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Mapping and Sustainable Land Use of Upland Soils in Southern Guinea Savanna Environ of Niger State, Nigeria

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Abstract

Soil survey and land evaluation is very important in agricultural planning especially in crop production. The upland soils formed from sandstone and quartz schists in Katcha Local Government Area of Niger State were mapped for sustainable land use and management. Representative sites were selected based on digital terrain model (DTM) and ancillary information. Final mapping was done by spatial interpolation in GIS environ. The results show that the controlling factors of soil formation include climate, relief and parent material. The major soil forming processes observed include lessivage, leaching, illuviation, ferrolysis, eluviation and ferrugination. The upland were classified as Arenic Hapludult, Rhodic Hapludult, Typic Plinthudult, Pellic Dystrochrept and Rhodic Udipsamment while Aquic Udipsamment was identified at lower to valley bottom. Sustainable soil use and management require minimum tillage, cover crop cultivation, and use of fortified organic manure/compost for structural stability of soil and optimum crop yields.

Keywords: Entisols, Ferrugination, Lessivage, Ultisols, Soil mapping

Introduction

Soil survey helps in understanding what a kind of crop a soil can support without degradation since crops are different in their requirements (Ogunkunle, 2004). It is therefore necessary that every soil type should be assessed so as to determine its suitability to produce a kind of crop. Nigeria has witnessed a remarkable historical progression in its soil surveys/inventory activities over the past sixty years. Previous efforts of inventory of the nation's soil resources executed in the 80s at reconnaissance (1:650,000) level are grossly inadequate for effective land use planning even though it proved to be a good benchmark for the identification of areas of high potential for agricultural development (Ojuola, 2013). Current efforts involve providing soil resources information/data in the crop production zones at semi-detailed (1:50,000-1:100,000) level in each zone. This is a better move towards providing detailed soil information that will be functional and useful to all stakeholders especially farmers. Thus, this approach is being used by Institute of Agricultural Research &Training (IAR&T) to address problem of low productivity among poor resource farmers. Recently, local government areas along major crop value chains spanning the major agro-ecological zones have been surveyed at 1:50,000 scale (e.g. ATISBO, Kastina Ala, Asa, Gusau, Ifelodun, Ijebu North, Ikwo, Ido, Iseyin and Ikole). The information generated make room for much needed soil/crop-specific fertilizers recommendations with focus on helping farmers to produce optimally without compromising agricultural potential of the areas.

The area of focus in this paper is the upland soils in Katcha LGA which has great potential for rice and other arable crop production (maize, cassava, groundnut, yam and millet). The flood plain with high potential for lowland rice production has been mapped and recommendations have been proffered for sustainable use (Ande *et al.,* 2015). Farmers and other stakeholders in the area were trained on proper soil and water management. The upland which are formed from sand stone are usually characterized with sandy to sandy loam texture at the surface and sandy loam to sandy clay loam in the sub soil (Ande *et al.,* 2014). They are consequently of low base status due to intensity of weathering and vulnerability to leaching and erosion. These soils are abundant in the savanna eco-system of Nigeria and represent the most intensively used area for crop production. Where there is regular wetting and drying, formation of plinthite occurs which may affect land use depending on management and soil conservation measures (USDA, 2014). However lack of adequate information has compounded land degradation on these soils.

Sustainable land use needs well executed soil survey to map different soil types and characterize them. Hence, the derived knowledge on the soil variability, fertility status, and limitations in terms of quality will enhance their sustainable management. Suitability assessment of the different mapping units will enhance good land use planning and sustainable land use. Moreover, the usual presentation of soil survey interpretation to farmers through extension activities of the Institute of Agricultural Research and Training has made soil survey results more meaningful to farmers resulting to more adoption of recommended soil management techniques.

Thus, the objectives of this work include characterization of the upland soils of Katcha LGA area for effective management and sustainable crop production.

Location

Katcha is a local government area in Niger State having its headquarters at Katcha town on A124 highway to the west of the area at (8^0 37`N, 6$^0$ 4'E and 9$^0$ 29`N,6^{0}28'E). It has an area of 1,681 km^2 and a population of over 122,176 (Federal Republic of Nigeria, 2007). Katcha local government area is located at the southern part of Niger State (Fig. 1). It is bounded by Gbako and Bosso local government areas, while in the east and west, it is bounded by Agale, Bida and Lavun local government areas.

