CHARACTERIZATION AND CLASSIFICATION OF SOILS DEVELOPED FROM SANDSTONE AND BASEMENT COMPLEX IN BENUE STATE, NIGERIA

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Abstract
Characterization and classification of soils developed from sandstone and basement complex in the hot humid tropics of the southern guinea savanna in Kyado, Benue state North Central Nigeria was studied. Four mapping units were identified and classified based on toposequence and associated landuse using a free survey method. Soil properties such as texture, effective soil depth, moisture status, available nutrient status and drainage condition were employed for site suitability classification for the commonest arable crops (yam, cassava, rice (fadama rice), sorghum, maize, millets, tomato, melon, soybean, and groundnuts). The results indicated that Kyado soils were moderately suitable (S2). The particle size distribution data indicates the preponderance of sand in all the pedons in the study area. Mean value of percentage sand are 80.0 %, 81.08 %, 83.08 % and 81.0 % for pedons I, II, III and IV respectively. Textural class ranges from loamy sand (Ap horizon) sandy loam (subsoil). The soils had colour matrix in the dark brown (2.5YR3/3) to yellowish brown (10YR5/6) to very pale brown (10YR8/4) to pink white (7.5YR8/2) for the genetic horizons and soil colours were taken under moist condition. The soil reactions generally range from strongly acidic in the topsoil to moderately acidic in the subsoil. The soil organic carbon (SOC) in all the pedons were generally low as the highest was 8.3g/kg recorded. TN ranges from very low to low and the highest mean values were recorded in pedon III and IV (1.1g/kg). The Ca and Mg were the dominant effective cations exchange capacity though the values are very low and the highest mean was recorded in pedon I (0.92 cmol/kg Ca and 0.74 cmol/kg Mg). The soils are classified as Typic isohyperthermic kanhaplustalfs in the USDA soil taxonomy and this corresponds to Arenic Acrisol in the FAO-ISSS-ISRIC world Base Reference classification.
Key words: Benue Soils, Classification, Characterization, Soil Suitability, Sandstone

Introduction

All cultivated soils are particularly susceptible to erosion when the dry, unprotected soil surface is exposed to wind or rain (Juo and Franzluebber, 2003). Soil taxonomy provides hierarchical grouping of natural soil bodies and it is based on soil properties that can objectively be observed or measured, rather than presumed mechanism of soil formation (Brady and Weil, 2015). They also pointed out that it uses a unique nomenclature, which gives a definite connotation of the major characteristics in question. There is an increasing demand for information on soils as a means to produce food (Fasina *et al*, 2007) while other authors blamed lack of detailed information of soil and land characteristics and the need to classify and characterize soil has become necessary to know the prospects and unravel some unique soil problems in the ecosystem (Lekwa *et al*., 2004, Okusami *et al*, 1987). Land is an important economic factor of production and it is the basic resource for meeting human needs (Brady, 1990). Important pedological properties that can be used for characterisation includes soil depth, soil colour, mottling, soil texture, structure, consistence, pore spaces, minerals composition, fragments, pans, roots and water retention capacity (Ojo- Atere *et al*, 2011). Other important soil properties are particle size distribution, bulk density and porosity. Particle size distribution, bulk density and porosity are very important soil characteristics that exert strong influence on plant development through infiltration, aeration, porosity, water holding capacity, drainage and permeability (Idoga *et al*, 2006).

Soil characterization study therefore, is a major building block for understanding the soil, classifying it and getting the best understanding of the environment (Esu, 2005). In an earlier work by Esu (2004), who remarked that lack of information on the soil resources of any region contributes to the problem of soil degradation due to wrong uses and poor management of land resources and in line with that, Nsor and Akamigbo (2015) argued that based on soils attributes and potential, every land is suitable for a particular use. Thus a good knowledge of soil resources is indispensable in planning agricultural development. The soil of Benue needs special attention as the state pride itself as "the food basket of the nation" and bearing in mind its heavy reliance on soil where there in an intense competition for land coupled with low or no fallows. Great demands are placed on soils of Benue state to meet food for a rapidly growing population where land use is at the expense their suitability resulting in land degradation. The declining productivity of soils is largely due to a combination of factors (scarcity of land and dearth of information about soils). The soils of Benue state are rarely derived from single parent material and usually from sandstone/ shale/basaltic intrusion/ limestone. In areas dominated by a particular parent material an intrusion or pockets extraneous materials usually occur. Hence there is information deficiency. This study aimed to characterize, classify and evaluate the suitability of these soils of Kyado for agricultural development.

