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CHARACTERIZATION AND CLASSIFICATION OF SELECTED FLOODPLAIN SOILS FOR ARABLE CROP PRODUCTION IN ABAKALIKI SOUTHEASTERN NIGERIA

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ABSTRACT

The study investigated soils of Abakaliki floodplains to characterize and classify them for sustainable use and management. Two profile pits each were dug in Mgbo-Abaja, Inyimagu and Nkwagu sites. Twenty-seven soil samples were collected from genetic horizons and sent to the laboratory for analysis. Results showed that soils were well drained except in Mgbo-Abaja 002 which was poorly drained. Colour varied from brown (10YR 5/3) to weak red (2.5YR 5/2), brown (10YR 4/3) to red (2.5YR 5/6) and dark yellowish brown (10YR 4/6) to reddish yellow (5YR 7/8) in Mgbo-Abaja, Inyimagu and Nkwagu respectively. Mottles were observed in Mgbo-Abaja and Inyimagu profiles as a result of redoximorphism. Soils were sandy and ranged from 526 – 764 mg/kg. The pH was moderately acidic (5.80 – 6.07); mean values of base saturation (%) was moderate (21.03 – 45.31 %), electrical conductivity was low (< 4.0 dSm^{-1}) and exchangeable sodium percent (ESP) was < 15 % except in Nkwagu profile 006. The soils were classified (USDA / WRB) as Typic Kandiaquults / Ferralic Gleysols (Mgbo-Abaja 001), Typic Kandiaquults / Cambic Gleysols (Mgbo-Abaja 002), Typic Kandiaquults / Ferralic Gleysols (Inyimagu 003), Grossarenic Kandiaqualfs / Ferralic Gleysols (Inyimagu 004), Typic Kandiaquults / Ferralic Acrisols (Nkwagu 005) and Grossarenic Kandiaqualfs / Ferralic Acrisols (Nkwagu 006). It is recommended that there should be creation of drainage channels to reduce water logging of sites, employ some management practices like liming, application of biochar technique, organic manure and inorganic fertilizer, which will boost the condition of soils and improve their fertility for arable crop production.

Keywords: Floodplain soils, Abakaliki, Characterization, Classification, Ultisol

INTRODUCTION

The global food system is in serious crisis as the soils of the uplands are been intensively cultivated for all purposes even at the expense of their fertility causing continuous degradation in their properties (Nnabuihe, 2014, Udo *et al*., 2016 and Nnabuihe *et al*., 2021b). There are fundamental challenges as regard to food security due to the result of ever increasing population and the high demand on available food. Presently there are increasing importance on the use of floodplain soils for food production and economic growth, because of their great potentials for agriculture. Floodplain soils are found along rivers, lakes, lagoons and / or depressions on adjacent low terraces where they develop in sediments from various sources under various drainage classes often with hydromorphic conditions (Ibrahim and Omotesho, 2012). Floodplain soils occupy an area of approximately 65,783km^2 or 7.3% landmass in Nigeria with southeastern region constituting about 22,859km^2 or 2.56% of the landmass (Chukwu *et al*., 2009). They are part of the intermediate ecosystems with environmental and agricultural importance for the maintenance of plant and animal species, through their nutrients and water supplied by the adjacent rivers or streams (Udo, 2007). Despite these attributes in supporting yields of arable crops, the properties of most floodplain soils have not been characterized by land users especially in Abakaliki areas. This has led to limited usage, poor management and destruction of most productive floodplain soils (Babalola *et al*.; 2011 and Nnabuihe *et al*., 2021a). Apart from the pressure on arable uplands for continuous cultivation and other land use developments, many agricultural uplands are severely degraded due to non agricultural practices, which has resulted to severe ecological and environmental deterioration as well as massive degradation (Senjobi and Ogunkunle, 2011; Udo *et al*., 2016). Presently, information on characteristics of most floodplain soils especially in the study area has been scanty, which constitutes a serious problem for the efficient management and utilization of these soils by farmers (Yakubu *et al*., 2008). The knowledge of these soils requires a detailed characterization, classification and management strategies, which will help to understand the relationship between soil properties and crops to be established (Japhet *et al*.; 2006, Madueke *et al*., 2021). It will also provide information on the nutrient status and limitations ensuring sound judgment on response of these soils to specific uses (Egbuochua and Ojobor, 2011). Classifying these soils is important for easy identification of the most appropriate use of soil, estimating production, extrapolating knowledge gained at one location to the other; develop relevant information for policy decisions on land utilization for sustainable agriculture and providing the basis for future research needs (Nortcliff, 2006).

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OBJECTIVE OF THE STUDY

The main objective of this study was to characterize and classify selected floodplain soils for arable crop production in Abakaliki Ebonyi southeastern Nigeria. The specific objectives of this study were to: (i) characterize floodplain soils of Mgbo-Abaja, Inyimagu and Nkwagu using their macro morphology, physical and chemical properties. (ii) classify these soils using the USDA Soil Taxonomy and correlating it with World Reference Base (FAO/WRB) classification systems.

MATERIALS AND METHODS

The study was carried out on soils of a floodplain of Mgbo-Abaja, Inyimagu and Nkwagu in Abakaliki Local Government of Ebonyi State Nigeria located within Latitude 06^o 18' 46" and 06^o 20' 74" N and Longitude 08^o 08' 74" and 08^o 20' 46" E. The climate is humid tropical with rainforest and savannah vegetation and low-lying and undulating slopes. Rainfall is bimodal and starts from April to July and September to November, with break in August, although it has been altered as a result of weather changes and climate change phenomenon. The minimum and maximum rainfalls are 1700mm and 2000 mm respectively, with mean rainfall of 1800 mm (Nwite *et al.*; 2014). The minimum temperature is 27^{o}C and maximum temperature is 31^{o}C, with relative humidity of 60% and 80% during dry and rainy seasons respectively (MANR, 2020). Agriculture is a major socio-economic activity in the state, as major crops grown are: Rice (*Oryza sativa*), Cassava (*Manihot esculentus*), Maize (*Zea mays*), Yam (*Dioscorea spp*), Cocoyam (*Colocasia spp*), etc. Others are Plantain (*Musa paradisiaca*), Banana (*Musa sapientum*), Bread fruit (*Treculia africana*), Cashew (*Anacardium occidentale*) amongst others. Fish farming is carried out on a large scale due to presence of rivers and streams like Onu Ebonyi, Iyiudene, Iyiokwu and Aboine Rivers which crosses the southern part of Cross River State. Livestock farming is also practiced in Abakaliki (Ebonyi State) as animals like chickens, pigs, donkeys, goats and native cows are also reared. The state is also blessed with huge mineral deposits: salt lakes at Uburu, Okposi and Oshiri; Zinc and Lead deposits at Enyigba as well as Kaolin and Limestone at Ishiagu, Afikpo and Nkalagu. Geology and geomorphology is Coastal Plain Sands (Benin formation) of the Oligocene-Miocena era, influenced by fluvial deposition of alluvium. These soils show strong mottling of gray and red colour due to periodical water logging (Onweremadu *et al.*, 2007). The study area is part of the lowlands in southeastern Nigeria with flat topography (Onweremadu *et al.*, 2006; Chukwu *et al.*, 2009). The vegetation stretches from mangrove swamp in the coast through rainforest to derived savanna in the interior, and is that of secondary forests-savannah mosaic, as anthropogenic activities have reduced the density of these forests (Chukwu *et al.*, 2009).