Niger State is acclaimed the “Power House” of Nigeria because it houses the two hydroelectric dams of the nation: Shiroro and Kainji hydroelectric dams. All local government areas and most wards in the state are connected to the national grid Katcha LGA inclusive. There exists evidence of government intervention in terms of availability of potable water through boreholes and deep wells with hand-powered pumps in most of the wards within the local government.

Climate

Katcha local government area has a tropical climate characterized by seasonal rainfall, high temperature, high wind speed and humidity. The environment is noted for two distinct seasons of rainy and dry periods in a year. Climatic anomalies in the form of recurrent drought, frightening dust storms and rampaging floods have overprinted their rhythms, creating short duration climatic oscillations as against the normal cycles of larger amplitudes.

The amount of rainfall, its distribution and intensity are very important factors in determining the suitability or otherwise of a land, apart from the soil quality. Katcha local government is essentially agrarian; hence, highly influenced by the pattern of rainfall. The annual rainfall is 1095 ± 32 mm with the onset and cessation being 30th April (± 3 days) and 1st November (± 4 days), respectively (Ref). The length of the growing season is about 186 (±15) days. There are two distinct seasons: wet and dry. April to October is the wet season with the highest mean monthly rainfall in September and dry season during the months of November and March, which is completely devoid of rain.

The temperature of the area like most tropical environment is generally high and characterized by minimum fluctuations. The maximum temperature (33 °C) is recorded in the month of March, while the minimum is usually between December (25.6 °C) and February (Ref). Temperature range (25 – 33 °C) is not a limiting factor to the good performance of crops, livestock and humans in the area. It is thus feasible to have an all-year round production where moisture is not a limiting factor. Supplemental irrigation will ensure that moisture is not a limiting factor in the environment during the dry season.

The pattern of evapo-transpiration is directly related to temperature; that is, the higher the temperature, the higher the evapo-transpiration rate. The month of March has the highest evapo-transpiration. This is due to the high temperature of the local government area. March is the peak of dry season; hence, more water loss from the earth surface and from plant cells. The least evaporation was in the month of September (the peak of the rainy season). The evapo-transpiration ranges between 38 mm in September to 95 mm in March. There is usually a direct correlation between rainfall/temperature status and relative humidity of an area. The mean monthly relative humidity ranges between 38.6 % in December to 83 % in September.

Lithological units in the study area are granite, gneiss and schist. The granite is the most widely spread rock unit and are porphyritic, medium-coarse-grained in texture. The granite mostly occurs as intrusive, low-lying outcrops into gneisses. They are severely jointed and fairly incised by quartz veins. The major structural features are fractures and lineaments.

Hydrology and drainage

The Katcha watershed is part of the Bida Basin, a sub-basin of the Niger River Basin Drainage System with its major tributaries been Benue, Sokoto-Rima, Kaduna, Gongola, Katsina-Ala, Donga, Taraba, Hawal and Anambra Rivers. The Bida Basin is underlain by sedimentary formation. Bida Basin is within the Upper Niger River Basin Development Authority management. The major rivers within this particular study watershed are Batako and Ebba rivers. The rivers are major tributaries to river Kaduna.

Cropping systems and patterns

Crops such as millet, maize, sorghum, yam, cowpea and groundnut are prominent in the upland areas. The upland farming are majorly mixed farming with crop combinations of millet/melon, millet/groundnut, cowpea/millet, while sole cropping like maize, groundnut and millet are found in few places. Few scattered trees dominated by shea butter trees (*Vitellaria paradona*) are found in the upland, while the lowland (close to the river valleys and streams) is devoted to rice cultivation. Farmers generally migrate from the upland areas to the floodplains of rivers and lowlands at the onset of rains. Rice is planted sole.

Methodology

The base map for the study area was produced with the aid of satellite imageries from Nigeria Sat-1 of 2006. The soil survey was carried out using soil land scape model from the digital elevation model developed from remote sensing imagery. Based on the DEM, four most representative toposequences were identified. The soils were examined from auger hole borings and minipits using flexible grid survey along transects at 100 to 250m intervals, depending on the homogeneity of the mapping units. Global Positioning System (GPS) was used to determine the coordinates and slopes of the terrain. The morphological characteristics of the soils were examined from the soil surface to a depth of 120 cm along the toposequences. Morphological and physical characteristics of the soils were examined and recorded appropriately for each of the auger holes based on changes in soil color, texture, wetness, depth to mottles. Changes in physiography, soil surface form and micro-relief, were recorded and also used to identify different mapping units and establishment of soil boundaries. The information was recorded on the base map, field notebook and proforma. The international guideline for field soil survey and mapping (FAO, 2006) was adopted for the study.