Materials and methods

Site Description

The study area was Kyado in Ukum local government area of Benue state North central Nigeria. The study area lies on 7^0 33'N and $9^0$43'E in the southern guinea savanna and it is characterized by tropical hot/wet with distinct rainy and dry seasons. The rainy season months are May to October while the dry months are November to April. Annual rainfall ranges from 1100-1250mm. The mean annual temperature is about 29^0C (temperature can reach 40^0C in March). The relative humidity varies as the months of rain with 70-80% in July-August been the highest and with high intensity solar radiation (5-8 hours effective sunshine overhead). The topography is flat to gentle undulating with drainage characterized by non-perennial streams and a tropical lowland (<600 masl). The Ukum LGA falls within the yam (tuber) belt of Nigeria. The sand stone/ shale/ undifferentiated basement complexes (figures 1 and 2) are the parent materials and the substratum is usually petroplinthic kandiustalfs (Imadojemu et al, 2017 and Okoye, 2014). It is typically an agrarian community with low to medium levels of farm inputs. Its major produces are yam, cassava, rice (fadama rice), sorghum, maize, millets, tomato, melon, soybean, bambara nuts (*vigna subterranean*) and groundnuts. Forest resources also abound in the study area particularly the *Daniella olivera*, *Gmelina arborea*, while plantations of mangoes, citrus etc are common features. Livestock keeping is also a common practice (pig, sheep and goats).

Field work

Four mapping units were identified and classified based on toposequence and associated landuse. A stratified random sampling technique was adopted in the study. The profile pits were positioned at crest, upper, mid-slope and lower slopes. A total of four profile pits was sunk and described following the guidelines of FAO, (2006). Soil samples were taken for routine physical and chemical analysis while morphological studies were done in-situ.

Location data of the Toposequence taken with hand held GPS receiver

Position	Profile code	Elevation (m.a.s.l)	North-East coordinates
Lower slope	I	190	7° 38' 46.32"N, 9°43'35.2"E
Mid-slope	II	191	7° 38' 53.0"N, 9°43'10.8"E
Upper slope	III	193	7° 38' 48.4"N, 9°43'16.8"E
Crest	IV	197	7° 38' 50.5"N, 943'4.70"E

Laboratory analysis

The pH was determined by glass electrode pH meter, particle size analysis was by hydrometer method. Organic carbon was determined by wet dichromate method. Total nitrogen was determined by micro-Kjeldal method. Extraction of available phosphorus was done using Bray 1 method. Exchangeable cation (K, Ca, Mg, and N) were extracted by neutral normal ammonium acetate, K and Na in the extraction were determined by flame photometer while Ca and Mg were by atomic absorption spectrophotometer. Cation exchange capacity was by summation method. The exchangeable acidic cations: hydrogen and aluminium were estimated titrimetrically. The following micro nutrients (Zn, Pb, Cd, Cr) were analyzed with atomic absorption spectrophotometer after wet digestion with concentrated HCL and HNO_3. Bulk density was measured by core method (Grossman and Reinsch, 2002). Total porosity (P_o) was obtained from bulk density (ℓp) values with assumed particle density (ℓs) 2.65 g cm^{-3} as follows, Porosity (Po) =100 – (ℓp/ℓs) ×100/1

Statistical analysis was performed using Genstat statistical package for the analysis of variance and treatment mean compared using least significant difference at 5% level of probability.

Results and Discussions

Morphological properties of the studied soils are shown in table 1, the physiographic mapping units have different colour matrix range and all the horizons are well drained characterized by loose top soil. The peds are generally arranged in sub angular blocky, gradual wavy horizon boundaries and soils have fine and medium roots and pronounced faunal activities in the epipedons. Pedon I, had colour matrix in the dark brown (2.5YR3/3) to yellowish brown (10YR5/6) to very pale brown (10YR8/4) to pink white (7.5YR8/2) for the genetic horizons Ap, AB, Bt_1, Bt_2 and Bt_3 respectively. It has evidence of mottling in Bt_2 (5YR4/4) and Bt_3 (2.5YR4/4). The pink white colour observed in the Bt3 horizon may be due to anaerobic condition common to low lying land and usually used for rice farming. In pedon II, the colour matrix are dark yellowish (10YR4/6), pale red (10R7/4), pink (5YR8/4) reddish yellow (7.5YR7/8) and stronger brown (7.5YR5/8) for the genetic horizons Ap, AB, Bt_1, Bt_2 and Bt_3 respectively. The red colours in the subsurface horizon are indicative of good soil drainage, aeration and porosity. The soils are highly friable at top soil while sticky at the subsoil, this variation made due to illuviation / eluviation interplay. The pedons III &IV, is similar to morphological features of pedon II, the variations observed are consistence with respect to stickiness of the sub soil overburdened by friable topsoil. The structure of the soil is predominantly sub angular blocky moderate to medium weak grade and the higher clay content at the sub surface horizons accounts for greater aggregation hence firmer consistency (Mustapha, 2002).