Pre-field work: Field reconnaissance was carried out with the aid of location map of the study area to obtain accurate information of the study locations. These include the general site information, assembling of road maps, geological, vegetation, topographic and land use maps of the area.

Field study: Materials such as location map, topographic and geological maps, Munsell colour chart and a handheld global positioning system receiver (Model: Garmin) were used. A total of six profile pits were sunk using a target survey technique and two profile pits per site that of which depended on the water table. Sampling points were geo-referenced using handheld GPS receiver (Model: Garmin).

Table 1: GPS Coordinates of the studied sites in Abakaliki Ebonyi State

Location	Profile no.	Latitude(º N)	Longitude (º E)	Slope (m)
Mgbo-abaja	01	06° 20' 70"	08º 07' 07"	0 – 3
Mgbo-abaja	02	06º 20' 74"	08º 07' 72"	0 – 1
Inyimagu	03	06º 18' 56"	08º 08' 45"	1 – 2
Inyamagu	04	06º 18' 58"	08º 08' 40"	0 – 2
Nkwagu	05	06º 18' 55"	08º 08' 46"	1 – 3
Nkwagu	06	06º 18' 46"	08º 08' 32"	0 – 2

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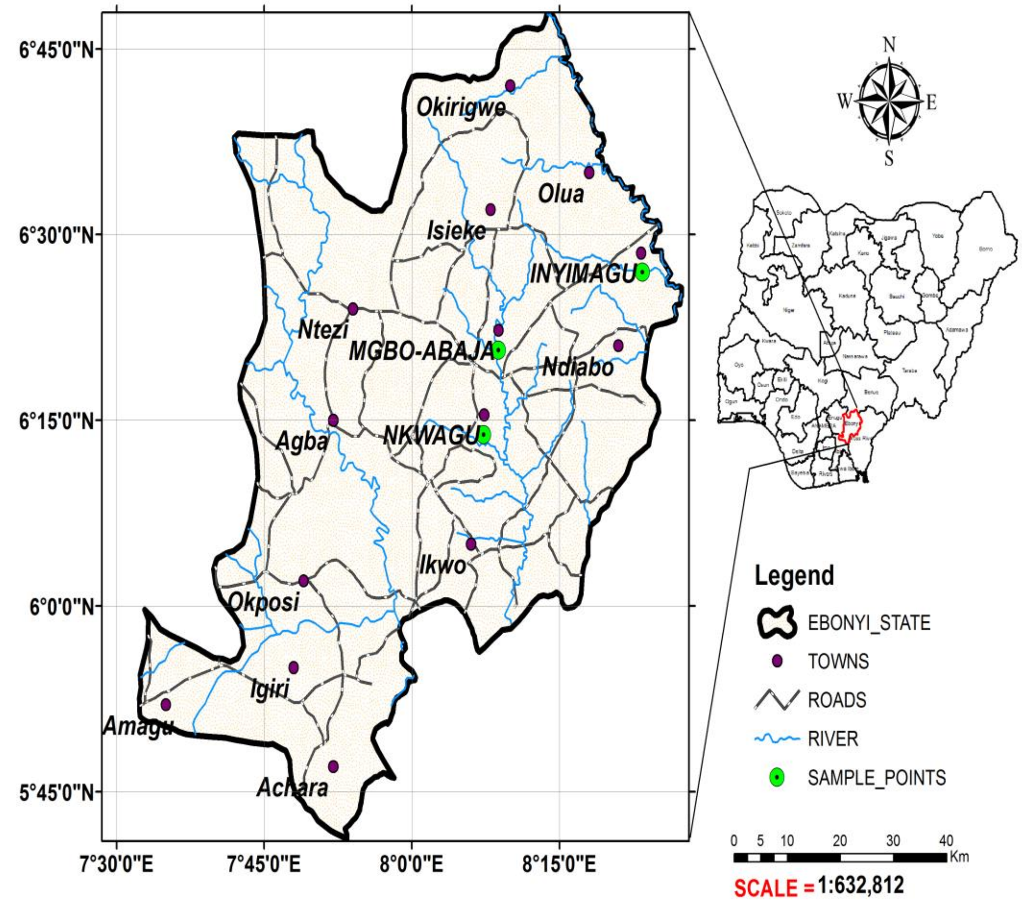

LOCATION MAP OF THE STUDY AREA

Soil sample collection and preparation: six profile pits were dug and twenty-seven samples collected according to the procedure outlined by FAO for profile description (FAO, 2006). After careful delineation of horizon boundaries, composite samples were collected from each of the identified horizon starting from the bottom horizon using appropriate labeled black polythene bags. Soil samples were air-dried for one week, crushed and sieved with 2mm mesh sieve, re-bagged, labeled and stored for laboratory analysis. A sub sample (about 10g soil) of each soil was ground and preserved for determination of organic carbon and total nitrogen. Undisturbed soil samples were taken using core samplers for the determination of bulk density and saturated hydraulic conductivity.

Laboratory Analysis: soil samples were analyzed for selected physical and chemical properties using routine analytical methods. These include: Particle size which was determined using the Bouyoucos hydrometer method (1962) as modified by Gee and Or (2002). The method is calibrated to read the amount of solid particles remaining in suspension. 5% of a dispersing agent (calgon: sodium hexamethaphosphate-$Na_6O_{18}P_6$) was used to separate sand, silt and clay particles bonded together for determination of their compositions. Bulk density was determined by the core method (Grossman and Reinsch, 2002). The undisturbed soil samples were collected and weigh in oven dry basis; while bulk density was calculated by dividing the weight of soil core on oven dry basis by the volume of the soil core which is the volume of the steel tube. Bulk density (D_b) = Mass of oven dry sample / Volume of sample (g/cm^3). Gravimetric moisture content was determined after oven-drying of core soil samples (Obi, 1990) and amount of moisture calculated as follows: W_1 =weight of can with lid, W_2 =weight of soil+ weight of can with lid, W_3 =weight of oven-dry soil

$$\%MC\ (wet - soil\ basis) = \frac{W_2 - W_3}{W_2 - W_1} \times \frac{100}{1} \quad \text{OR}$$

$$\frac{Mass\ of\ wet\ soil - mass\ of\ oven\ dry\ soil}{mass\ of\ wet\ soil} \times \frac{100}{1}$$

Saturated hydraulic conductivity (Ksat) was determined using the constant head method as described by Topp and Dane (2002). It was then computed using Darcy's equation, as:

$$K_{sat} = \left[\frac{QA}{AT}\right]\left[\frac{LK}{\Delta H}\right] \text{cm/s} \quad \text{Where}$$

K_{sat} = Saturated hydraulic conductivity (cm/s), Q = Quantity of percolate,

A = Area of core in Cm^2, T = Time interval in seconds (s), L = Length of sample in cm

ΔH = Change in hydraulic head (cm)