Modal soil profile pits were dug based on the most representative minipits and attributes of each of the identified soil types. Fourteen profile pits were dug, described and sampled. Seven most representative ones were reported, to avoid repetition of mapping units. Profile pits description followed standard methods according to the FAO guideline (FAO, 2006). The soil characteristics and morphological properties were described for each of the identified horizons (layers) in the profiles. The soil colour was identified with the aid of Munsell Soil Colour Charts; texture was determined on the field by hand feel method at moist state. Structure, concretions, roots and boundary forms were described using visual assessment. The soil consistence was determined at moist and wet states on the field.

Three replicated undisturbed soil cores were taken from each of the horizons of the soil profiles with cylindrical core sampler (5 cm in height and 5 cm in diameter) for the determination of bulk density, total porosity and saturated hydraulic conductivity (K_{sat}). After the description of the sites and soil profiles, soil samples were taken from each of the soil profiles, starting from the lowest to the top horizon. The samples taken were put into sampling bags and appropriately labeled for laboratory analyses. The field data combined with ancillary data from satellite imageries (Nigeria Sat-1) was used to produce provisional soil map in GIS system which was refined further after laboratory analyses.

Laboratory analyses

The soil samples collected were air-dried, gently crushed and allowed to pass through a 2.00 mm mesh sieve. The gravel content (> 2.00 mm diameter) of the soil samples was weighed and the ratio of gravel to fine earth calculated as a percentage of total air-dried soil. Particles size distribution was determined by a modified Bouyoucos hydrometer method as described by Gee and Or (2002). The soil cores were soaked into water overnight to saturate the soil and thereafter weighed at saturation. Total porosity was thereafter estimated as water content at saturation using the following relationship described by Flints and Flints (2002):

$$TP = (M_{SW} - M_{ds})/V_b \qquad (1)$$

Where TP is the total porosity, M_{SW} is the mass of soil at saturation, M_{ds} is the mass of dry soil at 105^0C and V_b is the volume of the soil.

Bulk density was determined by dividing the oven-dry mass of the soil by the volume of the soil as described by Grossman and Reinsch (2002). Saturated hydraulic conductivity (K_{sat}) was determined using a constant head permeameter method (Reynolds and Elrick, 2002). Soil pH was determined in 1:1 soil: water ratio, and by KCI media using a glass electrode pH meter with calomel electrode (Bates, 1964). Organic carbon was estimated by the Dichromate wet oxidation method of Walkley and Black (1934). Total nitrogen was determined by the micro-Kjedah method of Jackson (1962). Available phosphorus was evaluated by Bray 1 method of Bray and Kurtz (1945); while exchangeable cations (Ca, Mg, K and Na) were extracted by neutral NH_4OAC. Calcium, K, and Na were measured through a flame photometer, while Mg was determined by atomic absorption spectrophotometer AAS (Rhoades, 1982). Exchangeable acidity was determined by 1N KC1 extraction and titrated with 0.05N NaOH solution (Black, 1975). Effective Cation Exchange Capacity (ECEC) was calculated by the summation of the values of exchangeable cations and exchangeable acidity. The micronutrients (Fe, Mn, Zn and Cu) were determined in 0.1N HC1 and evaluated using the atomic absorption spectrophotometer (Jackson, 1962).

Soil Classification

The soil types were identified, characterized and classified using the USDA soil classification system (2011). The soils were also classified at the series local level using the approach of Moss (1957).

Suitability evaluation

Suitability evaluation was carried out for major crops grown in the area for sustainable land use recommendation using parametric method of Sys (1985).

Results and Discussion

Mapping units

The mapping units identified based on morphological description on the field (Table 1) followed established toposequences typical to soils formed generally from sand stone in Nigeria. The redder and more clayey sub soil occupied higher position on the landscape. Different soil properties were encountered along the landscapes. The area has Udic moisture regime which is also a factor of climatic cycling aiding pedoturbation and movement of materials within the soils.

Soil landscape relationship

Soil series were identified on multifaceted slopes representing the landscape in the area. Each transect has soil distribution similar to the work of Moss *et al.,* (1957) for savanna soils on sand stone with Alagba series at the upland, Ahiara at mid upper slope, Kulfo at the middle lower slope, Owode at mid upper slope whenever Alagba series is absent. While at the inland valleys, Mesan series was dominant. Katcha series was located on the mid lower slope and the identification was based on the work of Murdock *et al.,* (1976). The slopes from which transects were cut for mapping in the LGA include Bisanti, Barije, Gada Eregi, Kasanji and Kata Ereji. Soil genesis was also influenced by the position of the soils on the landscape. The major processes due to slope include leaching, lessivage and erosion.

