Bulgarian Journal of Agricultural Science, 26 (No 3) 2020, 605–611

Mineralogical properties of soils developed from colluvial deposits of Southern Nigeria

John Kingsley[1], Ackley Ufot Akpan-Idiok[2], Ayito Esther Okon[2] and Vit Penizek[1]

[1]*Czech University of Life Sciences, Faculty of Agrobiology, Food and Natural Resources, Department of Soil Science and Soil Protection, 165 00, Prague, Czech Republic*
[2]*University of Calabar, Faculty of Agriculture, Department of Soil Science, Eta 540004, Etta Agbo Rd, Calabar, Nigeria Cross River State, Nigeria*
[*]*Corresponding author:* Johnkingsley0107@gmail.com

Abstract

Kingsley, J., Akpan-Idiok, A. U., Ayito, E. O. & Penizek, V. (2020). Mineralogical properties of soils developed from colluvial deposits of Southern Nigeria. *Bulg. J. Agric. Sci., 26 (3)*, 605–611

Colluvial deposits are materials of rocks and soil fractions which are detached and transported by gravitational forces. The knowledge of the minerals they compose is vital for both nutrient assessment and pedological studies. The study aimed to investigate the textural and mineralogical properties of soils developed from basement complex geology in reflection to soil nutrient capacity.

The study was conducted on a 50-hectare land. Three soil mapping units were identified and labelled as S-I, S-II and S-III. Two profile pits were located in each mapping units except for S -III. A total of nineteen (19) soil samples were obtained from each pedogenic horizons. Particle size analysis was determined analytically while (5) representative samples collected and pretreated for mineral detection using XRD.

Particle size analysis revealed that the sand fraction = 665.3 g/kg, silt fraction = 94.7 g/kg and clay content = 240 g/kg. Texturally, sandy clay loam dominated the soil. This suggested that soils with high sand content are coarse. The XRD analysis revealed that quartz was high the soils ranging from 16.9–73.1% with a mean of 44.4% while others like, hornblende = 0.2–47.1% (mean 28.0%), muscovite =1.6–30.4% (mean 13.0%), kaolinite = 2.0–26.1% (mean 12.1%), illite =3.3–19.3% (mean 10.8%), Microcline = 0.6-23.3% (mean 9.6%), gibbsite = 1.0–15.0% (mean 6.8%), berlinite = 0.3–11.9% (mean 4.7%), feldspar = 0.3–11.6% (mean 4.0%), biotite= 0.9–4.1% (mean 2.2%), Rubidium feldspar = 1.0–3.0% (mean 2.0%) and montmorillonite = 1.0–3.0% (mean 0.6%).

Texture classes of the soils were sandy clay loam to sandy loam indicating that the colluvial soils of southern Nigeria are dominated by quartz mineral. This further revealed that the soils since they are resistant to weathering intensity they are referred to as old soils. Moreso, the mineralogical and textural characteristics are important in relation to soil fertility studies, of which soil users can incorporate employ in other to make the best crop management decision in solving real soil situation.

Keywords: colluvial soils; X-ray diffractogram (XRD); soil texture; mineralogy

Introduction

In pedological studies, colluvial deposits are materials of rocks and soil fractions which are detached and transported by gravitational forces (Esu, 2005). They are composed of different soils occurring in undulating geomorphology (Fyfe et al., 2000). Similarly, they are loose, heterogenous regolith deposits formed by biological action, pedogenic activities, mass movement, creep and landslides (Schulz, 2007). These impacts the soil as a complex system of air, water, organic matter and mineral particles that occurs in a definite structure. And their properties are a function of the formative factors such as geologic deposits, topography, climate, time and organism (Jenny, 1994).

Aki & Ediene (2018) and Moses & Edet (2013) reported low activity clays (6–10 cmol/kg) in the soils of colluvial deposits of Akamkpa, Nigeria. Their studies reported a low C.E.C. which are contributed by low activity clays. However, in this study, these low activity clays were identified in their percentages to understand the pedological processes of soil development. These minerals were reported to control soil fertility and textural properties (Jacobs, 2017). For instance, illite "breaks down to vermiculite through the release of potassium from the interlayer and the transformation of detrital chlorite by the weathering activities to vermiculite, smectite or mixed clay minerals" (Kingsley et al., 2019). Textural constituents of the soil system provide structural assistant, and the initial intergrain porosity is essential for optimum hydraulic conductivity and water storage (Jain & Kothyari, 2009; Ellis & Mellor, 2007). These properties contribute largely to soil reaction and mineral availability to plants. Geochemically, they buffer drainage waters, adsorb and exchange nutrients and pollutants, and biologically, they harbour microscopic organisms (Jacobs, 2017). These characteristic makes the soil mineral fractions a good factor for land use evaluation and soil management practices.