Soil pH was determined electrometrically using pH meter and this was done in distilled water and 0.1N KCl solution using a soil liquid ratio of 1:2.5 in a glass electrode (Thomas, 1996). Total nitrogen was determined by Kjeldahl digestion method (Bremmer 1996). Calculated as follows: Kjeldah N (%) = (T-B) x M x 2.8/S where T = ml of standard acid with sample titration, B = ml of standard acid with blank titration, M = molarity of sulphuric acid, S= weight of soil sample in g. Organic carbon was determined by wet digestion method (Nelson and Sommers, 1982). This involved adding 10ml of 0.1667M $K_2Cr_2O_7$ and 20ml of conc.H_2SO_4 to weighed soil sample (5g) in a Erlenmeyer flask (500ml) and heated to a temperature of 150^0C. It was allowed to cool at room temperature. As 20ml of water was added and 4-5 drops of ferroin indicator, titrating with 0.5M ferrous sulphate i.e. Organic C (%) = (meq of $K_2Cr_2O_7$ – meq of $FeSO_4$) x 0.336 /oven-dry soil (g). Available phosphorus was determined using Bray II method as described by Olson and Sommers (1982). Using spectrophotometer of absorbance at 882nm, P concentration of the sample was determined through calibration curve relating the readings of absorption units to concentration in µg P/ml. Thus: Pµg/g soil=P (µg/ml) x 50ml/10ml x 100ml/5g soil. Exchangeable acidity was extracted by leaching the soil with 1N KCl and titrating with 0.05N NaOH (Mclean, 1982). Exchangeable bases were extracted with 1N NH_4OAc solution and exchangeable calcium and magnesium determined using EDTA (Ethylene diamine-tetraacetic acid- 0.01N) complexometric titration. Exchangeable potassium and sodium was estimated by flame photometry (Jackson, 1962). It was calculated as follows: meq of K/100g soil=Reading (meq/l) x 100ml/1000ml x 100g/weight of soil (g) = R x 10/weight of soil (g). Cation exchange capacity was determined by ammonium acetate (NH_4OAc) of 1.0M leaching at pH 7 (Blackemore *et al.*, 1987) i.e. meq of Na/100g soil=Emission Reading (R meq/l)x 100ml/1000ml x 100g/weight of soil (g)=Rx10/weight of soil(g). Where, R is the meq/l of Na as determined by the flame photometer. The displaced Na is actually a measure of the CEC of the soil. Electrical conductivity was determined manually using a conductivity meter at a 1: 2.5 soil/water ratio at 25^o C (Janzen, 1993; Udo *et al.*, 2009). It was measured in millisiemens per metre (mS/m). Total porosity was calculated using the formulae:

$Porosity\ (F) = \frac{e_b}{\{e_s} \times \frac{100}{1}$) -100} Where e_b = bulk density (g/cm^3) e_s = particle density (2.65g/cm^3 which is the assumed value in most mineral soils). Effective cation exchange was calculated from the summation of all exchangeable bases (Ca, Mg, K, and Na) and exchangeable acidity (Al and H). Percentage base saturation was calculated by dividing total exchangeable bases (EBs) by ECEC and multiplying by 100. i.e. EBs/ECEC x 100/1. Percentage aluminum saturation was calculated by dividing exchangeable aluminum by ECEC and multiplying by 100. i.e. %Al= Al/ECEC x 100/1. Exchangeable sodium percentage was computed by dividing exchangeable sodium by CEC and multiplying by 100 .i.e. ESP (%) = Exchangeable Na (Cmol/kg) / CEC (Cmol/kg) x100/1.

Classification of soils: The USDA Soil Taxonomy (2014) was used for classification and correlated with FAO/UNESCO World Reference Base (WRB), (2015).

Statistical Analysis: Data generated were analyzed using descriptive statistics (mean, mode, median and standard deviation). Also, variation amongst soil properties with depth was determined using coefficient of variability. Relationships between soil properties were determined using correlation and regression analysis. The analyses were conducted using SAS (2016), Genstat (64- bit version 18) and SPSS (version 21) statistical packages.

RESULTS AND DISCUSSION

Macro morphological of soils: The macro morphological properties of soils of Abakaliki are presented in Table 1. The soil colour varied as brownish in A and AB horizons, reddish brown, yellowish red and weak red in Bt1, Bt2 and Bt3 horizons respectively in Mgbo-Abaja profile 001

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and was yellowish brown, light brown, dark reddish brown, pale red and yellowish brown in A, AB, Bg1, Bg2 and Bg3 horizons respectively in Mgbo-Abaja profile 002. The colour for Inyimagu profile 003 varied as brown, yellowish brown, reddish brown, reddish yellow and red in A, AB, Bt1, Bt2 and Bt3 horizons respectively and Inyimagu profile 004 was brown (Ap), light brown (AB), reddish (Bt1 and Bt2). In Nkwagu profile 005 it was brown (A), yellowish red (AB and Bt1) and red (Bt2) and Nkwagu profile 006 it was dark yellowish brown, yellowish brown, brownish yellow and reddish yellow in A, AB, Bt1 and Bt2 horizons respectively. The Ap horizon observed in Inyimagu profile 004 consists of fresh alluvial deposits, varying thickness and brown/dark colour due to organic matter accumulation (mineralization) (Esu, 2010, Orimoloye *et al*,; 2018). Gray colours as observed in some surface and subsurface horizons in sites could be attributed to drainage condition of the soils, as most soils were submerge during and after peak seasons (gleying) and are poorly or imperfectly drained. Yellowish and red colour (chroma) seen in most subsurface horizons could be attributed to the presence of sesquioxides (like goethite in a hydrated forms) as colour is the function of chemical and mineralogical composition as well as textural make up of soil and conditioned by topography position and moisture regime (Udoh and Lekwa, 2014). It also can be due to mobilization and immobilization of iron during reduction and oxidation (redox) cycles in the soils (Fasina *et al*.; 2007; Lawal *et al*.; 2013; Uzoho, 2014). There was dark reddish mottle in Bt2 horizon (Mgbo-Abaja profile 001), reddish and reddish brown mottles (Bg2 and Bg3 of Mgbo-Abaja profile 002), yellowish red mottle (Bt2 horizon of Inyimagu profile 003), reddish yellow mottles (Bt1 horizon of Inyimagu profile 004) and no mottles in Nkwagu 005 and 006 horizons. The mottles found in some profiles are characteristic of floodplain soils, an indication of anaerobic conditions, oxidation and reduction of iron oxides during periods of wetting and drying cycles. The soil profiles without mottles could be due to more macro pores, free movement of air, increased drainage conditions and less micro pores (Umeugochukwu *et al*., 2019). Soil structure varied as weak, very fine crumb (A), weak, very fine sub angular blocky (AB), moderate, medium sub angular blocky (Bt1, Bt2 and Bt3 horizons) in Mgbo-Abaja profile 001, weak, very fine crumb (A), weak, very fine sub angular blocky (AB), weak, fine sub angular blocky (Bg1), weak medium, sub angular blocky (Bg2) and weak, fine sub angular blocky (Bg3 horizon) of Mgbo-Abaja profile 002. In Inyimagu profiles, the structure varied as weak, very fine crumb (A), weak, very fine, sub angular blocky (AB) and moderate, medium and sub angular blocky (Bt1, Bt2 and Bt3) in Inyimagu profile 003 and weak, very fine crumb (Ap), weak, very fine, sub angular blocky (AB), weak, very fine, sub angular blocky (Bt1) and moderate, fine, sub angular blocky (Bt2) in Inyimagu profile 004, while in Nkwagu profiles, were weak, very fine crumb (A), weak, very fine sub angular blocky (AB), moderate, medium and sub angular blocky (Bt1 and Bt2 horizons) in profile 005 and weak, very fine crumb (A), weak, very fine sub angular blocky (AB), weak, fine sub angular blocky (Bt1), moderate, medium, sub angular blocky (Bt2)