The soil physical properties are presented in table 2. The particle size distribution data indicates the preponderance of sand in all the pedons in the study area, this suggests they have quartzite in its geology. The percentage sand mean values are 80.0 %, 81.08 % ,83.08 % and 81.0 % for pedons I, II,III and IV respectively. The highest and lowest averages were observed in pedon III and I. The sandiness of Kyado soils may be due to a combination of parent materials, tropical climate and landuse practices, these factor influences pedogensis and properties of soils (Akamigbo,1999). The silt content showed no regular pattern in pedons I and III but with an increase down the profile in pedons II and IV. Clay content was generally higher than silt fraction in all the pedons studied with the highest mean recorded in pedon II (14.94%) and a general increase down the profile. This trend is a common physical feature with soils in this zone and this is due to weathering of silt fraction into clay. The silt clay ratio (SCR) as observed in the study site showed mean values of <1. This is an indication of reserved weatherable mineral in the substratum as typical of petroplinthic kaniustalfs (USDA, 2015). The SCR is also an index for extent of weathering (Oleghe and Chokor, (2015). The textural class ranges from loamy sand (Ap horizon) sandy loam (subsoil), pedon II has sand in (Ap horizon) and sandy clay loam (subsoil), pedons III and IV had loamy sand (Ap horizon) and sandy loam (subsoil). The largely loamy sand and sand at the top soils while sandy clay loam and sandy loam at the sub-soils observed were consistent with the observations made by Juo and Franzluebber (2003). Maniyunda and Malgwi (2019) reported that soil texture had influence on several physical and chemical processes as well as workability of soil. The mean values of bulk density were 1.45 g/cm^{-3}, 1.44 g/cm^{-3}, 1.42 g/cm^{-3} and 140 g/cm^{-3} for pedons I, II,III and IV respectively, The bulk density increased with profile depth though values obtained are within the range for good rooting crops (soil Survey Staff, 2006 and Ladon, 1991). The total porosity values followed are relationship with the bulk density values (the inverse relationship that is the bulk density decreases as the porosity increases). The porosity values ranges from 40.76 % - 51.33 %. These porosity values are indicative of good soil-air condition.

The chemical properties of the studied soil are as presented in table 3. The pH had mean values of 5.47, 5.43, 5.88 and 5.37 for pedons I, II, III and IV respectively. The soil reactions generally range from strongly acidic in the topsoil to moderately acidic in the subsoil (acidity decreased with profile depth). The acidity may be due to leaching caused by rainfall and urea fertilizer application (many of the farmers are found to apply urea fertilizers in crop production). This indicates that the soils are strongly acidic and shows that there are significant exchangeable AL^{3+} and H^{+} hence the entire soil will have net negative charges on soil colloids and this will engender cation adsorption on the soil exchange complex site (Kolay, 2002) while Osodeke, (2017) reported such soils with strong acidity for precipitating and fixing nutrients such as phosphorous, potassium, and sulphur hence making them unavailable for plant uptake and further recommended the use of algae (cyanobacteria) to increase soil available phosphorus, reduced the standard P requirement, maximise adsorption capacity and bonding energy of phosphorus to soil particles and among other recommendations are use of wood ash to reduce soil acidity, increase total nitrogen and exchangeable bases as well as the use of micronutrient whereas Maniyunda and Malgwi (2019) reported that parent materials such as sandstone results in soils rated neutral to moderately alkaline pH. The SOC in all the pedons were generally low as the highest was 8.3g/kg recorded in pedon III. Asadu *et al* (2012) stated that coarse textured soils are usually low in soil organic compound. TN ranges from very low to low and the highest mean values were recorded in pedon III and IV (1.1g/kg) and it decreased with profile depth. The low total nitrogen may be due to its volatility owing to tropical high temperature and leaching due to heavy precipitation. The available P was very low and the highest mean value obtained was in pedon III (1.4 mg/kg) and this closely followed the pattern of distribution of organic matter in the soil, these suggested that some forms of phosphate is of organic sources (Brady and Weil, 2014). Osodeke (2017) noted that P is one of the important plant nutrient elements but usually in form not available to plants and it's largely influenced by pH, soil moisture status, organic matter content and microbial activities in the soil.

