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Mineralogical Characteristics of Soils in Southern Taraba State Northeast, Nigeria

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Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

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ABSTRACT

Mineralogy of fadama soils of southern Taraba state was carried alongside its influence on the soil's physical and chemical properties. The three local government areas selected for this study were Ibi, Wukari and Donga. The mineralogical compositions of the soils were evaluated using the clay fraction. X- ray diffraction (XRD) analysis showed ibi had quartz (21%), microcline (47%) and kaolinite (25%), Wukari Tsukundi had quartz (17%), microcline (20%) and kaolinite (32%), phlogopite (15.4%) and gibbsite (23%) while Donga had mineral composition of quartz (20%), microcline (33%) and kaolinite (47%) and therefore the clay minerals are interstratified (mixed mineralogy). The soil textures in these mapping units (MUs) are sandy clay loam (SCL), loam sand (LS) and sandy loam (SL) in the Ap horizons of pedons I, 2 and 3 respectively. The subsurface horizons are Silt Loam, SCL and LS. The silt clay ratio (SCR) indicated that the soils are relatively young soils with reserved weatherable minerals, mean SCR were 1.40, 1.50 and 4.00 in pedons 1, 2 and 3 respectively. The acidity decreased as the profile depth increased and it was moderately acidic soil with pH(KCl) ranged from 5.92- 4.75 for pedons. The delta pH (ΔpH) of the soils showed all negative values; this indicated that the soil colloids contained appreciable silicate clay minerals with relatively constant surface charge while C/N ratios indicated advanced stage of organic matter

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decomposition. Percentage Al saturation to the TEA stood at 15%, 19% and 9% for pedons I, 2 and 3 respectively, The exchangeable Ca constitutes above 70 % of the total exchangeable bases (TEB). The percentage base saturation (%BS), was largely dominated by exchangeable cations in moderately to very high rating and their mean values are 80%, 77% and 74% for pedons I, 2 and 3 respectively. The arrays of minerals are at different stages of weathering- quartz and phlogopite at moderate stage of weathering, microcline at minimal stage of weathering while kaolinite and gibbsite are at intense weathering stages. These minimally and moderately weathered soils are generally considered to be of good fertility status. The soils were classified as Alfisols/Entisols mix.

Keywords: clay minerals; soil pH; Texture; % base saturation; aluminosilicates; morphogenetic horizons.

1. INTRODUCTION

Soil behavior is affected by soil mineralogy which plays a prominent role along with the other two cores: physical properties (texture) and chemical properties (soil organic matter (SOM) and soil pH). Soil mineralogy includes primary minerals in the sand and silt fractions and secondary minerals that form in the clay fraction through inheritance, neo-formation and transformation [1]. Mineralogy determines inherent soil fertility through the type of weatherable minerals present in the sand and silt fractions and the cation and anion exchange capacity of the minerals in the clay fraction [2,3]. Primary minerals in soils are determined by their parent materials. The weatherable primary minerals – feldspars, micas, volcanic glass, olivine, apatite and others – provide the reservoir of all nutrients (except nitrogen) that are made available to plants with time. Other primary minerals, such as quartz, contain no nutrients. Secondary minerals are those formed in the soil through weathering processes and occur in the clay fraction. They, along with SOM and soil pH, provide the cation and anion exchange that controls plant nutrients in the soil solution. These ion-exchange processes are among the most important determinants of plant nutrient uptake and nutrient cycling. Soils low in SOM is most susceptible to erosion due to poor soil aggregate thereby leading to low water stable aggregate. The ions in soil solution come from the release from weatherable minerals, fertilizer and organic input additions, as well as leaching from horizons above. Clay mineralogy also influences the soil structure, porosity and stability through formation of micro and macro-aggregates while Okusami [4] added that clay mineralogy helps status-quo weathering index/ stage of any soil and other tactile properties reflected in consistence, cohesion, plasticity, colour, density, and specific gravity in many of such properties clay plays an integrating role depending on clay type and content. Ajiboye et al. [5] had a conclusion that mineralogy of the soils had a significant influence on K supplying power of soils. Clay minerals have electrostatic charge, consisting of negative charges to which exchangeable cations are retained, and positive charges to which exchangeable anions are retained while cation exchange capacity (CEC) measures the exchangeable cations that can be retained by soil colloids and is determined at different pH values (pH_7 and $pH_{8.2}$). The clay minerals with permanent charge are the 2:1 layer alumino-silicates, where two octahedral $Al_4(OH_8)$ sheets sandwiched a tetrahedral Si_4O_{10} sheet. Clay minerals have permanent negative charge due to the isomorphous substitution of silicon or aluminum ions for ions of a lower valency. Permanent-charge clay minerals are also known as constant-surface-charge minerals and high-activity clays. Clay minerals have permanent negative charge due to the isomorphous substitution of silicon or aluminum ions for ions of lower valence. However, according to Sanchez [2] the main permanent-charge clay minerals in descending order are: smectites, chlorites, vermiculites and hydrous mica while main variable-charge clay minerals are: allophane; imogolite; the 1:1-layer-silicate minerals halloysite and kaolinite (with little isomorphic substitution in the lattices but large edge effects, which provide variable charge); the various iron and aluminum oxides and hydroxides, including the crystalline gibbsite, $Al(OH_3)$, boehmite (AlOOH), goethite (FeOOH) and hematite (Fe_2O_3).

Kaolinitic soils are the most widely occurring soils in the tropics, especially in tropical Africa [6,7,8]. According to Juo and Franzluebber [8], these soils have a sandy, loamy sand, or sandy loam surface soil and sandy clay to clayey subsoil containing approximately 20-60% clay in the lower B- horizons. Silt content is usually low throughout the profile (< 20%) with the exception of soils derived from loess and colluival/ alluvial materials. Soil erosion, compaction, and low nutrient- and water-holding capacities are the major constraints under intensive cropping. High-base-status kaolinitic soils (Alfisols, Inceptisols and Entisols) are mostly used for maize *(Zea mays),* cowpea *(Vigna unguiculata),* cassava *(Manihot esculenta),* yam *(Dioscorea* spp.), cocoyams (*Xanthosoma saggitifolium)* and cropped to paddy rice and sugarcane when they occur in fadama (floodplains). Based on the forgoing, the major aim of this study was to characterize the mineralogical and physico-chemical properties of soils and relate it to soil fertility status in southern guinea savanna soils in Taraba state.