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in profile 006. The variations in soil structure have been reported as a result of clay and mineral movement down the profile, compaction and increased bulk density of soils. The blocky structure (sub angular blocky) especially in subsoil was due to the presence of high clay fractions, crumb structure might be due to the presence of polyvalent electrolytes and continuous addition of organic matter through cultivation (Udoh and Lekwa, 2014). The moist consistencies were friable in A and AB, firm in Bt1 and Bt2 and very firm in Bt3 horizon of Mgbo-Abaja profile 001 and friable in A and AB, firm in Bg1, Bg2 and Bg3 of Mgbo-Abaja profile 002. It was friable (A), firm (AB, Bt1 and Bt2) and very firm (Bt3) and friable (Ap and AB) and firm (Bt1 and Bt2) in Inyimagu profile 003 and 004 respectively, and finally friable (A and AB) in Nkwagu profiles 005 and 006, firm (Bt1 and Bt2) for Nkwagu 005 and loose (Bt1 and Bt2) horizons of Nkwagu profile 006. Consistence of soils showed that the parent materials from which they were derived (alluvium) played an important role. Most subsurface soils were firm and very firm and could be attributed to lateral movement of materials in response to drainage and water table, while some like Nkwagu 006 Bt1 and Bt2 were loose and could be due to increase sand fractions and fresh depositions from the rivers (Ndukwu *et al.*; 2010). Root activities varied as medium and common (A), very fine and few (AB), fine and few (Bt1) and non (Bt2 and Bt3) of Mgbo-Abaja profile 001, medium and common (A), very fine and few (AB), and fine and few (Bg1) in Mgbo-Abaja profile 002, common and medium (A) and fine and few (AB) of Inyimagu profile 003, medium and many (Ap), medium and common (AB) and medium and few (Bt1) in Inyimagu profile 004. Others include common and medium (A) and fine and few (AB) and medium and many (A), medium and few (AB) and fine and very few (Bt1) horizons of Nkwagu 005 and 006 profile locations respectively. Roots were more abundant at the upper layers of soils and could be due to presence of more of grasses than trees.

Predominance of plant roots was conspicuous in many surface and subsurface horizons, as a result of perennial crops like oil palm (*Elaeis guineensis*) and raffia palm (*Raphia hokeri*), with fibrous roots dominance. Also soils were well drained at all profile depths and locations except Bg2 and Bg3 (Mgbo-Abaja profile 002) that were poorly drained. The drainage conditions resulted in mottles observed in most profiles studied, as these soils are hydromorphic in nature (Orimoloye *et al.*, 2018). Finally horizon boundaries were wavy and clear (A and Bt1) and smooth and clear (AB and Bt2) and smooth and clear (A and AB) and smooth and diffuse (Bg1 and Bg2) in Mgbo-Abaja profiles 001and 002 respectively, wavy and clear (A), smooth and clear (AB) and smooth and diffuse (Bt1 and Bt2) and smooth and clear (Ap), smooth and diffuse (AB) and smooth and clear (Bt1) in Inyimagu profiles 003 and 004 respectively and finally wavy and clear (A) and smooth and diffuse (AB and Bt1) of Nkwagu profiles 005 and 006 respectively. Moreover the boundary forms of these soils could be as a result of lateral movement and properties of soils and weathering processes or clay lassivage in the soil horizons (Onweremadu *et al.*, 2007 and Ahukaemere, 2018).The findings in the study areas are in line with the works of

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other researchers on floodplain soils of Southeastern Nigeria (Ogbodo, 2011, Eze *et al.*, 2016, Orimoloye *et al.*, 2018, Nsor, 2019 and Okenmuo *et al.*, 2020).

Table 1: Macro morphological Properties of Pedons of Abakaliki study Area.

Depth (cm)	Horizon	Matrix Colour (moist)	Mottles	Structure	Consistence (moist)	Roots	Drainage	Boundary form
			Mgbo-Abaja profile 001					
0-21	A	B 10YR 5/3	-	1, vf, cr	friable	c,m	wd	w, c
21-58	AB	B 7.5YR 5/4	-	1, vf, sbk	friable	vf, fw	wd	s, c
58-99	Bt1	RB 5YR 5/3	-	2,m, sbk	firm	f,fw	wd	w, c
99-148	Bt2	YR 5YR 5/6		2, m, sbk	firm	-	wd	s, c
148-200	Bt3	WR 2.5YR 5/2	DR2.5 YR3/6	2, m, sbk	very firm	-	wd	-
			Mgbo-Abaja profile 002					
0-15	A	YB 10YR 5/6	-	1, vf, cr	friable	c,m	wd	s, c
15-27	AB	LB 7.5YR 6/4	-	1, vf, sbk	friable	vf, fw	wd	s, c
27-52	Bg1	DRB 5YR 3/2	-	1,f, sbk	firm	f,fw	wd	s, d
52-83	Bg2	PR 2.5YR 6/2	R 2.5 YR4/6	1, m, sbk	firm	-	pd	s, d
83-150	Bg3	YB 10YR 5/6	RB 2.5YR5/4	1, f, sbk	firm	-	pd	-
			Inyimagu profile 003					
0-12	A	B 10YR 4/3	-	1, vf, cr	friable	c,m	wd	w,c
12-21	AB	YB 10YR 5/4	-	1, vf, sbk	firm	f, fw	wd	s, c
21- 43	Bt1	RB 2.5YR 4/3	-	2,m, sbk	firm	-	wd	s, d
43-96	Bt2	RY 7.5YR 6/6	YR 5YR 4/6	2, m, sbk	firm	-	wd	s, d
96-200	Bt3	R 2.5YR 5/6	-	2, m, sbk	very firm	-	wd	-
			Inyimagu profile 004					
0-18	Ap	B 10YR 4/3	-	1, vf, cr	friable	m,m	wd	s, c
18-45	AB	LB 7.5YR 6/4	-	1, vf, sbk	friable	m, c	wd	s, d
45-98	Bt1	R 2.5YR 4/6	RY 5YR 6/6	1,vf, sbk	firm	m, fw	wd	s, c
98-200	Bt2	R 2.5YR 5/6	-	2, f, sbk	firm	-	wd	-
			Nkwagu profile 005					
0-20	A	B 7.5YR 4/3	-	1, vf, cr	friable	c,m	wd	s, c
20-50	AB	YR 5YR 5/6	-	1, vf, sbk	friable	f, fw	wd	s, d
50-92	Bt1	YR 5YR 5/8	-	2,m, sbk	firm	-	wd	s, d
92-200	Bt2	R 2.5YR 4/6	-	2, m, sbk	firm	-	wd	-
			Nkwagu profile 006					
0-22	A	DYB 10YR 4/6	-	1, vf, cr	friable	m,m	wd	w, c
22-38	AB	YB 10YR 5/6	-	1, vf, sbk	friable	m, fw	wd	s, d

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38-98	Bt1	BY 5YR 6/6	-	1,f, sbk	loose	f, vfw	wd	s, d
98-186	Bt2	RY 5YR 7/8	-	2, m, sbk	loose	-	wd	-