The potassium mean values obtained indicated that the soils of Kyado are moderate in K, the highest was in pedon I (0.68 cmol/kg). Generally K mean values were in good supply and in plant available form. The sodium was content highest in pedon (I .59 cmol/kg) in the soil are equally good as they do not pose any threat of salinity in the study area contrary to the findings of Zaku, *et* al (2011), where they stated in their conclusion that Wukari soil have salinity problem. The Ca and Mg are the dominant effective cations exchange capacity though the values are very low and the highest mean was recorded in pedon I (0.92 cmol/kg Ca and 0.74 cmol/kg Mg). The C/N ratio was highest in pedon III (16.6) which is below 25 set by Paul and Clark (1989) which favours mineralization of organic materials. Ca:Mg ratio of

<5.1 indicates low activity clay (Brady and Weil, 2014). Ca:Mg had mean of 1.75, 1.25, 1.19 and 0.74 in pedons I, II, III and IV respectively. The soils are infertile when compared with the rating (< 3) of (Landon, 1991). Generally, the mean values found at the foot-slope may be as result of its moisture status as it holds more water than the other profiles along the toposequence. The micronutrients determined in this study are found to be deficient. Zn mean values were 0.02 mg/kg, 0.03 mg/kg, 0.028 mg/kg, and 0.02 mg/kg in pedons I, II, III and IV respectively. These values are very low while Udo *et al*, (2008) described deficiencies as hidden hunger which the farmers are unaware; they stressed the urgency of the need to ensure each farmer knows the health of the soil in order to ensure the development of agriculture.

Classification

Based on the criteria of USDA soil taxonomy (2015), the soils meet the requirement for placement in the order; Alfisols (Alfisols are well-developed and moderately leached soils with a clayey B horizon (or argillic horizon) due to downward clay movement (lessivage). The degree of base saturation (Ca, Mg, K, and Na) of the lower B horizon is 35% or more, where leaching, eluviation and illuviation and subsequent accumulation of clay at subsurface horizon in an acidic environment as well as presence of/or occurrence of coarse-textured overlying a horizon with clay augmentation) since the percentage base saturation by NH_4OAC at pH 7.0 is less than 50% in the Bt horizon with an argillic/ kandic diagnostic subsurface horizons. The preponderance of sand in all the horizons, the moisture regime and the decrease of clay by > 20% indicated psammentic haplustalfs. The temperature is isohyperthermic and moisture regime is ustic, the reddish brown colour is an indication of good aeration and oxidation of Fe^{2+} to Fe^{3+}. The soils are therefore Typic isohyperthermic kanhaplustalfs and this corresponds to Arenic Acrisol (WRB, 2006) hence is classified in S2 suitability class.

Conclusion

The physical and chemical limitations of tropical Alfisols can be ameliorated using both sustainable agriculture (minimal soil disturbance, keep soil covered, mixing and crop rotation, promoting efficient use of agrochemicals, appropriate fertilizer application, use of household waste materials, controlled burning) and conventional farm practices that can help replenish the nutrient lost through cultivation of crops as well as incorporating nutrient-rich mound materials into the nutrient-poor acid sandy soils can potentially enhance the physical and chemical properties of the soils. Largely loamy sand and sand at the top soils while sandy clay loam and sandy loam at the sub-soils were indicators of good bulk density and porosity. The soil reactions generally range from strongly acidic in the topsoil to moderately acidic in the subsoil (acidity decreased with profile depth). The acidity may be due to leaching caused by rainfall and urea fertilizer application (many of the farmers are found to apply urea fertilizers in crop production). Generally K, was in good supply and in plant available form and Na do not pose any threat of salinity in the study area. C/N ratio was rated favourable to organic matter mineralization. However if Benue state will continue to be the food basket of the nation attention must focus on soil conservation and use of integrated soil fertility management and improve extension service delivery.

Table 1: Morphological characteristics of the pedons in the study area

COORDINATE	HORIZON	DEPTH	COLOUR	STUCTURE	MOTTLE	HORIZON BOUND.	TEXTURE	CONSIST	VEG	ROOT PRES
RICE LANDUSE [Pedon 1]										
$7^{0}38^{1}46.32^{11}$N	Ap	0-20	Dark brown 2.5YR 3/3	1Sab	None	GW	LS	Friable	SR	Many
$9^{0}43^{1}35.2^{11}$E	AB	20-40	Yellowish brown 10 YR 5/6	1Sab	None	GW	LS	Friable	SR	Few
190Masl	Bt1	40-60	Very pale brown 10yR 8/3	2Sab	5 YR4/4 Fewer mottle	Diffused	SL	Friable	SR	Fewer
	Bt3	60-80	Very pale brown 10 YR 8/4	2Sab	2.5 YR4/4 fewer mottle	GW	SL	Sticky/plasti c	SR	Very few
	Bt3	80-110	Pinkish white 7.5 YR 8/2	2Sab	None	GW	SL	Sticky/plasti c	SR	None
ORCHARD LAND USE [Pedon 2]										
	Ap	0-20	Dark yellowish brown 10 YR 4/6	1Sab	None	Smooth	S	Friable	SR	Many
$38^{1}53.0^{11}$N	AB	20-40	Pale Red 10R 7/4	1Sab	None	Smooth	S	Friable	SR	Few
$9^{0}43^{1}10.8^{11}$E	Bt1	40-60	Pink 5 YR 8/4	1Sab	None	Smooth	LS	Sticky	SR	Fewer
180 Masl	Bt2	60-80	Reddish yellow 7.5YR 7/8	1Sab	None	Smooth clear	SL	Sticky	SR	Fewer
	Bt3	80-110	Stronger brown 7.5YR 5/8	2Sab	None	Smooth	SCL	Sticky/plast ic	SR	Fewer