2. MATERIALS AND METHODS

2.1 Study Area

The study was carried out in three Local Government Areas (LGAs) of Southern Taraba State in the Guinea Savannah belt of Nigeria and it lies between latitude 6.5^0 - 9.5^0N and longitude 9.2^0 – 11.8^0E. The LGAs are Ibi, Donga and Wukari. The state is characterized by undulating landscape dotted with a few mountainous features. The vegetation of the state is low forest in the southern part and grass land in the northern part and the agroecological zone is Subhumid Jalingo-Donga-Ganye high plain [9]. Situated on the Benue trough or valley. The Benue valley is an elongated geological basin stretching from around the confluence of the rivers Niger and Benue to the Northeast of Nigeria. Wukari agro-ecological zone is in the southern Guinea Savanna and it is characterized by tropical hot/wet weather with distinct rainy and dry seasons (Aw Koppen's climate classification); as modified by Peel et al [10]. The rainy season months are May to October while the dry months are November to April. Annual rainfall ranges from 1100-1250 mm [11]. The mean annual temperature is about 29^0C (temperature can reach 40^0C in March). The hydrology is governed by the Benue and Donga Rivers. The dry and wet seasons are controlled by the annual migration of the inter-tropical zone of convergence (ITZC). The area falls within the yam (tuber) belt of Nigeria. The sand stone/ shale/ undifferentiated basement complexes are the parent materials. The soils are derived from cretaceous sediments and pre-Cambrian to Cambrian undifferentiated metamorphic sediments [12]. The soils are ferrallitic soils of deep porous brown soils on sandy materials/ undifferentiated ferruginous tropical soils on sandstone (Bima-sandstone) parent materials [13] and home to many minerals such as Galena, Gypsum, Quartz, Marble, Sapphires, brine, Lead etc

2.2 Field Work and Soil Sampling

A reconnaissance field study was carried out for the purpose of identifying the major fadama (floodplains) in the study areas through which mapping units (MU) were delineated on the basis of flooding, that is submerged soils, moderately saturated soils and adjoining upland in each location [14]. The soil survey was carried out at a scale of 1: 50,000 (semi intensity scale) on the fadama and mapping units were established using floodplain geomorphology and morphogenetic differences. Using a rigid grid survey along transects at 500m within MU and 300m between MU. Each mapping units have three replicates. A representative soil profile pit was sunk in each treatment, morphological elements of the pedons were described according to the revised soil survey manual (Soil Survey Staff, 2006). Soil colours of genetic horizon were determined in-situ using the Munsell soil colour chart under moist conditions. Composite samples were made after thoroughly mixing the soil samples collected from each MU for the XRD analysis while the sample for routine analysis were collected based on genetic horizon differentiation. This study was limited to the fadama soils within the catchment area.

2.3 Laboratory Analysis

A composite sample was made from the 2 mm-sieved soil for each of the study locations, this was done to have an over view of the type, quantity of the minerals present. The samples were subjected X-ray diffraction analysis (XRD). The soil samples underwent some washing and treatment to remove carbonates (acetic acid), removal of organics (hydrogen peroxide), separation of clay decantation and centrifuge to obtain the 2μmϴ and smear slide mounted for heat treatment and reading using the empyrean diffractometer at generator setting of 40 mA- 45 kV. The anode material used was copper (Cu). The followings were displayed: stick pattern and intensity (%) of the minerals identified, crystal system, calculated density (g/cm^3) and the displacement peaks at 2Theta. The method of analysis was as described by Bish [15] and in parts by method described by Unamba-Opara, Wilson and Smith [16].

3. RESULTS AND DISCUSSION

Morphological properties of the soils are presented in Table 1. All horizons have well drained upper horizons and poorly drained sub soil horizon this may be due to the coarse nature of the top and finer nature of the sub profile. The soil depth at this MU was deep > 120cm indicating a moderate profile and a slope gradient of < 2%. The MU has restriction zone of hardpan or sesquioxides/ plinthic horizons which is why it could retain water. The mean MASL for the MUs was 105, they are all well drained (it is also imperfectly drained and seasonally flooded). The various physiographic positions have different colour matrix ranges which are described. The MUs pedons are 1, 2 and 3. The soil in this MU was moderately deep and well drained though it is seasonally flooded and submerged. In pedon 3, it was observed that across the horizon, the colour ranges from Black (7.5YR 2.5/1) in Ap horizon to Reddish Yellow (7.5YR 6/6) to strong brown (7.5YR 5/6) to gray (5YR 5/1) to light gray (5YR 7/1) in Bt1, Bt2 andBt3 horizon respectively. Pedon 2 has dark yellowish brown (10YR4/4) in the Ap horizon while the subsoil horizons has pale red (10R6/2) and light gray (10R7/1) while pedon 1 has colour in the Ap horizon as brown (7.5YR4/4). The subsoil horizon are yellowish brown (2.5YR3/4), light reddish brown (2.5YR6/3) just below that was the pinkish white (10YR5/2) and this indicated that anaerobic condition exists in the deeper subsoil. The presence of mottles in the subsoil horizons of pedon 1 and 3 were in the hue of 7.5YR and 2.5YR (reddish yellow) while pedon 2 has mottles in the hue of 2.5YR in the Ap horizon and 10YR in the subsoils. The colour matrix of dark yellowish brown, strong brown and reddish yellow are associated with minerals such as goethite (FeOOH) and haematite (Fe_2O_3) and gibbsite [$Al(OH_3)$] [17,18]. The colours of the mottles also agrees with the findings of Aki et al. [18], that dark red (10YR3/6) to reddish yellow (7.5YR6/6) are indication that the soils were either imperfectly drained or poorly drained during the rainy season, which was the case in these study sites. The soil structure ranges from sub angular blocky and granular in the topsoil to angular in the subsoil. The changes in structure down the profile were seen to be connected to clay accumulation leading to clay bulge. The alternate flooding and drying have impact on all the soil characteristics. The soil consistence ranges from friable-crumby to firm –very firm while sticky and form ribbon under moist condition. The result presence ranges from many (very fine to coarse roots), common (very fine to medium roots) for all the pedons in the MUs. The pedons have other features as black artefacts, cracks, burrowing animals (rodents and frogs) earthworm caste and an abundance of macro fauna activities. The soil horizon boundaries in the MU are clear and smooth. Pedon 3 has black (5YR2.5/1) subsoil horizon which suggested buried horizon. The top soils in this study site were observed to be highly compacted due to herding and grazing of cattle. There was abrupt textural change in the pedon 2 where the third horizon had a very coarse (sandy) texture sandwiched between Bt horizons and the fourth horizon was highly plastic. The soil structure ranges from sub angular blocky in the subsoil and granular in the topsoil to angular in the subsoil except in pedon 2 where horizon 3 was structureless. The changes in structure down the profile were seen to be connected to clay accumulation leading to clay bulge. The alternate flooding and drying have impact on all the soil characteristics. The soil consistence ranges from friable (gritty) -crumby to firm –very firm. The root presence ranges from many (very fine to coarse roots), common (very fine to medium roots) for all the pedons in the MUs. The pedons have other features as black artefacts, cracks, earthworm caste absence of O horizon and an abundance of macro fauna activities. The soil horizon boundaries in the MU are clear and smooth in pedon 1, clear and wavy in pedon 2 and clear in pedon 3.