There was catena toposequence that influenced soil physical properties such as distribution of clay content were sandy soils occupied mid slope position and coarse poorly drained soils occupied the inland valley. In this study, seven mapping units were identified (Fig. 1) which include Alagba and Owode (Rhodic Hapludult) at the crest/mid upper slope positions, Kulfo (Arenic Hapludult) at mid lower slope, Ahiara series (Rhodic Udipsamment) and Etinan (Pellic Dysrochrept) were identified at the lower/middle slope. Mesan series (Aquic Udipsamment) dominated the inland valley bottoms. It occupied the little inland valleys and was not captured at the scale the map was produced. Only Katcha series (Plinthic Hapludult) was identified on the basement complex at the north eastern boundary of the Local Government Area studied (Fig.1).

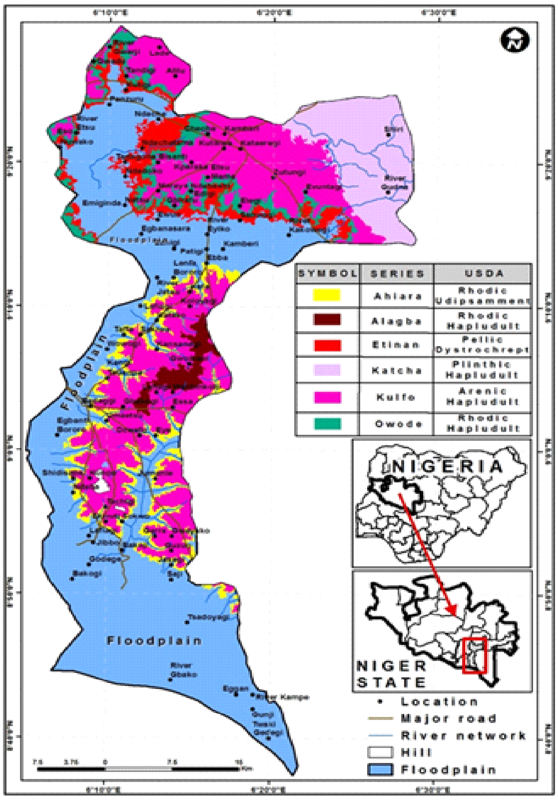

Figure : Location and Soil Maps of Katcha LGA in Niger State, Nigeria

Table 1: Morphological description of upland soils at Katcha LGA

Horizon Designation	Depth (cm)	Soil Series	Munsell Colour	Soil Colour	Texture	Structure	Consistence	Root Conc.	Pore	Boundary
A	0 - 32	Alagba	7.5YR 4/4	b	l,	sab	frnp,s	mf,ff		cs
AB	32 – 52		5YR 4/6	yr	l,	sab	fr,h,fr,np,s	fff		cs
B	52 -66		10YR 4/6	r	scl	sab	vh,vf,np,ss	ND		w
B	66 – 103		10YR 4/6	r	cl	ssab	vh,vf,vp,s	ND		cs
B	103 -193		10YR 3/6	dr	c	ssab	eh,ef,vp,s	ND		ND
A1	0 -16	Kulfo	7.5YR 3/4	db	ls,	wsab	l,fr,ns,p	mf,fw		cs
AB	16 -35		2.5YR 3/4	drb	s,cr,	ND	l,fr,ns,p	ff		cs
Bt	35 -106		10YR 3/6	dr	cs	ab	vh,vf,np,vs,ns	ND		cs
BC	106-155		10YR 3/6	dr	s,cl	ab	vh,vf,np,ss	ND		ND
A	0 - 9	Ahiara	7.5YR 6/6	rd	s,c,	ND	l,vfrns,p	ab, fw		cs
AB	9 – 44		7.5YR 3/2	db	s,l	sab	h,f,ns,p	ff		cs
B1	44 - 70		7.5YR 6/8	ry	s,cr	ND	,l,fr ns,p,	ND		cs
B2	70 –132		7.5YR 3/4	drb	s,sl	wsab	h,fr,ns,p	ND		cs
B3	132 - 200		7.5YR 5/6	yr	s,cr	ND	,l,fr ns,p	ND		ND
A1	0- 8	Mesan	10YR 3/3	db	s,cr,	ND	l,fr np,s,	mf,		cs
A2	8 -22		10YR 5/4	yb	s,cr,	ND	h,l,fr np,s	ff		cs
A3	22- 52		10YR 6/6	by	s,cr	ND	,h,l,fr np,s	ND		ND
	52 +									
	0 -16	Owode	7.5YR 3/4	db	m,s	wsab	l,f,ns,p	m,w	m	cs
A										
AB	16 -40		5YR 3/4	drb	m,s,	wsab	h,f,ns,p	m, fw	m,c	cs
B1	40 – 73		2.5YR 4/4	rb	m,ls	wsab	h,f,ns,p	ff,w	m,c	cs
Bt	73 -122		10R 4/6	r	m,scl	msab	vh,vf,ss,p	vff,w	c	cs