				MIXED CROP LANDUSE (PEDON 3)						
	Ap	0-20	Dark yellowish brown 10YR ¾	1Sab	None	DW	LS	Friable	SR	Many
$7^0 38^1 48.4^{11}$N	AB	20-40	Pink 7.5 YR 7/4	1SAB	None	GW	LS	Friable	SR	Few
$9^0 43^1 16.8^{11}$E	Bt1	40-60	Light red 10R 6/8	1Sab	None	GW	SL	Sticky/plastic	SR	Few
193Masl	Bt2	60-80	Light red 2.5 YR 7/8	2Sab	None	GW	SL	Sticky/plastic	SR	Fewer
	Bt3	80-110	Reddish yellow 5YR 7/8	2Sab	None	GW	SL	Sticky/plastic	SR	None
				CASSAVA LANDUSE (Pedon 4)						
$7^0 38^1 50.5^{11}$N	Ap	0-20	Dark brown 10YR3/4	1Sab	None	DW	LS	Friable	SR	Many
$9^0 43^1 4.7^{11}$E	AB	20-40	Dark brown 10YR 3/3	1Sab	None	DW	LS	Friable	SR	Many
187Masl	Bt1	40-60	Light reddish brown 5YR 6/3	2Sab	None	DW	LS	Sticky	SR	Fewer
	Bt2	60-80	Pink YR 8/3	2Sab	None	DW	SL	Sticky	SR	Fewer
	Bt3	80-110	pinkish white R 8/3	2Sab	None	DW	SL	Sticky	SR	Fewer

TEXTURE ; S=Sand, LS=Loamy sand, SCL= Sand clay loam, SL=Sandy loam.
VEGETATION; SR= Secondary regrowth
HORIZON; GW=Gradual way, DW=Difused/Way.
STRUCTURE;Sab=Subangular blocky

Table 2: Physical Properties of the Studied Pedons

Horizon	Depth	SAND	SILT	CLAY	SCR	TC	BD	Po
	Cm		%				g/cm^{-3}	%
			RICE LANDUSE (Pedon 1)_					
Ap	0 -20	84.8	5.4	9.8	0.23	LS	1.36	48.68
AB	20 -40	84.8	4.4	10.8	0.55	LS	1.43	46.04
Bt1	40 -60	70.8	16.4	12.8	1.28	SL	1.57	40.76
Bt2	60 -80	77.8	9.4	12.8	0.73	SL	1.44	45.66
Bt3	80 -110	81.8	5.4	12.8	0.42	SL	1.44	45.66
Mean		80	8.2	11.8	0.64		1.45	45.36
			ORCHARD LANDUSE {Pedon 2}					
Ap	0 -20	89.4	1.9	8.7	0.22	S	1.32	50.2
AB	20 -40	88.4	2.9	8.7	0.33	S	1.43	46.04
Bt1	40-60	83.4	3.9	12.7	0.31	LS	1.44	45.67
Bt2	60 -80	73.4	5.4	20.8	0.26	SL	1.5	43.39
Bt3	80 -110	70.8	5.4	23.8	0.23	SCL	1.49	43.77
Mean		81.08	3.9	14.94	0.27		1.44	45.81
			MIXED CROP (Pedon 3)					
Ap	0-20	82.8	7.4	9.8	0.75	LS	1.31	50.57
AB	20 -40	84.4	6.6	9	0.73	LS	1.41	46.79
BA	40 -60	82.4	7.6	10	0.76	SL	1.43	46.03
Bt1	60 -80	83.4	6.1	10.5	0.58	SL	1.45	45.28
Bt2	80 -110	82.4	7.6	10	0.75	SL	1.48	44.16
Mean		83.08	7.06	9.85	0.71		1.42	46.57
			CASSAVA LANDUSE (Pedon 4)					
Ap	0 -20	87.4	3.9	8.7	0.45	LS	1.29	51.33
AB	20 -40	85.4	3.9	10.7	0.36	LS	1.41	46.8
Bt1	4o -60	80.4	4.9	14.7	0.33	LS	1.43	46.04
Bt2	60 -80	75.4	5.9	18.7	3.15	SL	1.44	45.66
Bt3	80 -110	76.4	4.9	18.7	0.26	SL	1.44	45.66
Mean		81	4.7	14.3	0.91		1.4	47.09
LSD(0.05)		7.84	3.562	5.69	0.885		0.0928	3.5048