The preponderance textural properties of fadama soils in southern Taraba state are presented in Fig. 1. The parent materials are the shale/sandstone on a sedimentary basement complex. The soils here are moderately deep reaching 120 cm before plinthitic restriction are encountered though they are seasonally well drained. The soils in these fadama are alfisols / inceptisols mix [14]. The soil textures in these MUs are sandy clay loam (SCL), loam sand (LS) and sandy loam (SL) in the Ap horizons of pedons I, 2 and 3 respectively (Table 2). The subsurface horizons are Silt Loam, SCL and LS. The preponderance of sand in particle size distribution (PSD) is typical of tropical soils especially of savannah ecosystem where Maniyunda and Raji, [6] had already reported a similar preponderance of sand. Silt content averaged 28%, 20.54% and 13.53% in pedons 1, 2 and 3 respectively. Where silt values are higher than clay values is an indication for reserved weatherable minerals in the soil, silt weathering result in clay mineral development while soil with

Table 1. Morphology Properties southern Taraba Fadama soils

Coordinate	Horizon	Depth	Colour	Mottling	Text.	Str.	Consist	Bound.	Drainage	Veg.	Root pres.
PEDON 1: Ibi soils											
$7^{0}52^{1}51.0^{11}$N	Ap	P0-20	Brown7.5YR4/4	A	S	Granular	Friable	SC	WD/SF	grassland	Many (vf-c)
$10^{0}01^{1}41.2^{11}$E	AB	20-35	Reddish yellow 7.5YR 6/6	A	S	Granular/crumby	Friable	SC	WD/SF	savannah with no	Many(vf-c)
102Masl	Bt1	35-85	Strong brown 7.5YR 4/6	A	LS	SAB	firm & Sticky	SC	WD/SF	shrubs	Many(vf-m)
	Bt2	85-128	Yellowish Brown 10R 5/4	cF(2.5YR5/8)	LS	AB	Very firm & Sticky	SC	WD/SF		Few(vf-f)
	Bt3	128-200	Yellowish Brown 10YR 5/8	cF(2.5YR2.5/1&4/8)	LS	AB	Very firm & Sticky	SC	WD/SF		Few(vf)
PEDON 2: Wukari soils											
$7^{0}53^{1}27.9^{11}$N	Ap	0-18	Dark Reddish brown 2.5 YR 3/3	A	SL	Granular	Friable	CW	WD/SF	grassland savannah	common (vf-f)
$10^{0}01^{1}27.2^{11}$E	AB	18-58	Pale Red 2.5YR 7/2	cF(10YR6/8&3/3)	Si-loam	SAB	Firm	CW	WD/SF	with no	Few (vf-f)
109Masl	Bgq	58-97	Yellowish Brown 10 YR 5/8	cM(5Y3/1)	S	Granular(gritty)	Friable & gritty to touch	CW	WD/SF	shrubs	A
	Bt1g	97-120	Dark grayish Brown 10YR 4/2	cM(2.5YR5/4)	Ls	AB	firm & Sticky	CW	WD/SF		A
PEDON 3: Donga Soils											
$7^{0}37^{1}7.15^{11}$N	Ap	0-20	Black 7.5YR2.5/1	cC(7.5YR6/6)	SCL	Granular	Friable	C	WD/SF	grassland	Many (vf-m)
$9^{0}09^{1}9.23^{11}$E	AB	20-34	Reddish yellow 7.5YR 6/4	cC(7.5YR7/4)	SC	SAB	Friable	SC	WD/SF	savannah with no	A
100Masl	Bt1	34-49	Strong brown 7.5YR 5/1	cC(7.5YR5/8)	SC	AB	firm & Sticky	SC	WD/SF	shrubs	A
	Bt2	49-82	Gray 5YR 5/1	cF(5YR5/6)	SC	AB	Very firm & Sticky	SC	WD/SF		A
	Bt3	82-120	Light gray 5YR 7/1	A	SC	AB	Very firm & Sticky	SC	WD/SF		A

Mottle: A= absent, cc = common and coarse, cm = common and medium, cf= common and few,
Texture: SL = sandy loam, SCL= sandy clay loam, SC= sandy clay, LS= loamy sand
Structure: AB = angular blocky, WMSAB = weak medium sub-angular blocky,
Root presence: vf-c = very fine- fine-medium-coarse
Horizon boundary: c= clear, sc= smooth and clear, cw= clear and wavy, sw = smooth and wavy
Horizon: Ap =plough layer, Bt= argillic or kandic horizon, AB= transition horizon, g= strong gleying, r= weathered bedrock, q= silica accumulation, b = buried horizon, v= plinthite (hard, iron enriched subsoil)

Table 2. Physical properties of the Studied Soils

Horizon	Depth	Sand	Silt	Clay	SCR	TC	BD	Po	MC
	(cm)	%	%	%			g/cm³	%	%
PEDON 1: WUKARI SOILS									
Ap	0-18	64.24	30.28	5.48	5.53	SL	1.84	30.56	10.50
AB	18-58	26.00	64.28	9.92	6.47	Si-loam	1.56	41.10	10.50
Bt1gq	58-97	95.8	0.08	4.12	0.02	S	1.41	46.80	12.50
Bt2g	97-120	73.8	17.28	8.92	1.94	LS	1.01	61.90	21.50
Mean		65.00	28.00	7.11	3.49		1.46	45.10	14.00
Range		26.00-95.80	0.08- 64.28	4.12-9.92	0.02-6.47		1.01-1.84	30.56-61.90	10.50-21.50
PEDON 2: DONGA SOILS									
Ap	0-20	62.24	22.28	15.48	1.44	SL	1.41	49.81	10.00
AB	20-46	49.24	15.28	35.48	0.43	SCL	1.34	46.79	10.50
Bt1	46-67	46.24	21.28	41.48	0.51	SC	1.34	49.43	15.00
Bt2b	67-108	64.24	21.28	14.48	1.47	SL	1.12	57.73	21.50
Bt3	108-120	63.96	22.56	16.48	1.37	SC	1.29	51.32	16.50
Mean		57.20	20.54	25.00	1.04		1.30	51.02	14.70
		64.24-49.24	22.56-15.28	41.48-14.48	1.47-0.43		1.41-1.12	57.73-46.79	21.50-10.00
PEDON 3: IBI SOILS									
Ap	0-16	83.80	10.28	5.92	1.73	S	1.61	39.25	10.50
AB	16-30	80.24	16.28	3.48	4.67	LS	2.13	19.62	10.30
Bt1g	30-70	78.24	17.28	4.48	3.86	LS	1.97	25.66	21.50
Bt2g	70-110	79.36	10.28	10.36	0.99	LS	1.78	32.83	16.80
Mean		80.41	13.53	6.06	2.81		1.87	29.34	14.77
Range		78.24-83.80	10.28-17.28	3.48-10.36	0.99-4.67		1.61-2.13	19.62-39.25	10.30-21.50

