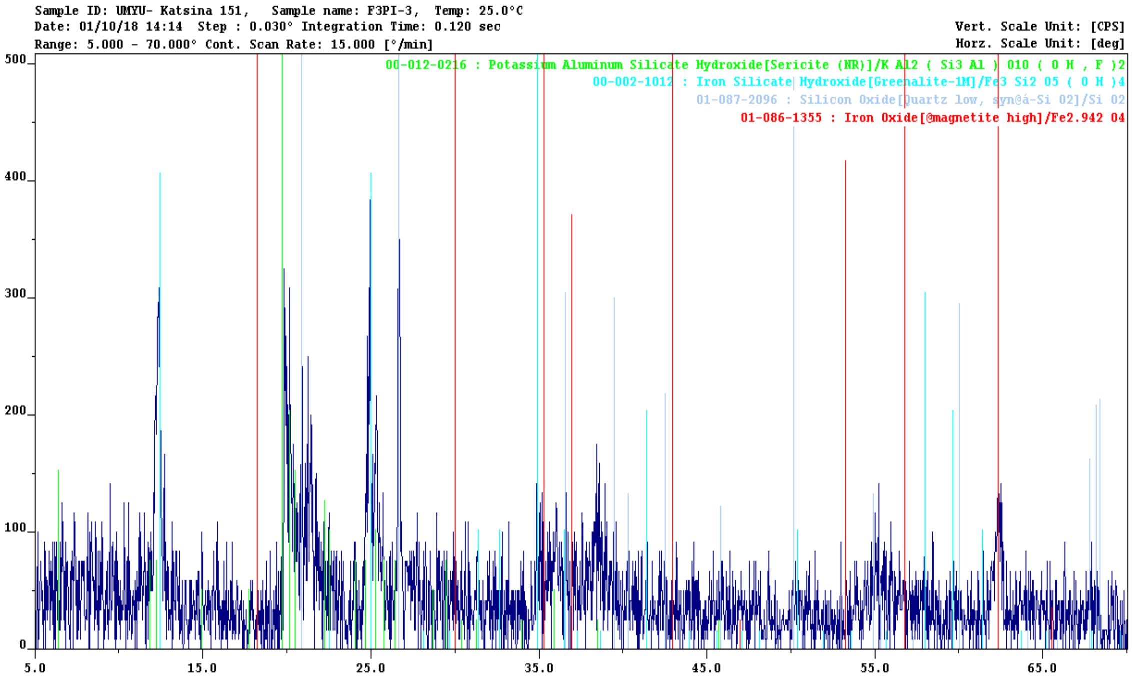
Horizon	Depth	XRD Diffractograms of clay sample
Bg2	40-142 cm	

Fig. 9 X-ray diffractograms of clay-sized particle of PDS 40-142 cm

Greenalite on the other hand is a species of the kaolinite that may have been inherited from the acid sediments from which the soil may have been formed. The low presence of quartz in this soil was attributed to its tolerance to weathering. Magnetite was abundant in this soil individual which contributed to its characteristic black color (black - 5Y2.5/2) at the subsurface horizons; and its formation might be attributed to the fluctuating water table. Ahmeda and Maherb (2018) linked reduction of iron to form Fe^{2+}- bearing magnetite to soil wetting/drying. Santana *et al*., (2001) opined that it is not clear if the pedogenic stability of lithogenic magnetite is related to the nature of the parent material. However, they submitted that factors affecting its formation from the parent material or through pedogenesis determine its fate through soil mineral genesis pathways; such as redox potential, pH and ions (e.g. Fe^{3+}), organic matter, and water availability. This implies that either in situ formation of soil-derived magnetite can occur but the latter may contribute to the natural remanent of the former.

4.0 Conclusion

The mineralogical characteristics of the soil individuals (IDS and PDS) as shown by the analysis carried out indicate that the soils were not ultimately a product of erosional and depositional processes considering the drainage and topographic positions of the soils (midslope – lower slope-floodplain) but to a larger extent developed from the parent material (Basement Complex rocks). The occurrence of quartz and zeolites even at the subsoils was attributed to inheritance from the parent material implying that the soils could have been formed largely in-situ. One could also infer given the mineral characteristics that eroded and decomposed minerals are basically from the adjacent land of the same parent material. The predominance of kaolinite (greenalite) in IDS and PDS with their depth characteristics implies the soils are highly weathered.