Previous studies (Aki & Ediene, 2018; Moses & Edet, 2013; John et al., 2019) who worked on the characteristics and classification of these type of soils in the humid tropical region of Nigeria could not explain the dynamics of soil weathering potentials in their studies owing to their lack of mineralogical data. Thus, this study was motivated in order to ascertain the percentage of occurrence of these minerals which happens to influence other soil characteristics. These minerals will help predict weathering potentials; evaluate soil nutrient capacity, and ensure soil stability. Similar studies conducted by Ogbaji et al. (2013) and Ogbaji et al. (2018) gave high quartz content which influenced sand contents in alluvial and aeolian deposits of Nigeria and China soils, respectively. Although, this study was conducted on colluvium deposit with a basement complex geology and since there are no recent publications on mineralogical constituents of this type of soil, this article will contribute a great deal to the already existing information available to soil users. Furthermore, the awareness of the mineralogical properties of soils developed on colluvial materials characteristics will necessitate the proper management of this type of soil for increased food and fibre production.

Materials and Methods

Research duration: The study was conducted within 2 years, from May 2015 to December 2017.

Study Area: The area under investigation is near Calabar River with 42 km distance from the north part of Akamkpa then emptying itself into Cross River (Figure 1). The area lies between the latitude 05°18′53″N and longitude 08°13′25″ E at an elevation 115cm above sea level of southeastern Nigeria(John et al. 2019). "The area, characterized by a sub-humid tropical climate with distinct wet and dry seasons. Rainfall range between 1500 mm and 3500 mm per annum; relative humidity between 80 and 90 percent and mean annual temperature", 25.4°C and 27.5°C (Nwajiuba et al., 2010). However, the soil-land relationship is predominant with an artificial forest. The topography of this land is strongly undulating and actively engaged for both perennial and annual crop production (John et al., 2019). The summary of the studied terrain, profile pits, and X.Y coordinate values presented in Table 1.

Geological formation: The area is characterized by basement complex rocks occupied about 10 000 km^2 in Southeast Nigeria, out of which about 40% found in Cross River State, which makes up the Oban-Obudu massif and, a continuation of the African-pan Basement Complex of the Cameroun highlands (Ekwueme, 2003).

Soil sampling: The study area was delineated into three soil mapping units (S-I, S-II, and S- III) (Figure 2). The S-I mapping unit occupied the crest region of the terrain with the total area of 5.2 hectares while S-II and S-III were located at the middle slope and lower slope of the landscape respectively; total land coverage of 44.8 hectares. The S-I soil type occurred at the elevation of between 100-115 m above sea level, properly drain, coarse-texture and suitable for the cultivation of both annual and perennial crops. The S-II occurred at the steep angle of the slope which was used in the growth of tree crops to prevent surficial erosion; and S-III soil mapping unit was located below 80 m above sea level, seasonally flooded, poorly drain and waterlog by the inflow of water. This section of the landscape was also utilized in the growth of cucumbers, pumpkin, and waterleaf. Two representative soil profile were dug in S-I and S-II soil mapping unit except for S-III, only one profile was dug. Samples were collected from each pedogenic horizons and transported to the laboratory for clay mineralogy, particles size distribution and bulk density determination.

Laboratory analysis: Core cylinder of 100 cm^3 was used the core samples, oven-dried at a temperature of 105°C to constant weight divided by the total volume of sample (Blake, 1965). Samples were air-dried, ground, and sieved

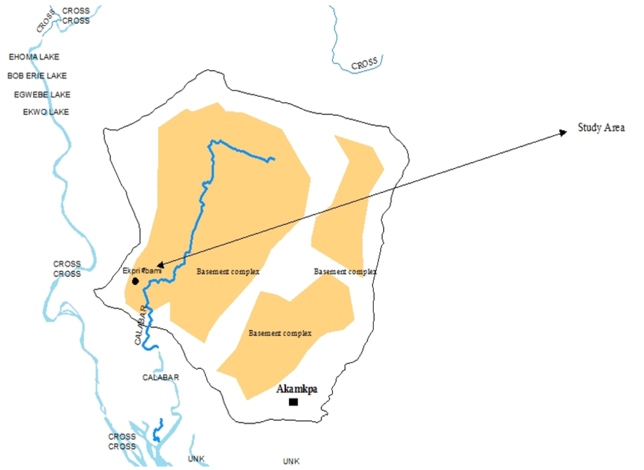

Fig. 1. Map of Akamkpa, Southeastern Nigeria showing study area (Kingsley et al., 2019)

through a 2-mm sieve, and a 50 g of this sample was weighed for particle size distribution analysis using the international pipette method (Gupt, 2009; Jackson, 1973; Piper,1966).