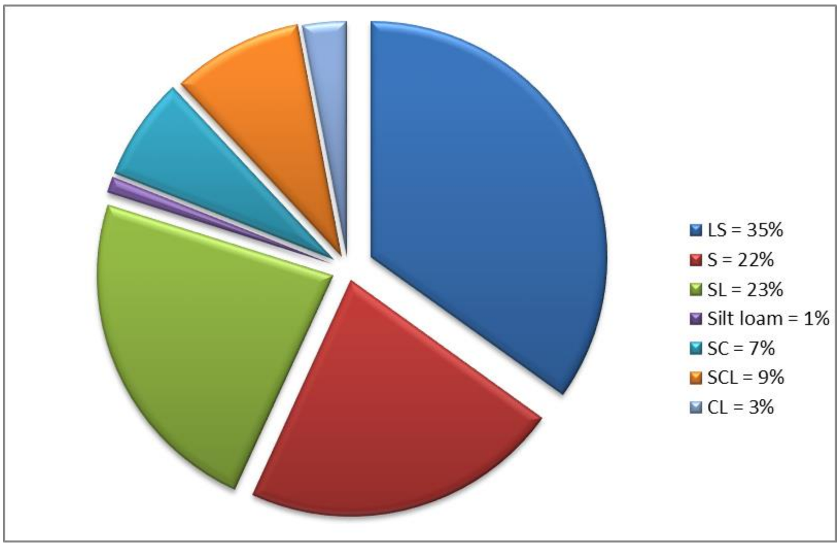

Fig. 1. Textural Class Distribution of Southern Taraba Fadama Soils
LS = Loamy Sand; S = Sand; SL =Sandy Loam; SC= Sandy Clay; SCL= Sandy Clay Loam; CL= Clayey Loam

weatherable minerals is an indication for higher fertility status. Clay contents of the soils increased with depth generally indicating the illuviation (translocation movement) soil finer particles down the profile. The argillic (Bt) horizons were finer than the overlain Ap horizon. It can be observed that the soils generally had textural classes around the loamy texture which suggests a soil with good texture for arable cropping. Rock outcrop was not encountered anywhere in the field. All the identified Bt (Argillic) horizons had mild presence of sesquioxide (Fe-Mn) concretion. This may be due to translocation of clay following illuviation and plinthization (lateritization- which is vividly manifested in tropical guinea savannah soils). Soils with higher sand content are prone to soil erosion and leaching. Clay in the subsoil horizons (Bt) was nearly three time greater than the value obtained for the Ap horizons these type of observations were made earlier by [19,6]. Other authors [20, Ahukaemere et al. [21] observed that colloidal particles contained in the soil increases as the content of plant nutrients bound by these particles increases, this was particularly true for fadama soils as sediments are annually supplied with high volumes of colloidal particles and clay particles are important to fadama users because of its ability to hold nutrient and water [22]. Floodplain systems are complex, comprising of an arrays of sediment enrichment occasioned by the annual flooding system which conveys particles of different sizes and are deposited in different physiographic position. These different materials settle at different rates depending on what condition is prevalent.

The silt/clay ratio (SCR), in these MUs also implied that the soils were relatively young or recently formed. The mean SCR were 1.40, 1.50 and 4.00 in pedons 1, 2 and 3 respectively. Yakubu and Ojanuga [23] had reported that SCR below 0.15 was indicative of an old soils (senile) while SCR above 0.15 was indicative of a young soil with weatherable reserves. The averages bulk density indicated no limitation to crop root penetration while Esu [24] reported that bulk density value less than 1.60gcm-^{3} is an indication that air and water movement in the soil are at optimum. However, the surface horizons recorded high level of bulk density which may be due to activities of herds grazing frequently and this coupled with routinely use of the land for fadama rice cultivation (ponding) in the study area. An inverse relationship was observed between Bulk density and porosity.

3.1 Chemical Properties

Select chemical properties of the soils in the study area are presented in Table 3.The pH (water) ranged from 6.99-5.78. The acidity decreased as the profile depth increased and it was moderately acidic soil according to the rating of Chude, et al., (2011) while the pH(KCl) ranged from 5.92- 4.75 for all pedons. The Ap (top soil) horizons for both the pH (H_2O) and pH(KCl) were 6.96 and 5.65 6.96 and 5.92, and 6.00 and 4.94 for pedon I, 2 and 3 respectively. The mean value for the pH (H_2O) and pH (KCl) were 6.91 and 5.35, 6.76 and 5.63, and 6.28 and 5.31 for pedon I, 2 and 3 respectively. The mean pH values obtained agreed with the levels reported by Jamala and Oke [25]. The pH range for these soils was within the optimal pH for release of both the macro and micro nutrients for sustainable agriculture. This agrees with the findings of Zaku, et al. (2011) and Osodeke [26] that found pH for Wukari soils series suitable for arable cropping and conforms to that of It was observed that top soil (Ap horizon) to subsoil had stability in decreasing acidity, this may be due to microbial transformation of soil organic matter and microbial intermediate by-product common to anaerobic (reducing) condition in floodplain systems. Osodeke [26] further stated that virtually all aspects of the soil properties ranging from nutrient availability and absorption by plants to effects on microbial population and activities, plant growth and distribution were influenced by the soil acidity and concluded that soil acidity determines the use to which any given soil can be put into. The delta pH (ΔpH) of the soils showed all negative values; this indicated that the soil colloids contained appreciable silicate clay minerals with relatively constant surface charge [2], Okusami et al. [27]. These soils with -ΔpH indicates that the clay has exchangeable capacity - cation exchangers. There exists a relationship between SOC and soil organic matter (SOM) found in the soil which is that about 58% of mass of OM exist as carbon are estimated as the percentage of SOM using the conversion factor 1.72.

The C/N is important for determining mineralization and immobilization of nitrogen, the C/N ranged from 30.00 – 7.68, ratios < 25 favours mineralization as stated by Paul and Clark [28]. C/N ratios indicate the advanced stage of organic matter decomposition [29]. Low C/N is indicative of higher microbial population and more rapid mineralization.