Colour (moist): B = brown, RB = reddish brown, YR = yellowish red, WR = weak red, DR= dark red, LB=light brown, DRB = dark reddish brown, DYB = dark yellowish brown, PR= pale red, R = red, YB = yellowish brown; Structure: sbk = sub-angular blocky, cr = crumb; 1= weak, 2= moderate; vf = very fine, m= medium, f = fine, Roots: m, fw = medium, few; m, vf = medium, very few; m,c = medium, common; f, fw = fine, few; m, m = medium, many; m, fw = medium, few. Drainage: wd= well drained, pd = poorly drained; Boundary form: w,c = wavy, clear; s, c = smooth, clear; s, d= smooth diffuse

Physical properties of soils: The physical properties of soils of Abakaliki are showed in Tables 2a and 2b. Mean sand, silt and clay contents ranged from 526 – 764 (CV > 4.03 ≤ 13.94 %), 103 – 231 (CV > 15.80 ≤ 30.75 %) and 104 – 247 (CV > 13.14 ≤ 36.58 %) respectively with sand fraction greater than other fractions which may be attributed to the depositions of alluvium of sediments/ materials and distribution of soil separates which may have influenced drainage characteristics of soils (Onweremadu *et al.*, 2007). Sandiness of the soils is due to parent materials and agrees with the findings of Eze *et al.* (2016) and Orimoloye *et al*. (2018) who characterized some alluvial soils of southern Nigeria. Clay movement down the profile (argillic horizon) was clear in most profiles, but without defined pattern, which could be due to eluviation and illuviation, surface erosion or runoff, overflows of river banks or combinations of these processes. The results in Abakaliki are in line with the findings of Ogbodo (2011) who studied the soils of flood plains of Iyiudene and Iyiokwu in Ebonyi river flood plains. Similar results were obtained from soils of flood plains of southern Nigeria (Onweremadu *et al.*, 2007, Orimoloye *et al.*, 2018, Nsor, 2019 and Okenmuo *et al.*, 2020). However sand recorded low variation which is an indication of homogeneity and influence of parent materials; silt had moderate variation and clay had high variation which could be due to movement or sorting of different materials down the profile. Mean silt clay ratios ranged from 0.61 – 1.67 (CV > 16.15 ≤ 69.51 %) and decrease irregularly within the profile. It was less than unity (< 1), except in few sites of Mgbo-Abaja 001 and Inyimagu 003 which were greater with small fractions. This showed that these sites were less weathered when compared with other locations, although tropical soils are known to be highly weathered. Low mean values indicate high degree and intense weathering (Madueke *et al.*, 2012). Mean textural classes showed that Mgbo-Abaja 001, Mgbo-Abaja 002, and Nkwagu 006 had sandy clay loam (SCL) while Inyimagu 003 and 004 and Nkwagu 005 were sandy loam (SL). Mean moisture contents, bulk densities, total porosities and saturated hydraulic conductivities values ranged from 14.35 - 24.87 % (CV > 13.67 ≤ 29.33 %), 1.13 - 1.45 g/cm^3 (CV > 6.03 ≤ 17.11 %), 45.13 - 57.28 % (CV > 2.74 ≤ 14.37 %) and 0.32 - 1.04 cm/min (CV< 48.57 ≤ 79.63 %) respectively.

The values of moisture content in soils showed that they have more macro pores than micro pores within the profiles with moderate variation. Alluvial soils have irregular pattern of distribution of moisture content because of the nature of deposited materials which also influence pore spaces (micro pores or macro pores). Moisture content is said to be linearly related to

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organic carbon content of soils (Onweremadu *et al*., 2007, Ndukwu *et al*., 2009, Anikwe, 2010). Bulk density of soils was influenced by organic matter content, compaction / sorting of materials, less aggregation, compaction of overlying layers and clay movement down the profile (Ndukwu *et al*., 2009, Anikwe, 2010). It had been reported that bulk density of alluvial soils vary in accordance with the nature of the deposited materials and has an impact with organic carbon and moisture contents of tropical soils (Baker *et al*., 2004, Umeugochukwu *et al*., 2019). The high total porosity recorded in most sites could be attributed to parent material, bulk density and organic carbon content, because increase in bulk density and decrease in organic carbon contents result in decline in total porosity (Kizilkaya and Dengiz, 2010; Mhawish, 2015). Saturated hydraulic conductivity of soils is influenced by texture and structure as surface soils tend to have high values, because of presence of macro pores than micro pores. Oguike and Mbagwu (2009) reported that high content of organic matter reduces bulk density and increases saturated hydraulic conductivity of soils.

Table 2a: Physical Properties of Pedons of Abakaliki study Area

Depth (cm)	**Horizon**	**sand** ←	**silt** mg/kg	**clay** →	**SCR**	**TC**	**MC** (%)	**BD** g/cm^3	**TP** %	**KSat** (cm/min)
					Mgbo-Abaja profile 001					
0-21	A	568	139	293	0.47	SL	25.80	1.35	49.06	0.68
21-58	AB	548	239	213	1.12	SCL	22.46	1.41	46.79	1.70
58-99	Bt1	528	269	203	1.33	SCL	16.12	1.25	52.83	1.08
99-148	Bt2	482	235	283	0.83	L	18.32	1.37	48.30	0.48
148-200	Bt3	502	275	223	1.23	SCL	16.73	1.50	43.40	0.37
	Mean	526	231	243	1.00	SCL	19.89	1.38	48.08	0.86
	CV (%)	6.57	23.59	17.22	34.99		20.76	6.61	7.14	62.77
	Ranking	LV	MV	MV	HV		MV	LV	LV	HV
					Mgbo-Abaja profile 002					
0-15	A	628	149	158	0.67	SCL	26.10	1.17	55.85	0.67
15-27	AB	608	169	223	0.76	SCL	18.80	1.10	58.49	1.19
27-52	Bg1	608	189	203	0.93	SCL	26.80	1.02	61.51	0.25
52-83	Bg2	668	129	203	0.64	SCL	18.80	0.96	63.77	0.10
83-150	Bg3	705	137	223	0.87	SL	18.80	1.41	46.79	0.46
	Mean	643	155	202	0.77	SCL	21.86	1.13	57.28	0.53
	CV (%)	6.57	15.80	13.14	16.15		19.20	15.42	11.50	79.63
	Ranking	LV	MV	LV	MV		MV	LV	LV	HV
					Inyimagu profile 003					
0-12	A	705	237	58	4.09	SL	11.20	1.15	56.60	0.50

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12-43	AB	775	149	76	1.96	SL	18.10	1.40	47.17	0.43
21-43	Bt1	725	172	103	1.00	SL	19.70	1.38	47.92	0.33
43-96	Bt2	705	162	133	1.22	SL	11.90	1.44	45.66	0.12
96-200	Bt3	702	149	149	1.67	SL	17.30	1.59	40.00	0.21
	Mean	722	174	104	1.67	SL	15.64	1.39	47.47	0.32
	CV (%)	4.26	21.08	36.58	62.05		24.55	11.37	12.58	48.89
	Ranking	LV	MV	HV	HV		MV	LV	LV	HV
					Inyimagu profile 004					
0-18	Ap	775	137	88	1.56	SL	10.60	1.16	56.23	0.62
18-45	AB	745	147	108	1.36	SL	16.04	1.34	49.43	1.03
45-98	Bt1	783	64	153	0.42	SL	16.70	0.94	64.53	0.14
98-200	Bt2	755	62	183	0.34	SL	14.06	1.40	47.17	0.61
	Mean	764	103	133	0.92	SL	14.35	1.21	54.34	0.60
	CV (%)	2.39	44.68	32.34	69.51		19.09	17.11	14.37	60.67
	Ranking	LV	HV	MV	HV		MV	MV	LV	HV