SCR=Silt clay ratio, BD=Bulk density, Po=Porosity, TC=Textural class. S=Sand, LS=Loamy sand, SL=Sandy Loam, SCL=Sandy Clay Loam

Table 3: Chemical properties of the studied pedons

Horizon	Depth	pH	OC	OM	TN	Av.P	Ca	Mg	K	Na	TEA	TEB	ECEC	Ca/Mg	BS	ESP	Zn	Pb	Cd	Cr
	Cm	H_2O	←	% →		mg/kg	←			cmol/kg			→		%	%	←	mg/kg		→
									RICE LANDUSE { Pedon 1}											
Ap	0 -20	5.3	0.32	0.55	0.13	2.57	0.9	0.74	0.31	0.78	1.6	2.73	4.33	1.22	63.04	18	0.023	0.001	0	0.022
AB	20 -40	5.45	0.69	1.19	0.12	1.1	0.9	0.74	0.38	0.87	1.6	2.88	4.49	1.22	64.36	19.37	0.023	0.001	0	0.022
Bt1	4o -60	5.5	1.1	1.9	0.12	2.57	0.92	0.71	1.92	4.35	1.6	7.9	9.5	1.3	83.15	45.78	0.023	0.001	0	0.022
Bt2	60 -80	5.55	0.18	0.31	0.09	0.74	0.92	0.75	0.48	1.04	1.6	3.19	4.79	1.23	66.59	21.71	0.015	0	0	0.022
Bt3	80 -110	5.55	0.18	0.31	0.05	2.57	0.95	0.75	0.31	0.91	1.6	2.42	4.02	3.8	60.19	22.63	0.015	0	0	0.02
Mean		5.47	2.47	0.85	0.1	1.91	0.92	0.74	0.68	1.54	1.6	3.82	5.43	1.75	67.47	25.49	0.02	0.001	0	0.02
									ORCHARD LANDUSE {Pedon 2}											
Ap	0 -20	5.45	0.13	0.22	0.12	2.57	0.78	0.64	0.14	0.52	1.6	2.08	3.67	1.22	56.67	14.16	0.032	0.002	0.001	0.024
AB	20 -40	5.3	0.13	0.22	0.12	0.37	0.78	0.63	0.13	0.52	2.4	2.06	4.46	1.29	46.18	11.65	0.031	0.002	0.001	0.024
Bt1	4o -60	5.6	0.13	0.22	0.08	0.37	0.81	0.65	0.18	0.61	1.6	2.25	3.85	1.25	58.44	15.84	0.031	0.002	0	0.024
Bt2	60 -80	5.5	0.43	0.74	0.08	0	0.83	0.67	0.28	0.78	1.5	3.56	4.16	1.24	61.53	18.75	0.023	0.001	0	0.022
Bt3	80 -110	5.3	0.22	0.38	0.06	0	0.83	0.67	0.34	0.87	1.5	2.71	4.21	1.24	64.37	20.66	0.021	0	0	0.022
Mean		5.43	0.21	0.36	0.09	0.66	0.81	0.65	0.21	0.66	1.72	2.53	4.07	1.25	57.44	16.21	0.03	0.001	0.002	0.02