Mineralogical analysis: Five (5) representative samples of clay fractions obtained by the pipette method were pretreated. "Chemical cementing agents were removed and clay fractions separated" – (Kingsley et al., 2019) southeastern Nigeria. Materials and Methods: The study mineralogy of clay components of Aquic arenic paleudults soils of Akamkpa, southeastern Nigeria was carried out on 50 ha land. Two soils were collected from each pedogenic horizon of a representative pedon dug at valley bottom from the depth: Ap = 0–12 cm and Bt1 = 12–25 cm. The clay fraction of the soil was separated and the fine and coarse-clay fractions analyzed for its mineralogical content with the aid of an X-ray diffractometry. Results: The XRD analysis showed the abundance of the available clay mineral in this order: Illite > Chlorite > Quartz > Kaolinite and Quartz > Kaolinite >Illite > montmorillonite> Chlorite for surface and subsurface soils, respectively. While the overall abundance of clay mineral component in the soil system were in this order: Illite > Quartz > Chlorite > kaolinite > montmorillonite. Illite proved to be the dominant clay mineral at both surface and subsurface. This relative amount of clay minerals may be attributed to weathering conditions probably due to internal drainage and inter stratification. Conclusion: The study revealed that 2:1 expanding clay (illite. Iron-free samples were centrifuged at 750 rpm for 5.4 min to separate total clay (< 2 μm) and at 2700 rpm for 42 minutes to separate fine clay (< 0.2 μm). The fine and coarse-clay fractions were analyzed for mineralogy using X-ray diffractometry. The same concentration of clay suspensions was used for all samples to give reliable comparisons between relative peak intensities. Two drops of the prepared suspension were used on each glass slide. The (001) reflections were obtained following Mg saturation, ethylene glycol solvation, and K saturation. The K-saturated samples were studied both after drying and after being heated at 550°C for 4 h (Whitting, 1965).

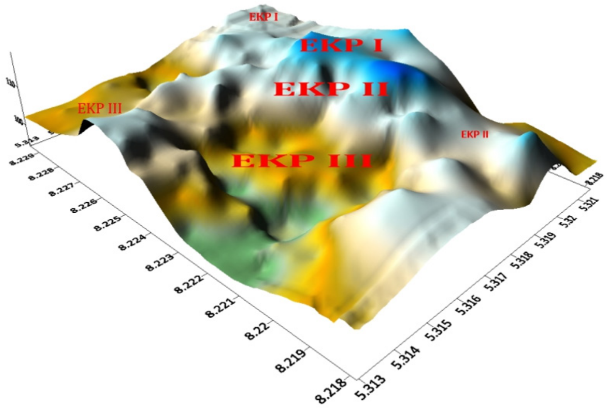

Fig. 2. Digital elevation model of Ekpri Ibami

Results

In Table 2**,** the sand content recorded the highest soil separates with the overall mean of 665.3 g/kg. This was followed by the clay contents with the mean of 240 g/kg and the least

Table 1. Geographical positioning system

Soil unit	Pedons	Landscape position	Village	LGA	State	Latitude & Longitudes
S-I	I	Crest	EkpriIbami	Akamkpa	Cross River	N05˚ 19' 16.84"; E008˚ 13' 36.1"
S-I	II	Crest	EkpriIbami	Akamkpa	Cross River	N05˚ 19' 25.3"; E008˚ 13' 35.7"
S-II	III	Middle slope	EkpriIbami	Akamkpa	Cross River	N05˚ 19' 11.3"; E008˚ 13' 36.8"
S-II	IV	Middle slope	EkpriIbami	Akamkpa	Cross River	N05˚ 19' 23.3"; E008˚ 13' 33.8"
S-III	V	Lower slope	EkpriIbami	Akamkpa	Cross River	N05˚ 18' 52.9"; E008˚ 13' 22.8"

LGA=Local Government Area

was silt content with the mean of 94.7 g/kg. Down the profile depth and across the different soil unit sand content was highest. The overall mean of sand/silt and silt/clay ratios were 7.6 and 0.6 respectively. The overall means of bulk density and porosity were 1.30 g/cm^3 and 49.0% respectively.