Table 2b continued

					Nkwagu profile 005					
0-20	A	702	134	164	0.82	SL	27.51	1.44	45.66	0.78
20-50	AB	772	83	145	0.57	SL	28.53	1.33	49.81	0.88
50-92	Bt1	762	72	166	0.43	SL	19.62	1.50	43.40	0.30
92-200	Bt2	755	132	113	1.17	SL	14.64	1.33	49.81	0.39
	Mean	748	105	147	0.75	SL	22.58	1.40	47.17	0.59
	CV (%)	4.18	30.75	16.71	43.42		29.33	6.03	6.75	48.57
	Ranking	LV	MV	MV	HV		MV	LV	LV	HV
					Nkwagu profile 006					
0-22	A	625	184	191	0.96	SL	20.45	1.38	47.92	0.70
22-38	AB	602	122	276	0.44	SL	26.38	1.42	46.42	1.72
38-98	Bt1	587	107	306	0.35	SL	24.25	1.45	45.28	1.25
98-186	Bt2	643	144	213	0.68	SL	28.4	1.38	47.92	0.48
	Mean	614	139	247	0.61	SCL	24.87	1.41	46.89	1.04
	CV (%)	4.03	24.04	21.74	44.97		13.67	14.62	2.74	53.83
	Ranking	LV	MV	MV	HV		LV	LV	LV	HV

Key: SCR=silt clay ratio, TC=textural class: SL=sandy loam, SCL=sandy clay loam, MC=moisture content, BD=bulk density, TP=total porosity, Ksat=saturated hydraulic conductivity. CV (%): 0-15 (low variation, LV) 16-35 (moderate variation, MV) 36-100 (high variation, HV)

Chemical properties of soils: The results of the chemical properties of Abakaliki soils are presented in Tables 3a, 3b and 3c. Soil pH ranges from moderate to slight acid (5.62 – 6.35) in water (H_2O) and very strong to moderate acid (4.63 – 5.83) in potassium chloride (KCl), with

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surface soils been more acidic than subsurface soils. Soils had low variations and mean values and ranged from 5.87 – 6.07 (CV> 0.85 ≤ 6.68 %) and 4.80 – 5.35 (CV > 0.88 ≤ 8.34 %) in H_2O and KCl respectively. Mgbo-Abaja 001, Nkwagu 005 and 006 had very strong acid conditions which could be as a result of oxidation of anions like sulphides and nitrites leading to these acid conditions (Onweremadu *et al*., 2007). Organic carbon (OC) content (g/kg) of soils mean values ranged from 3.09 – 10.90 (CV> 32.13 ≤ 87.54 %) with high variation. It was high in epipedons than endopedons and reduces with depth although in some cases it was irregular in distribution. This high OC content of the surface soils could be as a result of fresh and undecayed plant materials deposited on the river banks. The highest and lowest mean values were obtained in Nkwagu 005 and Mgbo-Abaja 002 respectively. Alves and Ross (2010) noted that uneven distribution of organic carbon within the horizons is a diagnostic test for fluvial materials from the rivers or lakes. The average Organic carbon content recorded in the study area was below critical level (<10 g/kg) (Esu, 1991). This result is not in agreement with Ogbodo (2011) who recorded high OC in soils of some floodplains of Ebonyi state. Total nitrogen (TN) of soils varied highly and ranged averagely from 0.49 – 1.16 g/kg (CV > 40.87 ≤ 75.66 %) with high values observed on the surface soils like in OC and decreased down the profiles without a definite pattern. Most sites fell below critical levels (<1.0) (except Mgbo-Agbaja 001 and Nkwagu 008 and were rated low (Esu, 1991). This result was in disagreement with the findings of some researchers who recorded high TN values in flood plain soils of southeastern Nigeria (Ogbodo, 2011; Orimoloye *et al*., 2018). Available phosphorus (AP) varied moderately and ranged from 8.11 – 13.10 mg/kg (CV > 9.96 ≤ 30.52 %) with lowest and highest mean values obtained in Mgbo-Abaja 001 and Inyimagu 003 respectively. It decreases down the depth except for few cases where it was otherwise. All soils of Abakaliki fell below critical levels of < 15 mg/kg, and could be as a result of sorption reaction which is a major problem in southeastern Nigeria (Uzoho, 2014). This result is in agreement with the work of Ogbodo (2011) that recorded significantly low values of available phosphorus. Amongst the exchangeable cations, mean exchangeable calcium (Ca) magnesium (Mg), sodium (Na) and potassium (K) ranged from 1.02 – 2.88 cmol/kg (CV > 11.00 ≤ 69.44 %), 0.67-1.58 cmol/kg (CV > 5.98 ≤ 77.54 %), 0.09 – 0.79 cmol/kg (CV > 13.04 ≤ 63.20 %) and 0.10 – 0.99 cmol/kg (CV > 38.85 ≤ 94.67 %) respectively with irregular pattern and high variations in most horizons. The results showed that Ca and Mg were predominant basic cations in these soils. The recorded values of Ca, Mg, Na and K in soils were rated low, medium, medium and low respectively in pedons of the study area (Landon, 1991). The higher rates of cation losses have been reported to occur in wetlands through erosion and leaching (Ambeager, 2006). The total exchangeable acidity of soils varied within the horizons as soils were acidic as a result of parent materials and low basic cations which negatively affect arable cropping and yields. Cation exchange capacity (CEC) average values showed that soils ranged from 7.88 – 11.46 cmol/kg (CV > 10.03 ≤ 38.02 %) with more concentrations on subsurface soils than surface soils which could be as a result of clay and organic residues accumulation. The mean values obtained were moderate to medium (6-12 cmol/kg) and soils become acidic very quickly when CEC is low (Umeugochukwu *et al*., 2019). Percent base saturation average values ranged from 21.03 – 59.72 (CV > 12.29 ≤ 77.50) with high values at surface than subsurface horizons. The values were rated medium (< 60%) in all profiles (FAO, 1987) and are not in agreement with the findings of Ogbodo (2011), and could be attributed to intense leaching by water and low organic matter. Exchangeable sodium percent (ESP) average values ranged from 3.74 – 23.70 % and varied highly within the profiles (CV > 38.63 ≤ 107.70 %). The values were below critical limits of 15% standard for sodic soils (Brady and Weil, 2005), except in Nkwagu 006 that has value >15%. High values of ESP in soils could be as a result of high movement and deposition of salts by the flood waters. The low ESP results agree with the findings of Ogbodo (2011). Electrical conductivity (EC) (dS/m) was low averaging 0.14 – 0.85 (CV > 14.36 ≤ 49.13 %). Within the profile, values decreased down though without a definite pattern but high in some subsurface soils. These EC values were low (< 4 dS/m) indicating non-saline nature of soils and as a result of leaching of released bases with the percolating water (Udoh and Lekwa, 2014). Soil EC much like pH is a good indicator of soil fertility and shows capacity of soil to store nutrients.