Mixed CROP (pedon 3)																				
Ap	0-20	5.85	0.29	0.5	0.15	0.74	0.81	0.68	0.18	0.52	0.8	2.19	2.99	1.19	73.24	17.39	0.031	0.002	0.001	0.024
AB	20 -40	5.75	0.19	0.33	0.12	1.84	0.81	0.68	0.14	0.52	1.6	2.15	3.75	1.19	60.53	13.86	0.031	0.002	0.001	0.024
BA	40 -60	5.8	0.19	0.33	0.12	0.74	0.83	0.7	0.13	0.61	2.4	2.27	4.67	1.19	48.6	13.06	0.028	0.002	0	0.024
Bt1	60 -80	6.05	0.83	1.43	0.1	0.74	0.85	0.7	0.09	0.39	1.6	2.03	3.63	1.21	55.92	10.74	0.026	0.001	0	0.022
Bt2	80 -110	5.95	0.83	1.43	0.05	2.94	0.85	0.72	0.13	0.57	1.6	2.27	3.87	1.18	58.65	14.72	0.022	0.001	0	0.022
Mean		5.88	0.47	0.8	0.11	1.4	0.83	0.69	0.13	0.52	1.6	2.18	3.78	1.19	59.39	13.95	0.028	0.002	0.001	0.023
CASSAVA LANDUSE {Pedon 1}																				
Ap	0 -20	4.65	0.73	1.26	0.15	1.84	0.81	0.69	0.21	0.65	0.8	2.34	3.16	0.17	74.68	20.56	0.028	0.002	0	0.022
AB	20 -40	5.35	0.77	1.33	0.14	2.94	0.81	0.7	0.21	0.7	1.2	2.42	3.26	1.16	66.85	19.33	0.031	0.002	0	0.022
Bt1	4o -60	5.65	0.42	0.72	0.12	0.37	0.83	0.74	0.3	0.87	1.2	2.74	3.94	1.12	69.54	22.08	0.022	0	0	0.022
Bt2	60 -80	5.7	0.32	0.55	0.09	0.37	0.83	0.75	0.3	0.78	2.4	2.66	5.06	1.11	52.56	15.41	0.022	0	0	0.02
Bt3	80 -110	5.5	0.13	0.22	0.06	0.37	0.85	0.75	0.33	0.78	1.6	2.71	4.31	1.13	62.87	18.09	0.01	0	0	0.02
Mean		5.37	0.47	0.82	0.11	1.18	0.83	0.73	0.27	0.76	1.44	2.57	3.9	0.74	65.3	19.09	0.02	0.001	0	0.021
LSD(0.05)		0.32	0.4	0.69	0.05	1.39	0.03	0.03	0.47	1.05	0.61	1.6	1.69	0.82	11.22	8.4	0.01	0.001	0.0005	0.001

OC=organic cabon, OM=organic matter, TN=Total Nitrogen, Av.P=Available Phosphorus, Ca=calcium, Mg=Magnesium, K=potassium, Na=Sodium, TEA=total exchangeable acidity, TEB=total exchangeable bases, ECEC=exchangeable cat ion exchange capacity, Ca/Mg= calcium-magnesium ratio, BS=base saturation, Zn=Zinc, Pb=Lead, Cd=cadmium, Cr=chromium