Available P has been described as one of the most important plant nutrient elements and one of the most limiting nutrient elements in agricultural soil due to its high disposition to fixation by several soil constituents. In an acidic soil, P can form complexes with Fe, Al, Mn while in an alkaline soils, complexes are formed with Ca, hence P availability is greatly restricted by the soil pH and climatic condition, soils has higher P in rain forest zones than in savanna grassland [26]. The soil total exchangeable acidity (TEA) is governed by the presence of high amount of Aluminum and hydrogen in the soils of the tropics. The amount of TEA in the soil is responsible for the declining fertility status of tropical soils as they take hold of the exchange site and dominate it [30]. However, the contribution of Aluminum (% Al saturation) to the TEA stood at 15%, 19% and 9% for pedons I, 2 and 3 respectively. This implies that TEA contributed to ECEC is virtually due to H^+ and contrary to the findings of Okusami et al. [27] where they found Al contributing as much as 99% to the TEA. The low Al presence may be due to the near neutral soil pH (significant negative correlation exist between Al and pH), ferrolysis, drainage and mineral type found in the study area. The total exchangeable bases (TEB) which is the sum of all the soil exchangeable cations such as Ca, Mg, Na and K had mean values of 7.24 cmol/kg, 6 cmol/kg 1.94 cmol/kg for pedons 1,2 and 3 respectively. The exchangeable Ca constitutes above 70 % of the TEB and this agrees with Maniyunda [31] who observed similar trend in lithosequence study in the sub-humid savanna of the northwestern Nigeria while this findings also agreed with Samndi (2011) who reported that a higher TEB value in the top soils are due to the recirculation of Ca, Mg and K to the surface through organic matter mineralization. Effective cation exchange capacity (ECEC) had a mean of 9.08 cmol/kg, 8.04 cmol/kg and 2.61 cmol/kg. The ECEC was low when compared to the ratings of Landon [32]. The ECEC of soils is dependent on the amount and type of clay and organic matter. This was in conformity with the findings of Brady and Weil [33]. The cation exchange capacity (CEC) ranged from 13.20 – 7.23 cmol kg^{-1} with mean value of 9.31cmol kg^{-1}, 10.02cmol kg^{-1} and 10.00 cmol kg^{-1} for pedons I, 2 and 3 respectively. The CEC was rated moderate to high [32]. The percentage base saturation (%BS), was largely dominated by exchangeable cations in moderately to very high rating and their mean values are 80%, 77% and 74% for pedons I, 2 and 3 respectively. Such high %BS holds promising future only if fadama soil is put to sustainable use and owing to the very high %BS saturation the soils has been classified in the order level as alfisols. Ca:Mg ratio of <5.1 indicates low activity clay [33]. The Ca:Mg had mean of 2.50, 1.90 and 2.30 for pedons I, 2 and 3 respectively. The soils are moderately fertile when compared with the rating (< 3) of Landon [32]. However, the Ca:Mg ratio found in Wukari Tsukundi was higher than that of Ibi and Donga.

Table 3. Chemical Properties of the Studied Soils

Hor. Desig	depth (cm)	pH(water)	pH(KCl)	∆pH	SOC (%)	TN (%)	C:N	Av.P(mg/kg)	TEA (cmol/kg)	EAl (cmol/kg)	TEB (cmol/kg)	ECEC (cmol/kg)	CEC (cmol/kg)	%BS	Al sat (%)	Ca:Mg
PEDON 1: WUKARI SOILS																
Ap	0-20	6.96	5.6	-1.63	0.4	0.02	20	0.12	1.8	1.3	7.69	9.49	13.2	81	14	2.40
AB	20-34	6.99	5.13	-1.86	0.3	0.01	30	0.12	1.61	1.18	7.47	9.08	5.9	82	13	1.70
Bt1	34-49	6.99	5.67	-1.32	0.4	0.04	10	0.55	1.63	1.19	7.25	8.88	9.7	82	13	2.60
Bt2	49-82	6.81	5.32	-1.49	0.2	0.02	10	0.22	2.29	1.40	6.35	8.64	7.23	73	16	2.00
Bt3	82-120	6.80	5.01	-1.79	0.3	0.01	30	0.59	1.89	1.67	7.42	9.31	10.5	80	18	3.80
Mean		6.91	5.35	-1.62	0.32	0.02	14.06	0.32	1.84	1.35	7.24	9.08	9.31	80	15	2.50
Range		6.99-6.80	5.67-5.01	-1.86-1.32	0.4-0.2	0.04-0.01	30-10	0.59-0.12	2.29-1.61	1.67-1.19	7.96-6.35	9.49-8.64	13.20-7.23	80-73	18-13	2.60-1.70
PEDON 2: DONGA SOILS																
Ap	0-20	6.96	5.92	-1.04	0.4	0.04	10	0.1	2.3	1.4	5.86	8.16	12.3	72	17	1.1
AB	20-46	6.99	5.78	-1.12	0.3	0.03	10	0.37	1.93	1.7	5.65	7.58	11.2	75	22	1.8
Bt1	46-67	6.81	5.33	-1.51	0.2	0.02	10	0.64	2.09	1.8	5.47	7.56	8.9	72	24	2.2
Bt2b	67-108	6.56	5.57	-0.99	0.4	0.03	13.33	0.15	2.2	1.6	6.98	9.18	7.71	76	17	2.4
Bt3	108-120	6.48	5.54	-0.94	0.3	0.01	30	0.15	2.19	1.3	6.01	8.2	10	73	16	1.9
Mean		6.76	5.63	-1.12	0.32	0.026	14.67	0.28	2.14	1.56	6	8.04	10.02	74	19	1.9
Range		6.96-6.48	5.92-5.33	-2.06	0.40-0.30	0.04- 0.01	13.33-10.00	0.64-0.10	2.30-1.93	1.80-1.30	6.98-5.47	9.18-7.56	12.30-7.71	76-72	24-16	2.40-1.10
PEDON 3; IBI SOILS																
Ap	0-16	6	4.94	-1.06	2.494	0.26	9.59	9.45	1.44	0.85	2.7	4.14	11.4	65	20	2.1
AB	16-30	5.78	4.75	-1.03	1.516	0.12	12.63	13.65	0.61	0.2	1.51	2.11	8.6	72	9.6	2.4
Bt1g	30-70	6.69	5.76	-0.93	0.898	0.11	8.09	4.69	0.51	0.16	2.54	2.96	7.6	86	5.4	2.6
Bt2g	70-110	6.63	5.78	-0.85	0.998	0.13	7.68	3.29	0.21	0.01	1	1.21	12.4	83	0.8	2.2
Mean		6.28	5.31	-0.97	1.48	0.155	9.5	7.77	0.69	0.305	1.94	2.61	10	77	9	2.3
Range		6.69-5.78	5.78-4.75	-1.91	2.48-0.88	0.26-0.11	12.63-7.68	13.68-3.29	1.44-0.21	0.88-0.01	2.70-1.00	4.14-1.21	12.4-7.6	86 – 72	20-0.80	2.6-2.1

3.2 Clay Minerals

The XRD reveals the crystal structure (monoclinic, triclinic hexagonal, trigonal, orthorhombic, anorthic, tetragonal etc), density (g/cm^3) which is important in the understanding of soil mineral particularly the colloidal minerals which are important to cation exchange and to chemical weathering release of nutrient elements in soils. The most active portion of the soil are those in colloidal fraction (clay and SOM), they are the seat of ion exchange. The climate of an area, parent materials and duration as well as the weathering intensity influences the mineralogical processes and composition in soils [6]. Maniyunda and Raji [6] further concluded that in soils sand and silt fractions as mainly characterized by inherited primary minerals while clay fraction is mostly secondary minerals. As a generalization the parent material will greatly influence the mineralogy of the weathering bye-products in the soil or with soils but with high leaching the influence will gradually diminish. Mitchell and Soga [1] stated that mineralogy was the primary factor controlling the size, shape and properties of soil particles, these same factors determine the possible ranges of physical and chemical properties of any given soil; therefore a priori information about soil provides intuitive insight as to its behaviour.