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Table 3a: Chemical Properties of Pedons of Abakaliki study Area

Depth (cm)	Horizon	pH H$_2$O	pH KCl	OC (g/kg)	TN (g/kg)	AP mg/kg	Ca	Mg	Na	K	TEB cmol/kg	H	Al	TEA	ECEC	CEC	BS %	ESP %	EC dS/cm
							← cmol/kg									→			
Mgbo-Abaja profile 001																			
0-21	A	5.89	4.95	7.68	0.88	8.68	2.50	1.04	0.10	0.05	3.69	0.79	0.89	1.68	5.37	9.70	38.04	2.71	0.56
21-58	AB	5.87	4.92	3.69	0.53	6.44	1.09	0.45	0.45	0.07	2.06	0.70	0.70	2.30	4.01	9.50	21.68	5.85	0.31
58-99	Bt1	5.83	4.89	3.46	0.49	7.07	0.84	0.43	0.43	0.13	1.83	0.50	0.50	2.00	3.54	12.10	15.12	9.00	0.29
99-148	Bt2	5.95	4.80	1.90	0.30	7.49	0.55	0.50	0.50	0.14	1.69	0.70	0.70	2.40	3.73	11.50	14.70	10.53	0.14
148-200	Bt3	5.83	5.00	1.50	0.23	10.85	0.83	0.93	0.93	0.12	2.81	0.80	0.80	2.70	4.71	14.50	19.38	6.47	0.27
	Mean	5.87	4.91	3.65	0.49	8.11	1.16	0.67	0.48	0.10	2.41	0.70	0.72	2.22	4.27	11.46	21.03	6.91	0.31
	CV	0.85	1.52	67.13	52.19	21.45	66.44	43.48	61.43	38.85	34.48	17.26	20.24	17.61	17.73	17.73	17.77	43.83	49.13
	Ranking	LV	LV	HV	HV	MV	HV	HV	HV	HV	HV	MV	MV	MV	MV	MV	MV	HV	HV
Mgbo-Abaja profile 002																			
0-15	A	5.66	5.04	16.30	1.63	13.65	2.84	1.80	1.70	0.46	6.80	0.20	0.40	0.60	7.40	10.22	66.54	25.00	0.81
15-27	AB	6.35	5.83	7.28	1.24	10.15	1.36	0.98	0.16	0.74	3.24	0.40	0.50	0.90	4.14	9.49	34.14	4.94	0.69
27-52	Bg1	5.90	5.37	18.10	1.29	15.75	0.96	0.83	0.08	0.11	1.98	0.40	1.20	1.60	3.58	11.26	17.58	4.00	0.66
52-83	Bg2	5.84	5.30	5.29	0.57	13.93	1.20	1.06	0.11	0.10	2.47	0.50	1.10	1.60	4.07	12.05	20.50	4.45	0.54
83-150	Bg3	5.78	5.21	3.49	0.48	9.45	1.36	1.17	0.12	0.11	2.76	0.50	1.40	1.90	4.66	11.89	23.21	4.35	0.85
	Mean	5.91	5.35	10.09	1.04	12.59	1.54	1.17	0.43	0.30	3.45	0.40	0.92	1.32	4.77	10.98	31.42	8.55	0.71
	CV	4.46	5.52	65.96	47.63	21.29	48.11	32.05	63.2	94.67	55.88	30.62	48.24	41.29	31.85	10.03	62.01	107.70	17.63
	Ranking	LV	LV	HV	HV	MV	HV	MV	HV	HV	HV	MV	HV	HV	MV	LV	HV	HV	LV

Table 3b

Inyimagu profile 003																			
0-12	A	5.95	5.18	7.28	1.30	14.35	1.84	2.11	0.09	0.07	4.11	0.27	0.13	0.30	4.41	10.68	38.48	2.19	0.78
12—43	AB	6.04	5.24	9.28	1.15	11.06	1.34	1.70	0.11	0.16	3.31	0.34	0.16	0.50	3.81	10.74	30.82	3.32	0.54
21-43	Bt1	5.95	5.20	4.49	0.58	10.75	1.04	0.73	0.07	0.10	1.94	0.46	0.76	1.20	3.14	6.09	19.56	3.61	0.37
43-96	Bt2	5.89	5.16	2.09	0.34	8.26	0.64	0.85	0.16	0.31	1.96	0.47	1.25	1.72	3.68	9.88	19.84	8.16	0.30
96-200	Bt3	5.92	5.30	1.30	0.28	6.18	0.61	0.88	0.08	0.07	1.64	0.48	0.86	1.34	3.01	9.92	26.93	4.79	0.37
	Mean	5.95	5.23	4.89	0.73	10.12	1.09	1.25	0.10	0.14	2.59	0.40	0.63	1.01	3.61	9.46	27.38	4.41	0.47
	CV	0.94	1.06	69.28	64.19	30.52	47.06	48.99	34.94	71.02	41.15	23.26	76.09	58.74	15.58	20.38	29.32	51.86	41.44
	Ranking	LV	LV	HV	HV	MV	HV	HV	MV	HV	HV	MV	HV	HV	LV	MV	MV	HV	HV
Inyimagu profile 004																			
0-18	Ap	6.25	5.46	10.10	1.29	12.39	3.44	2.05	0.16	0.24	5.89	0.32	trace	0.32	6.21	9.83	59.92	2.72	0.43
18-45	AB	6.15	5.40	13.80	1.37	11.90	5.28	2.50	0.13	0.11	8.02	0.23	trace	0.23	8.25	12.43	64.52	1.62	0.30
45-98	Bt1	5.98	5.25	2.69	0.34	16.37	1.76	1.09	0.12	0.54	3.51	0.78	0.30	1.08	4.59	9.58	36.64	3.42	0.45
98-200	Bt2	5.90	5.30	2.09	0.22	11.76	1.04	0.66	0.15	0.23	2.08	0.44	1.08	1.52	3.60	11.24	18.51	7.21	36.50
	Mean	6.07	5.35	7.17	0.81	13.10	2.88	1.58	0.14	0.28	4.88	0.44	0.34	0.79	5.66	10.77	45.31	3.74	0.43
	CV	2.62	1.78	79.88	75.66	16.74	65.62	53.8	13.04	65.40	53.75	54.44	0.00	78.67	35.90	12.31	47.69	64.86	22.68
	Ranking	LV	LV	HV	HV	MV	HV	HV	MV	HV	HV	HV	LV	HV	HV	LV	HV	HV	MV
Nkwagu profile 005																			
0-20	A	5.84	4.90	6.08	1.10	9.52	1.84	1.08	0.14	0.12	3.18	1.23	0.37	1.60	4.78	11.30	28.14	4.40	0.49
20-50	AB	5.83	4.92	2.49	0.88	11.27	0.88	1.00	0.08	0.12	2.08	0.88	2.04	2.92	5.00	7.51	27.70	3.85	0.33