In Table 3, the quartz was recorded high in the soil with the mean of 44.4% while others contributed the remaining percentages: hornblende = 28.0%, muscovite =13.0%, kaolinite = 12.1%, illite = 10.8%, microcline = 9.6%, gibbsite = 6.8%, berlinite = 4.7%, feldspar = 4.0%, Biotite = 2.2%,

Table 2. Soil physical properties and textural class of the colluvial soils

Horizon	Depth, cm	Sand	Silt, g/kg	Clay	Textural class	Sand/Silt	Silt/Clay	Bulk density g/cm^3	Porosity
S-I PEDON I									
Ap	0–17	766.4	83.6	150	SL	9.2	0.56	1.2	55
Bt_1	17–62	614.8	65.2	320	SCL	9.4	0.2	1.5	43
Bt_2	62–122	616.4	103.6	280	SCL	5.9	0.37	1.5	43
Cr	122–200	496.4	143.6	360	SCL	3.5	0.4	1.4	47
PEDON II									
Ap	0–16	834	86	80	LS	9.7	1.08	1.2	55
Btr_1	16–65	734.8	105.2	160	SL	7.0	0.66	1.4	47
Btr_2	65–112	670.4	89.6	240	SCL	7.4	0.37	1.0	62
Cr	112–200	785.2	54.8	160	SL	14.3	0.34	1.0	62
surface mean		800.2	84.8	115		9.5	0.82	1.2	55
Surface range		766.4–834.0	83.6–86.0	80–150		9.2–9.7	0.56–1.08	0.0	0.0
Subsurface mean		653	93.7	253.3		7.9	0.57	1.3	50.7
Subsurface range		496.4–785.2	54.8–143.6	160–360		3.5–14.3	0.20–0.82	1.0–1.5	43–62
S-II PEDON III									
Ap	0–13	726.4	123.6	150	SL	5.9	0.82	1.3	50
Bt	13–63	674.8	85.2	240	SCL	7.9	0.36	1.5	43
Btr	63–128	492.2	87.8	420	SC	5.6	0.21	1.3	50
Cr	128–200	550.4	69.6	380	SC	7.9	0.18	1.4	47
PEDON IV									
Ap	0–14	634.8	145.2	220	SCL	4.4	0.66	1.1	58
Bt_1	14–69	614	106	280	SCL	5.8	0.37	1.5	40
Bt_2	69–130	630.4	49.6	320	SCL	12.7	0.16	1.6	40
Cr	130–200	654.8	105.2	240	SCL	6.2	0.44	1.6	43
Surface mean		680.6	134.4	185		5.2	0.74	1.2	54
Surface range		634.8–726.4	123.6–145.2	150–220		4.4–5.9	0.66–0.82	1.1–1.3	50–58
Subsurface mean		602.7	83.9	313.3		7.6	0.29	1.5	43.8
Subsurface range		492.2–654.8	49.6–106.0	240–420		5.2–12.7	0.16–0.37	1.2–1.6	40–50
S-III PEDON V									
Ap	0–16	715.2	104.8	180	SL	6.8	0.6	0.7	74
Bt_1	16–50	734	86	180	SL	8.5	0.5	1.6	40
Bt_2	50–92	694.8	105.2	200	SCL	6.6	0.5	1.6	40
Mean		714.7	98.7	186.7		7.3	0.5	1.6	51
Range Overall Mean		694.8–734.0 665.3	86.0–105.2 94.7	180–200 240		6.6–6.8 7.6	0.5–0.6 0.5	0.7–1.6 1.3	40–74 49

rubidium feldspar = 2.0% and montmorillonite = 0.6%. The soil gave a vast diversity of minerals.

Discussions

The sand fraction recorded highest in this soil with a predominant sandy clay loam texture down the profiles. These results were in line with the reports (Akinbola, 2001; Aki & Ediene, 2018; Kingsley et al., 2018). The soils were porous with low bulk density. And this collaborates with the result (Aki & Ediene, 2018; John & Akpan-Idiok, 2019; Kingsley et al., 2018). And the consequent effect on soil characteristics includes the inability to retain nutrient and moisture.