3.3 XRD of Clay Minerals and Their Preponderance in Southern Taraba

These dominant clay minerals are indicative of the parent materials undergoing weathering and are similar to that of Wukari Tsukundi while few differentiated genetic horizon observed suggests that the fadama soils of Donga are younger than that of Wukari Tsukundi fadama while Ibi soils are mainly composed of quartz (21%), microcline (47%) and kaolinite (32%) (Fig.2). These soils are mainly composed of quartz (16.5%), microcline (19.8%), phlogopite (15.4) gibbsite (23%) and kaolinite (25.3%) (Fig.3). The dominant clay minerals are also indicative of the parent materials (undifferentiated basement complex of black shale, limestone, sandstone, siltstone, mudstone), the type and extent of weathering. The soils belong to the Eze – Aku shale group (Wukari series). The very many number of minerals identified in its XRD and the many differentiated genetic horizon suggests that the fadama soils of Wukari Tsukundi was older than the two other fadama. Donga soils are mainly composed of quartz (20%), microcline (33%), and kaolinite (47%) (Fig.4). The variations in mineral composition apart from nature of parent materials may be due to erosional activities, land utilization types and other anthropogenic impact as well as climatic variations (precipitation and temperature).

3.4 Quartz (Si_3O_6)

Quartz (Si_3O_6), with a crystal system of hexagonal and density of 2.65 g/cm^3. It has peaks which ranges from 20.861(2theta) to 87.454 (2theta) but highest recorded peak was at 26.642 at 100% intensity (Fig. 5). Quartz is widely spread in igneous rock and sedimentary rock. It is resistant to both physical and chemical weathering. Quartz is ubiquitous, plentiful and durable. It dominates the sand fraction of the soil; it gives the gritty feel to soil and helps to improve soil aeration and soil workability. Its composition in the XRD analysis was 21% and with the least percentage in the XRD is an indication that the soils of ibi fadama has finer soil separates or that the highly resistant quartz has been degraded [8]. Quartz is a tectosilicate mineral, its crystal system confer that resistant to weathering. In the order of resistance to weathering quartz is the most resistant [8].

3.5 Microcline ($K_2NaAl_2Si_6O_{16}$)

Microcline ($KAlSi_3O_8$), is an important igneous rock forming tectosilicate mineral and it is also found in metamorphic. It is potassium rich alkali feldspar with less of sodium. It is also granite and pegmatites igneous rock formed underground. The mineral crystal system is anorthic with density of 2.56 g/cm^3. It has peaks which ranges from 12.01(2theta) to 60.04 (2theta) but highest recorded peak was at 27.50 at 100% intensity (Fig. 6). Microclines (orthoclase) are found in igneous, metamorphic, and sedimentary rocks in all parts of the world. Feldspar minerals have very similar structures, chemical compositions, and physical properties. Feldspar is the second most common mineral after quartz. The composition of microcline was 47% indicating that the soils still possess weatherable minerals though feldspar have high resistance to weathering third after quartz [8] and number six (6) on the Moh scale. Feldspar been a tectosilicate holds an appreciable amount of K and have no Fe or Mg meaning that the Fe and Mg in the soils sourced from sediments of fluvial origin. However, parent materials are black shale and siltstone, shale and limestone, fine-medium grained sandstone and mudstone and alluvium [12]. Under this agroecological zone, the impact of temperature, low rate organic matter return and fluctuation in rainfall pattern has great influence on the soil's physical characteristics such as bulk density, porosity, clay content etc

3.6 Kaolinite $AlSi_2O_5(OH)_4$

Kaolinite $AlSi_2O_5(OH)_4$ is a 1:1 lattice clay (one silica tetrahedral to one aluminium octahedral sheet) mineral, that is dominant in tropical soil. Okusami [4] described kaolinite as most discernable and ubiquitous in soil of the tropics. Kaoliniztaion is favoured in high temperature- induce water dissociation of parent material, leaching, low electrolyte content, low pH, and high precipitation [6,1]. It is orthorhombic clay with density of 2.61 g/cm^3. It belongs to the phyllosilicate (layered) group. Kaolinite is formed from the chemical weathering (alteration) of feldspar or other aluminium silicate minerals (mica) and is an important components in many tropical soils. Kaolinite has low capacity to adsorb cations due to its restricted external surface area which makes isomorphous substitution less likely thus low cation exchange capacity (3-15 cmol/kg). It has peaks which ranges from 20.8(2theta) to 89.04 (2theta) but highest recorded peak was at 26.50 at 100% intensity (Fig.7). The abundance of kaolinite indicates that the floodplain soils have some features of aging this is further buttressed by the preponderance of sand in the particle size analysis. The composition of kaolinite was 25.3% indicating that the fadama soils of Ibi are inherently fertile for hydromorphic crops such as rice (Oryza sativa and sugarcane (Saccharum officinarum) and the dry season farming of early maturing cassava and yam as well as vegetables. The variation in basal intensities found for kaolinite, microcline and phlogopite are indicative of clay mineral found in shales [34].

3.7 Gibbsite

Gibbsite ($Al_8O_{24}H$) is one of the forms of aluminium hydroxide and a monoclinic crystal system. It is common in highly weathered soil, these results from micronutrient with in-situ desilicification. Gibbsite composition is 23%, with the potential for contributing to soil acidity through the hydrolysis of Al^{+3} to form alumino-hydroxy which in any case constitute a burden to soils of the tropics [35]. It has peaks which ranges from 17.01(2theta) to 20.50 (2theta) but highest recorded peak was at 17.01 at 100% intensity (Fig. 8). The findings agrees with the results of Marcelino et al. [35] who further concluded that the presence of gibbsite signifies strongly weathered soil characterized by low activity clay (LAC), Fe, AlO_3 and with silt and sand fractions mainly composed of quartz. Gibbsites are in oxic and ferralic horizons and are diagnostic horizon of oxisols and ferralsols. Gibbsite developed from acid rocks [35].