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Table 3c

50-92	Bt1	5.94	4.95	1.70	0.48	10.71	1.04	0.65	0.12	0.09	1.90	0.80	2.10	2.90	4.80	8.63	22.02	6.32	0.46
92-200	Bt2	5.96	5.00	2.10	0.50	9.10	0.32	0.34	0.14	0.46	1.26	0.36	2.04	2.40	3.66	4.07	30.96	11.10	0.30
	Mean	5.89	4.94	3.09	0.74	10.15	1.02	0.77	0.12	0.20	2.11	0.82	1.64	2.46	4.56	7.88	26.78	6.42	0.39
	CV	1.14	0.88	65.24	40.87	9.96	61.55	44.39	23.57	88.90	37.93	43.75	51.63	25.20	13.34	38.02	13.78	51.36	27.69
	Ranking	LV	LV	HV	HV	LV	HV	HV	MV	HV	HV	HV	HV	MV	LV	MV	LV	HV	MV
									Nkwagu profile 006										
0-22	A	5.92	4.96	8.31	1.30	9.44	2.87	1.37	0.10	0.16	4.50	0.52	0.72	1.24	5.74	8.48	53.07	2.22	0.58
22-38	AB	5.87	4.89	2.10	0.80	4.04	1.63	1.18	0.88	0.12	3.81	1.23	0.64	1.87	5.68	10.24	37.21	23.10	0.72
38-98	Bt1	5.68	4.80	4.58	1.15	12.32	0.76	0.86	0.74	0.20	2.56	0.55	1.66	2.21	4.77	9.87	25.94	28.91	0.40
98-186	Bt2	5.74	4.78	10.50	1.40	11.78	0.84	0.62	0.52	0.14	2.12	0.52	1.78	2.30	4.42	8.09	26.21	24.53	0.33
	Mean	5.80	4.86	6.37	1.16	9.40	1.52	1.00	0.56	0.16	3.25	0.71	1.20	1.91	5.15	9.17	35.44	19.69	0.51
	CV	2.08	1.39	32.13	50.70	17.65	11.53	5.98	40.44	47.10	7.99	25.46	5.95	11.09	6.42	17.06	14.06	38.63	14.36
	Ranking	LV	LV	MV	HV	MV	LV	LV	HV	HV	LV	MV	LV	LV	LV	MV	LV	HV	LV

Key: pH H20 = pH in water, pH Kcl = pH in Kcl, TN=total nitrogen, AP = available phosphorus, C:N = carbon-nitrogen ratio, TEB = total exchangeable bases, TEA = total exchangeable acidity, ECEC = effective cation exchange capacity, CEC = cation exchange capacity, BS = base saturation, ESP = exchangeable sodium percentage, EC=electrical conductivity. CV (%): 0-15 (low variation, LV) 16-35 (moderate variation, MV) 36-100 (high variation, HV)

Taxonomic Classification of Soils

The USDA soil taxonomy (2014) was used in the classification of soils and correlated with World Reference Base (WRB, 2015) legend (Table 4). Morphology, physicochemical and mineralogical properties were the major criteria used for classification of soils to series level. Soils of Mgbo-Abaja 001and P002, Inyimagu 003 and 004 and Nkwagu 005 and 006 of Abakaliki (Ebonyi state) were classified as: Order: Soils were classified as Ultisols due to the presence of Argillic or Kandic diagnostic horizons. They have brown/brownish yellow subsurface horizons, very strongly acid to moderately acid (4.63 – 5.83), low base saturation and activity clay properties of humid tropical conditions (FDALR, 1990). Suborder: Soils were classified as Aquults because of their aquic moisture regime. Great group: Mgbo-Abaja 001 and 002, Inyimagu 003 and Nkwagu 005 were Kandiaquults (CEC <16 cmol/kg) while Inyimagu 004 and Nkwagu 006 were Kandiaqualfs (CEC >16 cmol/kg). Subgroup: Mgbo-Abaja 001 and 002, Inyimagu 003 and Nkwagu 005 were Typic because their properties were typical in their groups. Inyimagu 004 and Nkwagu 006 were Grossarenic due to sandy or sandy-skeletal particle size class that is between 100 and 200 cm thick. Mgbo-Abaja 001 and 002 and Nkwagu 006 were coarse loamy, mixed, active, isohyperthermic because of the texture (coarse loamy, < 35% by weight of clay in fine earth fraction), mixed (clay mineralogy), active (because of possession of CEC class of < 0.60) and isohyperthermic (temperature of 22^{o}C or more). Inyimagu 003 and P004, Nkwagu 005 and 006 were sandy, mixed, super active, isohyperthermic because of texture

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(sandy), mixed (clay mineralogy), super active (possession of CEC class of 0.60 or more), isohyperthermic (temperature of 22ºC or more). Series: Pedons at this level were classified according to locations: Mgbo-Abaja, Inyimagu and Nkwagu series. These soils correspond to Typic Kandiaquults coarse loamy, mixed, active, isohyperthermic Mgbo-Abaja series / Ferralic Gleysols (Mgbo-Abaja 001), Typic Kandiaquults coarse loamy, mixed, active, isohyperthermic Mgbo-Abaja series / Cambic Gleysols (Mgbo-Abaja 002), Typic Kandiaquults sandy, mixed, super active, isohyperthermic Inyimagu series / Ferralic Gleysols (Inyimagu 003), Grossarenic Kandiaqualfs sandy, mixed, super active, isohyperthermic Inyimagu series / Ferralic Gleysols (Inyimagu 004), Typic Kandiaquults sandy, mixed, active, isohyperthermic Nkwagu series / Ferralic Acrisols (Nkwagu 005) and Grossarenic Kandiaqualfs coarse loamy, mixed, active, isohyperthermic Nkwagu series / Ferralic Acrisols (Nkwagu 006) characteristics (WRB, 2015).

Table 4: Taxonomic Classification of Soils of the study area

Profiles	USDA Soil Taxonomy	Family/ Series	World Reference Base
Mgbo-Abaja 001	Typic Kandiaquults	Coarse loamy, mixed, active, isohyperthermic/ Mgbo-Abaja series	Ferralic Gleysols
Mgbo-Abaja 002	Typic Kandiaquults	Coarse loamy, mixed, active, isohyperthermic/ Mgbo-Abaja series	Cambic Gleysols
Inyimagu 003	Typic Kandiaquults	Sandy, mixed, super active, isohyperthermic/ Inyimagu series	Ferralic Gleysols
Inyimagu 004	Grossarenic Kandiaqualfs	Sandy, mixed, super active, isohyperthermic/ Inyimagu series	Ferralic Gleysols
Nkwagu 005	Typic Kandiaquults	Sandy, mixed, active, isohyperthermic/ Nkwagu series	Ferralic Acrisols
Nkwagu 006	Grossarenic Kandiaqualfs	Coarse loamy, mixed, active, isohyperthermic/ Nkwagu series	Ferralic Acrisols

CONCLUSION AND RECOMMENDATIONS

The study evaluated the characteristics and classification of soils of Abakaliki floodplains for arable crops production. The soils were formed from river alluvium, well drained except in Mgbo-Abaja 002, sub angular blocky structure and firm to very firm consistency in their subsurface horizons. Soils were generally acidic with low nutrient status (organic carbon, total nitrogen, base saturation and cation exchange capacity) as a result of the nature of the parent materials deposited. Soils varied in macro, physical and chemical properties within their respective profiles after careful profile description and examinations. The soils were classified using USDA soil taxonomy/ FAO-WRB. It is important to monitor the water table and adopt good irrigation schedule, contour ridging and furrow to reduce excessive water especially in Mgbo-Abaja profile 002. It is vital to create drainage channels which will reduce water logging and loss of basic cations through leaching and also use of some management practices like biochar addition, liming, accurate applications of organic manure and inorganic fertilizer, which will boost the condition of soils and improve their fertility for arable crop production.

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