Thus there is a need to improve the soil nutrient management adopted by the current soil users in the area under investigation. On this note, measures to improve pores spaces in order to control drainage, water-holding capacity, and reduce erosion have been reported by Berry et al. (2007) and Ofem et al. (2017). The overall mean of sand/silt and silt/clay ratios was 7.6 and 0.6, respectively. The result is in line with the report (John & Akpan-Idiok, 2019; Aki et al. 2014; Aki & Ediene, 2018; Yakubu et al., 2009). And the result revealed that the soils were old with advanced weathering potentials.

The mineralogical results from the XRD analysis revealed the abundance of twelve (12) minerals in the soils and also in their percentage of occurrence (Table 3). High quartz content was reported by Ogbaji et al. (2013); Ogbaji et al. (2018) and Akpan-Idiok et al. (2012) except for Kingsley et al. (2019) who reported the slight dominance of illite in *Aquic Arenic Paleudults* soils which was contributed by internal drainage interstratification. The abundance of quartz and other secondary minerals revealed in the studied soil revealed that the soils are in their advanced stage of weathering as confirmed with low to non-content of biotite and this confirmed the result by Aki et al. (2014) and Yakubu et al. (2009). This also maybe have been contributed by geographical position and climatic conditions as reported by (Jacobs (2017). Furthermore, quartz rarely contributes to soil nutrient status as such but often interacts with textural characteristics to influence their structural development, water permeability, biomass productivity and resistant to soil erosion (Essien et al., 2001; Aki et al. 2014). Other minerals like hornblende ($NaCa_2(Mg,Fe,Al)_5(Si,Al)_8O_{22}(OH)_2$) which is next abundant mineral (28%)composed of Al and Fe may have been contributing to the acidity of the soils and also particle segregations. Muscovite which is a potassium-rich mica ($KAl_2(AlSi_3O_{10})(OH)_2$) contributes to the availability of K (Bajwa, 1981). This mineral is not resistant to chemical weathering, thus quickly transformed into clay minerals resulting in K-fixation (Jacobs, 2017). Kaolinite also dominated the mineralogy of the soil. This mineral has a low exchange site which yields low fertility condition (Jacobs, 2017; Essien et al., 2001). Moreover, their abundance are in this order: Qr > Hb > Ms>Ko > It > Mc > Gs> Be > Fp > Bt > Rfe> Mo. And the interstratified minerals detected from clay fractions are in harmony with the findings of Ogbaji & Akpan-Idiok (2013) in floodplain soils of Nigeria; (Ogbaji et al., 2018) in loess soils of China; (White,1985) and (Khan et al., 1997) soils of Bangladesh.

Conclusions

The textural and mineralogical properties of soils of Ekpri Ibami area of southern Cross State revealed the relevance of these properties in correlation to soil nutrient conditions, which guides soil users most especially farmers to modify management technologies best suitable to the current soil condition. Sand content of over 60% has been yielded by high quartz content and hornblende impacting detachment of soil separates. But since the land is under active agricultural production, fertility management measures such as organic

Table 3. Approximate mineral contents (%) in the studied colluvial soils

Depth, cm	Qr	Hb	Ms	Ko	It	Mc	Gs	Be	Fp	Bt	Rfe	Mo
0-17	54.1	0.2	1.6	7.5	–	21.1	1.3	11.9	–	1.2	1.0	0.1
17-45	–	36.8	3.1	2.0	–	23.3	10.3	1.0	11.6	0.9	–	–
45-63	16.9	47.1	7.6	23.3	–	0.7	1.5	0.3	0.3	0.9	–	1.3
63-89	25.9	–	24.6	26.1	–	18.7	–	–	–	1.7	3.0	–
89-110	53.3	–	–	–	19.3	1.8	15.0	–	5.8	4.1	–	0.4
110-150	43.0	–	30.4	–	9.7	0.7	11.8	–	1.6	2.8	–	–
150-200	73.1	–	10.7	1.5	3.3	0.6	1.0	5.5	0.8	3.6	–	–
Mean	44.4	28.0	13.0	12.1	10.8	9.6	6.8	4.7	4.0	2.2	2.0	0.6
range	16.9-73.1	0.2-47.1	1.6-30.4	2.0-26.1	3.3-19.3	0.6-23.3	1.0-15.0	0.3-11.9	0.3-11.6	0.9-4.1	1.0-3.0	0.1-1.3

Qr = Quartz, Mc = Microcline, Be = Berlinite, Ko = kaolinite, Ms = Muscovite, Gs = Gibbsite, Bt = Biotite, Rfe = Rubidium feldspar, Hb = Hornblende, Mo = Montmorillite, lt = Illite, Fp = Feldspar manure and biochar application should be incorporated into the farming practices in order to improve the nutrient and water holding capacities of the soils for continuous crop productions.