3.8 Phlogopite

Phlogopite [$K(MgFe)_3AlSi_3O_{10}$] is a kind of micaceous (biotite) clay mineral that is rich in Mg and it is also known as Mg- mica [8]. It is a phyllosilicate which has a monoclinic crystal system. Generally biotite (black) mineral are more easily weathered compared to the muscovite (white). The biotite species of the mica are usually found in close combination with goethite (goethite is an Fe- oxide) more important to soil's CEC because it has Mg and Fe that available for exchange [35,8]. It has peaks which ranges from 8.01(2theta) to 86.50 (2theta) but highest recorded peak was at 8.01 at 100% intensity (Fig.9). The arrays of materials that are added to the fadama system year on year tend to buffer the soil against the impact of gibbsite which is an Al- oxide containing mineral. Phlogopites are more desirable in soils of the tropics, this agrees with Maniyunda and Raji [6] that the presence of micas in the clay fraction was indicative of a relatively low degree of weathering in the soils. Schaetzl and Anderson [36] reported that most micas have K+ as the interlayer cation. Interlayer K+ is held tightly or fixed between adjacent mica layers because the properties of micas and of the K+ ion provide ideal conditions for K+ fixation. The arrays of minerals are at different stages of weathering-quartz and phlogopite at moderate stage of weathering, microcline at minimal stage of weathering while kaolinite and gibbsite are at intense weathering stages according to the rating of Foth [37]. These minimally and moderately weathered soils are generally considered to be of good fertility status Foth [37,38].