Table 1: Summary of soil mineralogical characteristics of the study area

MAP UNIT	HORIZON	2θ	D (Å)	INTENSITY	MINERAL
IDS	Surface Soil	19.83, 28.05, 15.78, 29.15, 17.66	4.4720Å, 3.1780Å, 5.6090Å, 3.0600Å, 5.0180Å	100, 90, 80, 45, 35	Scorodite
		12.03, 24.29, 19.53, 36.49, 60.15	7.3500Å, 3.6600Å, 4.5400Å, 2.4600Å, 1.5370 Å	100, 70, 15, 15, 12	Clinochrysotile
		35.02, 12.35, 30.93, 24.92, 42.78	2.5600Å, 7.1600Å, 2.8880Å, 3.5700Å, 2.1120Å	100, 70, 60, 40, 40	Mcgillite
	Subsurface Soil	26.64, 20.86, 50.14, 36.55, 39.47, 59.96	3.3430Å, 4.2545Å, 1.8176Å, 2.4564Å, 2.2810Å, 1.5413Å	100, 22, 10, 6, 6, 6	Quartz
		24.84, 12.33, 37.65, 38.42, 39.22	3.5809Å, 7.1697Å, 2.3867Å, 2.3409Å, 2.2951Å	100, 79, 14, 2, 2	Kaolinite
		9.28, 25.21, 25.70, 22.32, 23.60	9.5216Å, 3.5296Å, 3.4634Å, 3.9796Å, 3.7665Å	100, 79, 63, 50, 40	zeolite-ferrierite
	Sub Sub-surface Soil	20.78, 16.19, 9.57, 30.91, 24.92	4.7000Å, 5.4700Å, 9.2300Å, 2.8900Å, 3.5700Å	100, 72, 57, 54, 38	zeolite-chabazite
		26.65, 32.64, 35.52, 40.33, 51.00, 71.96	3.3420Å, 2.7410Å, 2.5250Å, 2.2340Å, 1.7890Å, 1.3110Å	100, 100, 100, 90, 90, 90	Sialon
		20.33, 12.89, 25.95, 21.70, 21.44, 23.41	4.3626Å, 6.8594Å, 3.4297Å, 4.0906Å, 4.1396Å, 3.7964Å	100, 82, 50, 45, 31, 26	kaolinite-mullite
PDS	Surface Soil	26.61, 33.92, 51.83, 37.99, 66.04, 54.81	3.3468Å, 2.6404Å, 1.7623Å, 2.3666Å, 1.4135Å, 1.6734Å	100, 75, 53, 21, 14, 12	cassiterite
		12.33, 56.78, 62.30, 24.85,20.32, 58.11	7.1700Å, 1.6200Å, 1.4890Å, 3.5790Å, 4.3660Å, 1.5860Å	100, 70, 90, 80, 60, 60	kaolinite
	Subsurface Soil	11.58, 25.41, 23.32, 62.53, 35.36	7.6300Å, 3.5020Å, 3.8100Å, 1.4840Å, 2.5360Å	100, 47, 20, 20, 17	amphibole
		12.36, 24.87, 20.34, 21.23, 23.12, 21.50	7.1538Å, 3.5769Å, 4.3612Å, 4.1809Å, 3.8430Å, 4.1289Å	100, 52, 50, 47, 32, 23	kaolinite
	Sub Subsur-face Soil	19.71, 20.11, 6.39, 20.49, 22.20	4.5000Å, 4.4100Å, 13.8000Å 4.3300Å, 4.0000Å	100, 40, 30, 30, 25	sericite
		34.88, 12.42, 24.99, 57.95, 41.38, 59.59	2.5700Å, 7.1200Å, 3.5600Å, 1.5900Å, 2.1800Å, 1.5500Å	100, 80, 80, 60, 40, 40	greenalite
		35.29, 62.27, 29.96, 56.72, 42.89,18.22	2.5406Å, 1.4895Å, 2.9790Å, 1.6216Å, 2.1065Å, 4.8648Å	100, 34, 29, 26, 20,10	magnetite-high
		26.64, 20.86, 50.14, 36.55, 39.47, 59.96	3.3430Å, 4.2545Å, 1.8176Å, 2.4564Å, 2.2810Å, 1.5413Å	100, 22, 10, 6, 6, 6	quartz

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