Significant Statement

This study discovered that the soil coarse-texture are largely impacted by the high quartz content of over 40% occurred in the geological material and as such this information can be beneficial to soil users for planning good management of the soil resources and this study will help researchers to uncover the critical areas of soil weathering processes of that many researchers were not able to explore. Thus a new theory on soil mineralogical characteristics may be arrived at.

Acknowledgement

The research was supported by the Czech University of Life Sciences Prague (internal project n.21130/1312/3131).

OrcidID: https://orcid.org/0000-0003-2934-5670

References

Aki, E. E. & Ediene, V. E. (2018). Characteristics and classification of soils derived from Awi sandstone formation in Awi, Akamkpa local government area of Cross River State, Nigeria. 11.

Aki, E. E., Esu, I. E. & Akpan-Idio, A. U. (2014). Pedological study of soils developed on biotite-hornblende-gneiss in Akamkpa Local Government Area of Cross River State, Nigeria. *International Journal of Agricultural Research, 9(4),* 187–199. https://doi.org/10.3923/ijar.2014.187.199

Akinbola, G. E. (2001). Characterization and Classification of some valley bottom soils of basement complex of South Western Nigeria. *Proceedings of 27th Annual Conference of Soil Science Society of Nigeria,* Held at Calabar, 100-111.

Akpan-Idiok, A. U. & Ukwang, **E. E. (**2012). Characterization and classification of coastal plain soils in Calabar, Nigeria. *J. Agric. Biotechnol. Econ., 5:* 19-33.

Anderson, R. P., Tosca, N. J., Gaines, R. R., Mongiardino Koch, N., & Briggs, D. E. G. 2018. A mineralogical signature for Burgess Shale–type fossilization. *Geology, 46(4),* 347–350. https://doi.org/10.1130/G39941.1

Bajwa, M. I. (1981). Soil clay mineralogy in relation to fertility management: Effect of soil clay mineral composition on potassium fixation under conditions of upland rice soils. *Fertilizer Research, 2(3),* 193–197. https://doi.org/10.1007/BF01834812

Berry, W., Ketterings, Q., Antes, S., Page, S., Russell Anelli, J., Rao, R. & DeGloria, S. (2007). Soil Texture. *Agronomy Fact Sheet Series, Fact Sheet 29.* Cornell University Cooperative Extension. http://water.rutgers. edu/Rain_Gardens/factsheet29.pdf

Blake, G. R. (1965). Bulk density in methods of soil analysis. *Agronomy, No. 9, Part 1*, C. A.

Ekwueme, B. N. (2003). The Precambrian geology and evolution of the Southeastern Nigerian basement complex. University of Calabar Press, Calabar, Nigeria, ISBN: 9870070109, 135.

Ellis, S. & Mellor, A. (2007). Soils and Environment. Routledge, New York, p. 394.

Essien, N. and Edet, A. (2001). Mineralogy of the components of the Mfomsing limestone, S.E. Nigeria. *Global Journal of Pure Applied Sci., 7*, 683-687.

Fyfe, J. A. Shaw, R., Campbell, S. D. G., Lai, K. W. & Kirk, P. A. (2000). The Quaternary geology of Hong Kong. Geotechnical Engineering Office, Civil Engineering Department. 209.

Gupt, P. K. (2009). Soil, water, plant and fertilizer analysis. 2nd edition, Agrobios Publishers, Jodhpur.

Jackson, M. L. (1973). Soil chemical analysis. Prentice Hall of India, New Delhi.

Jacobs, P. M. (2017). Soil and clay mineralogy. In: D. Richardson, N. Castree, M. F. Goodchild, A. Kobayashi, W. Liu, & R. A. Marston (eds.), International encyclopedia of geography: People, the earth, environment and technology, 1–8. https://doi.org/10.1002/9781118786352.wbieg0256

Jain, R. K.., & Kothyari, U. C. (2009). Cohesion influences on erosion and bed load transport: Influence of Cohesion. *Water Resources Research, 45(6).* https://doi.org/10.1029/2008WR007044

Jenny, H. (1994). Factors of soil formation: A system of quantitative pedology. New York: Dover.