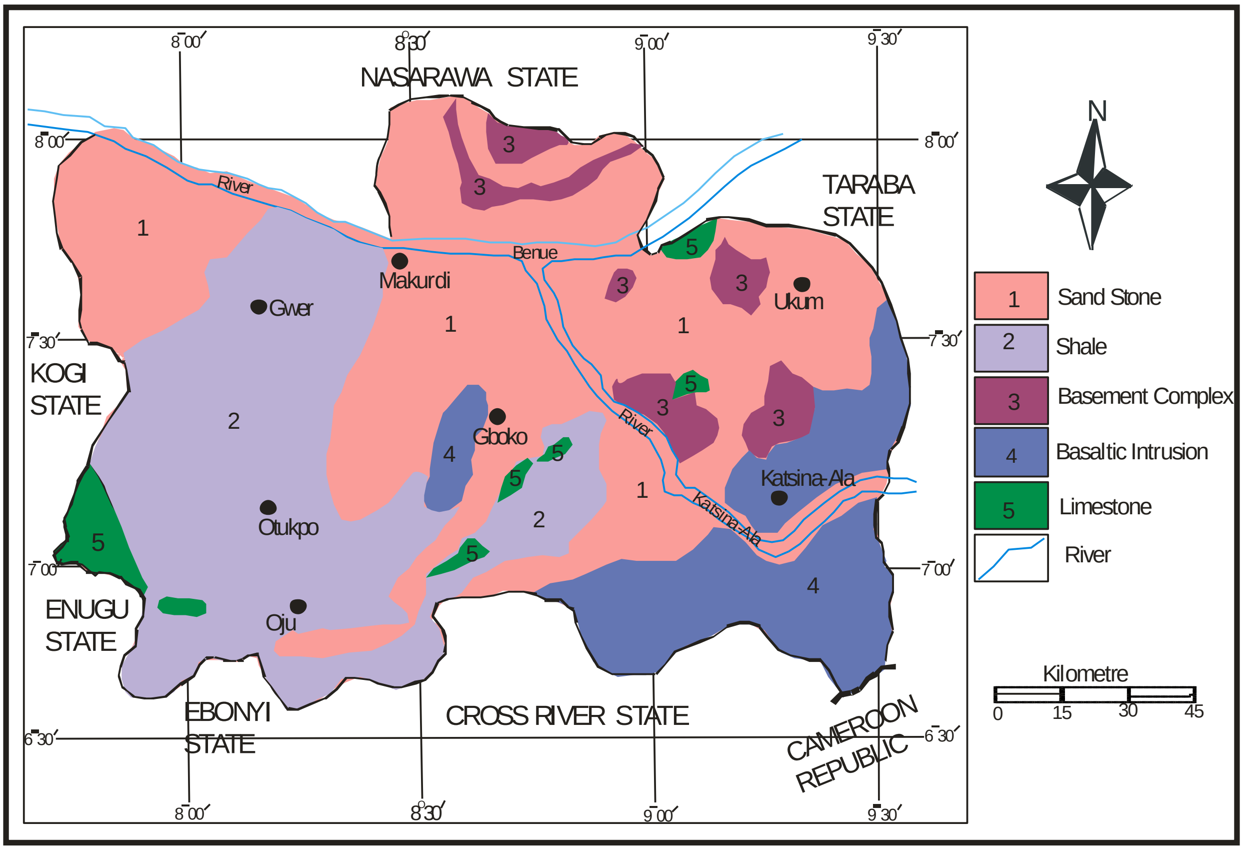

Figure 1: Geology of Benue State
Source: Ministry of Lands and Survey makurdi

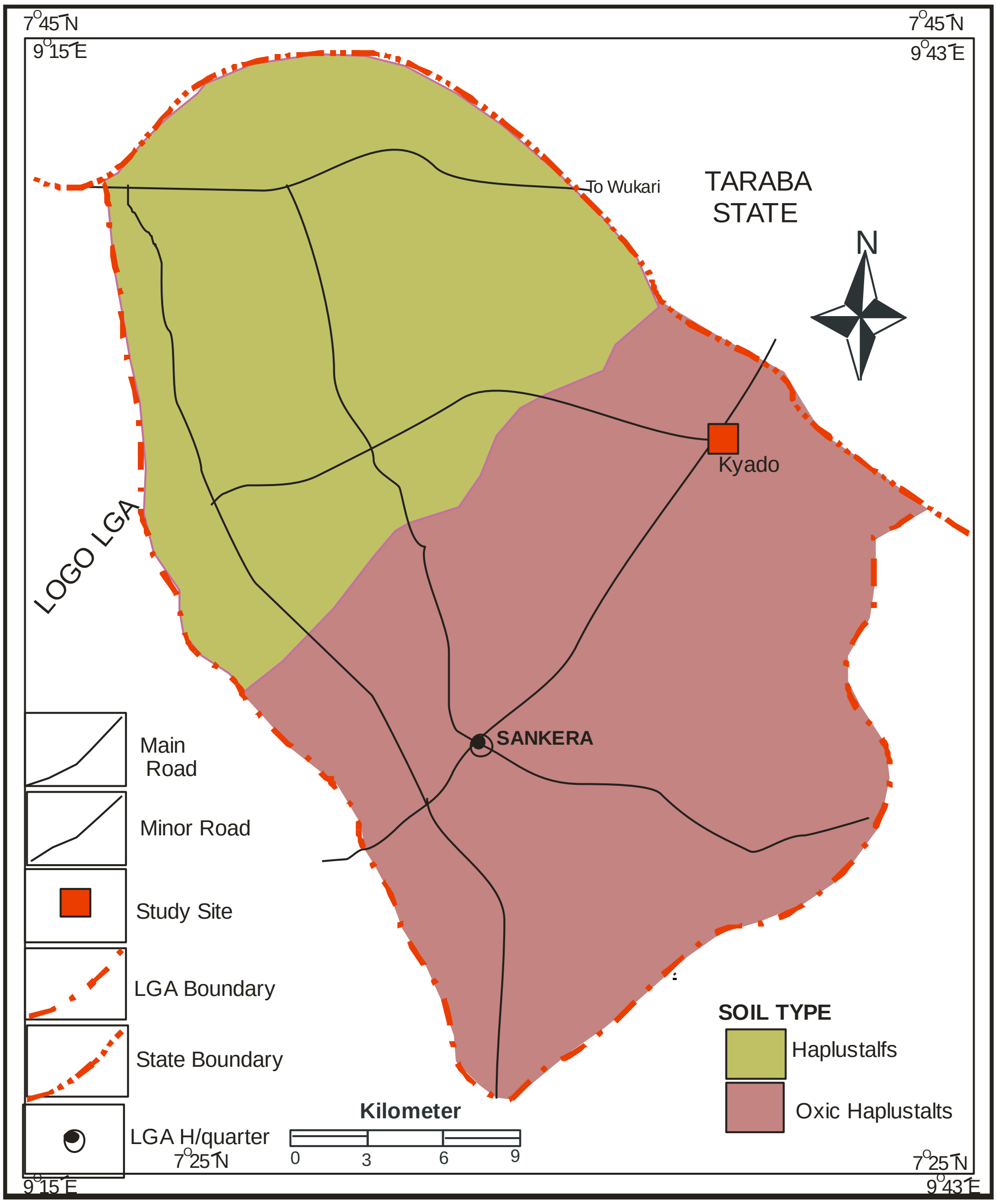

Figure.2: Location map of Study Area
Source: Ministry of Lands and Survey Makurdi

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