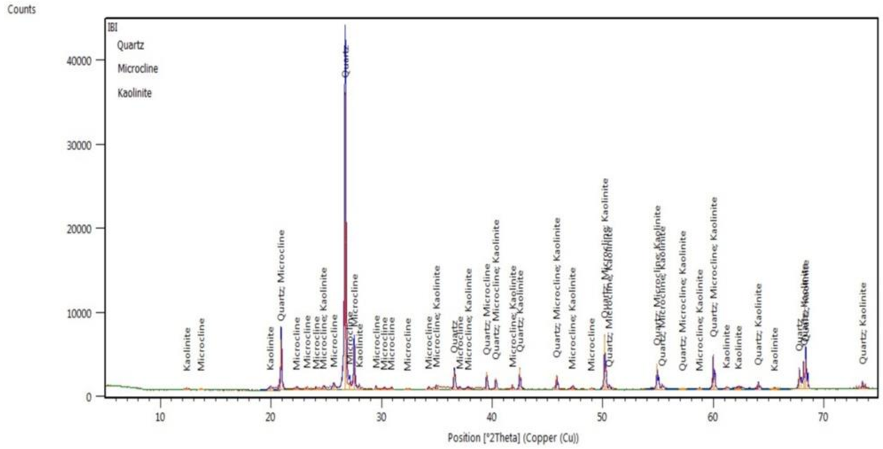

Fig. 2. XRD measurement for IBI soils

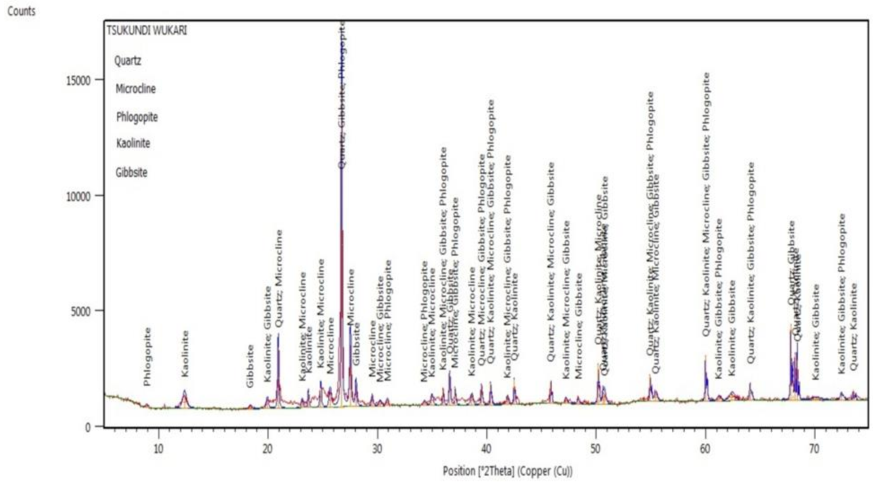

Fig. 3. XRD measurement for wukari soil

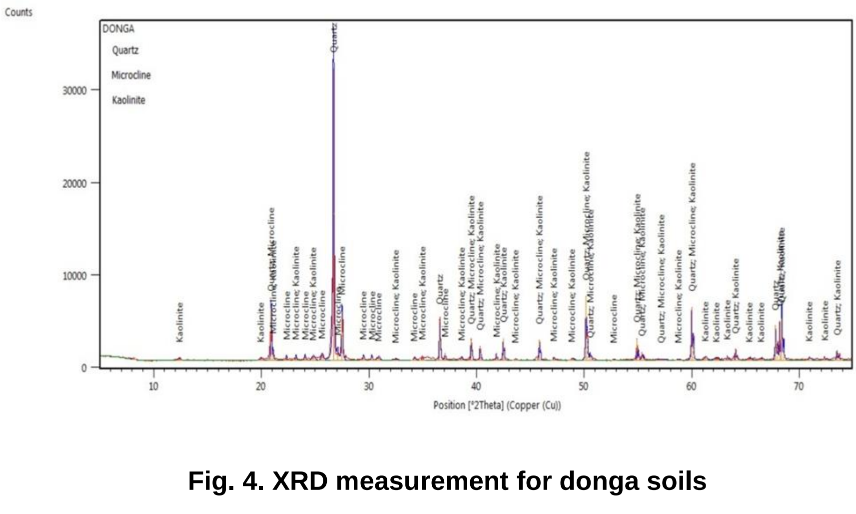

Fig. 4. XRD measurement for donga soils

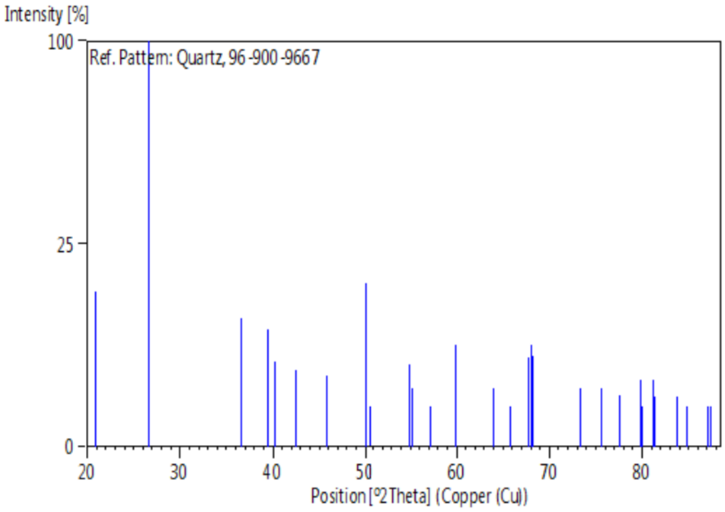

Fig. 5. Stick Pattern showing peaks of Quartz in clay samples

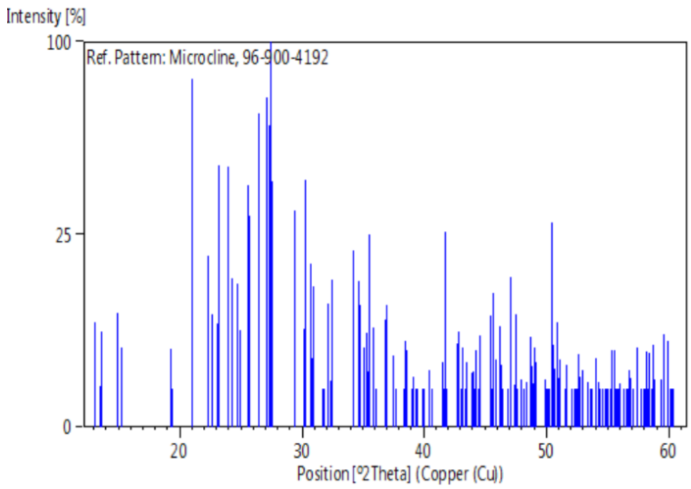

Fig. 6. Stick Pattern showing peaks of Microcline in clay samples

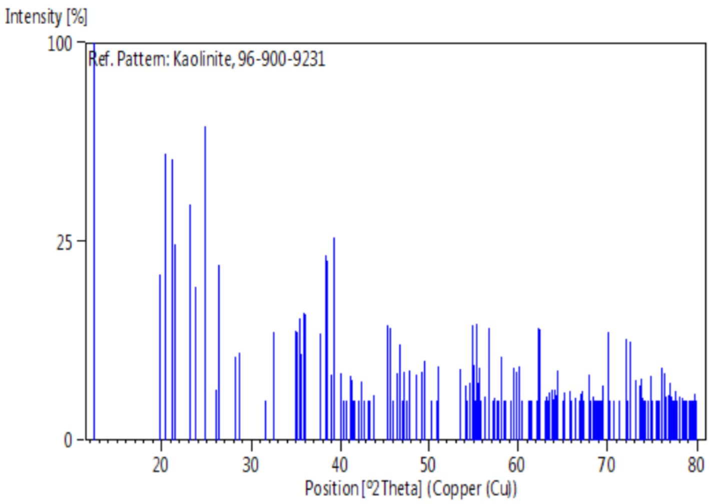

Fig. 7. Stick Pattern showing peaks of kaolinite in clay samples

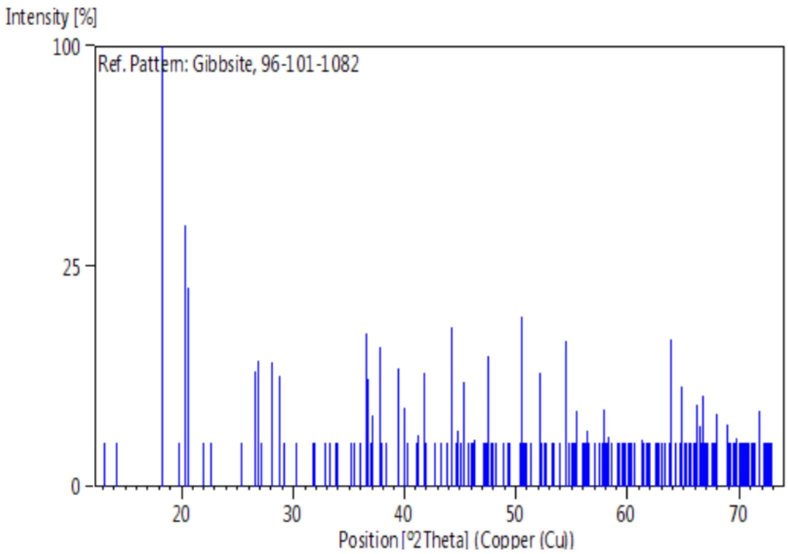

Fig. 8. Stick Pattern showing peaks of Gibbsite in clay samples

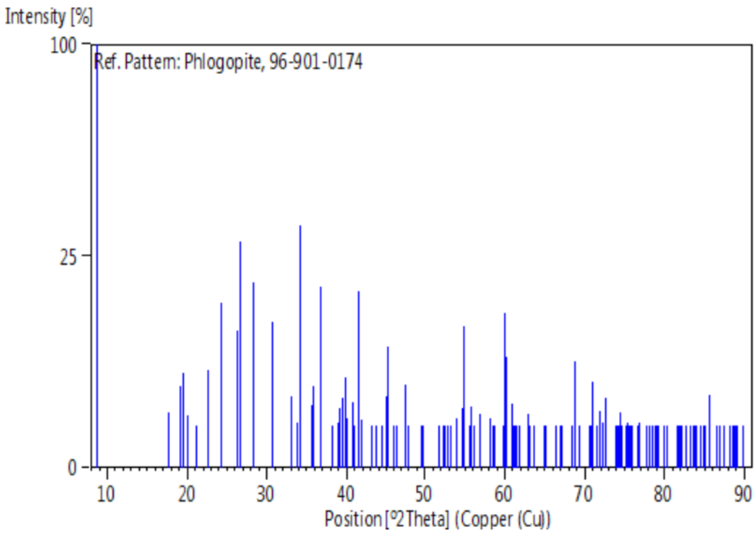

Fig. 9. Stick Pattern showing peaks of Phlogopite in clay samples

4. CONCLUSION

Mineralogical analysis showed the presence of kaolinite, phlogopite, gibbsite, quartz and microcline minerals in the clay fraction. Kaolinite and microcline were the most dominant minerals as they occurred in all the samples. Mineralogical characteristics of the soil in southern Taraba state have diverse origin and that has kept the soil as different stages of weathering. In general, the presence of moderately and minimally weathered minerals such as phlogopite, quartz and microcline were indicative of reserved weatherable minerals in the soils. The intensely or advanced stage weathering minerals (kaolinite and gibbsite) were the least preponderance. The composition of quartz in Wukari Tsukundi fadama soil with the least of the three, which was an indication that the highly resistant mineral has been degraded and Wukari soils has the least of kaolinitic composition as well when compared to that of Ibi and Donga fadama soils. Morphologically, soil colours were in the yellowish red hues with varying values and chromas as evident in soil drainage conditions at different physiographic positions on the landform. Most of the soil colours had the imprint of Fe ions occurring at different seasons due to alternate flooding and drying. Silt fraction of the soil was higher than clay which was indicating the presence of reserved weatherable minerals as inherited from its geologic materials.

Soils of the study are sandy in the topsoil and sandy clayey loam in the subsoil. The pH of the study area showed moderately acid soil and a negative ΔpH which indicates that the soil had capacity as a net cation exchanger. The percentage base saturation (%BS), was largely dominated by exchangeable cations in moderately to very high rating and their mean values are 80%, 77% and 74% for pedons I, 2 and 3 respectively. The soils were classified as Alfisols/Entisols mix. Further studies of these soils during flooding/ submergence are recommended.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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