John, K. & Akpan-Idiok, A. U. (2019). Land evaluation, characterization and classification of soil for the proposed oil palm plantation in Ekpri Ibami, Akamkpa Local Government Area, Nigeria. *International Journal of Environment, Agriculture and Biotechnology, 4(3),* 621–634. https://doi.org/10.22161/ijeab/4.3.6

John, K., Ayito, E. O., Akpan-Idiok, U. A. & Effiom, O. D. (2019). Status and distribution of soil available micronutrients along a hillslope at Ekpri Ibami in Akamkpa Local Government Area of Cross River State, Nigeria. *African Journal of Agricultural Research, 14(1),* 40–45. https://doi.org/10.5897/AJAR2016.13634

Khan, Z. H., Mazumder, A. R., Hussain, M. S. & Saheed, M. S. (1997). Chemical and mineralogical properties of some benchmark soils in the floodplains of Bangladesh. *Journal of the India Society of Soil Science 45 (2)*, 485–89.

Kingsley, J., Esther, O. A., Akpan-Idiok, A. U., Bodede, O., & Moodley, R. (2019). Mineralogy of clay components of Aquic arenic paleudults soils of Akamkpa, Southeastern Nigeria. *Journal of Environmental Science and Technology, 12(2),* 102–107. https://doi.org/10.3923/jest.2019.102.107

Kingsley, J., Esther, O. A. & Scholastica, O. (2018). Interaction between some soil physicochemical properties and weather variables on sub-humid tropical rainforest soils of Cross River State, Southeastern Nigeria. *Annual Research & Review in Biology, 29(6),* 1–12. https://doi.org/10.9734/ARRB/2018/45619

Moses, A. & Edet, E. (2003). Assessment of soils around quarry terrain in Akamkpa local government area, Cross River State-Nigeria. *Merit Research Journal of Agricultural Science* *and Soil Sciences, 1(1),* 001-005.

Nwajiuba, C. & Oyeneke, R. (2010). Effects of climate on the agriculture of Sub-Saharan Africa: Lessons from Southeast Rainforest Zone of Nigeria. Oxford Business and Economic Conference Program, June 28-29, 1-18.

Ofem, K. I., Ediene, V. F., Kingsley, J. & Akpan-Idiok, A. U. (2017). Spatial Variability of Soil Properties in Yakurr Local Government Area, Southeast Nigeria. 11.

Ogbaji, P. O. & Akpan-Idiok, A. U. (2013). Mineralogical and Textural Characteristics of Onwu Floodplain Soils,Yala Cross River State, Nigeria. 6.

Ogbaji, P. O., Li, J., Xue, X., Shahrajabian, M. H. & Eneji, A. E. (2018). Mineralogical and textural characteristics of soils of Hancheng and Shannxi Province, China. *Communications in Soil Science and Plant Analysis, 49(3),* 286–290. https://doi.org/10.1080/00103624.2017.1421217

Piper, C. S. (1966). Soil and plant analysis. Hans Publication Bombay.

Schulz, W. H. (2007). Landslide susceptibility revealed by LIDAR imagery and historical records, Seattle, Washington. *Engineering Geology, 89,* 67–87.

White, J. L. (1985). Summary of results of mineralogical study clay fractions of Bangladesh soils. *Proceedings of Workshop on Mineralogy of Soils,* BARC Dhaka, Bangladesh.

Whitting, L. D. (1965). X-ray Diffraction techniques for numerical identification andmineralogical composition. In: Methods of soil analysis, ed C. A. Black, 671–96. Madison WisconsIn: America Society of Agronomy.

Yakubu, M. & Ojanuga, A. G. (2009). Pedogenesis, weathering status and mineralogy of the soils on ironstone plateau (laterites), Sokoto, Nigeria. In: Fasina AS, Ayodele O.J., Salami A.E. and Ojeniyi SO (ed). Management of Nigeria soil resources for enhanced agricultural productivity. Proceedings of the 33rd Annual Conference of the Soil Science Society of Nigeria held at University of Ado-Ekiti, Ado-Ekiti, Ekiti State, Nigeria. March 9-13, 2009, 26-37.

Received: June, 30, 2019; *Accepted:* August, 27, 2019; *Published:* June, 30, 2020