Bw	122 -170		10R 4/6	r,dr	m,scl	msab	vh,vf,ss,p	ND	c	ND
			10R 3/6							
A1	0 -10	Etinan	10YR 3/2	vdgb	s,cr,	ND	l,frns,p,	mf,fw	m	gs
A2	10 -38		10YR 4/2	dgb	s	wsab	l,f,np,p,	mf,fw	m	cs
A3	38 -77		10YR 6/3	pb	s	vwsab	l,fr,ns,p	ff,w	f	cs
	77 – 126		10YR 6/3,	pb	s	vwsab	l,fr,ns,p	ff,wr	f	cs
	126 -193		10YR 7/3,	lg,	S,cr	vwsab	l,fr,ns,pl	ND	m	ND
			5YR 4/4	rb						
A1	0 -23	Katcha	10YR 2/2	vdb	m,scl	msab	h,f, vs,mp	m,w	ND	cs
A2	23 -47		10YR 3/2	vdgb	m,scl	msab	h,f,ms,p	m,w	ND	cs
Bt	47 -76		10YR 4/6	dyb	m,c	vwsab	vh,vf,vs,p	ff,	ND	cs
B	76 -120		10YR 4/6,	dyb,	m,c	vsab	vh,vf,vs,p	ND	ND	ND
			5YR 3/4	drb						

Texture: sl = silty loam, ls = loam sand, cs =clay sand, scl= sandy clay loam, m = moist, s=sandy; [b]Structure: msab= medium sub angular blocky, vsab= very sub angular blocky, ab = angular blocky, wsab =weak sub angular blocky;Colour: db=dark brown, drb=dark reddish brown, rb=reddish brown, r =red, dr=dark reddish, dyb=dark yellowish brown, vdyb=very dark yellowish brown, by=brown yellowish, pb=pale brown, b=brown, rb=reddish brown, ry=red yellowish, Consistence: h =hard, vh =very hard, ns = non-sticky, mpl = moderately plastic, npl= non-plastic, h= hard, vh=very hard, vf= very firm, ss=slightly sticky, p=plastic, f=friable, nst =non-sticky, p=plastic, spl = slightly plastic, Concretion: mf=many fibrous, fw-few woody, ab=abundant fibrous, ff= few fibrous vff=very few fibrous, w= woody. Boundary: cs= clear smooth, wb=wavy boundary, Pore: m=many: c=common.ND = Not Determined.

Alagba series (Crest)

Depth cm	%Sand	%Silt	% Clay	pH (H_2O)	Mg cmo/Kg	K cmo/Kg	Na cmo/Kg	H^+	Ca cmo/Kg	ECEC	CEC	%BS	% T.C	% T.N	P ppm	Mn ppm	Cu ppm	Fe ppm	Zn ppm
0-32	76.06	9.46	14.48	5.46	2.04	0.50	0.46	0.14	1.15	4.29	4.15	96.73	0.61	0.04	1.31	57.21	0.90	76.38	0.99
32-52	68.06	17.46	14.48		3.32	0.75	0.35	0.15	1.65	6.22	6.07	97.58	0.61	0.04	2.21	53.20	0.86	62.34	1.04
52-66	68.06	3.46	28.48	4.96	2.34	0.59	0.28	0.57	1.12	4.9	4.33	88.36	0.63	0.04	2.88	46.50	0.82	78.00	1.00
66-103	54.06	7.46	38.48	5.51	1.36	0.59	0.29	0.13	2.68	5.41	5.28	97.59	1.39	0.10	1.75	86.82	1.35	138.54	0.90
103-193	56.06	7.46	36.48	5.21	1.22	0.43	0.26	0.15	1.61	3.67	3.52	95.91	1.29	0.09	4.82	63.00	0.79	170.26	0.92

Kulfo series (Middle slope)

Depth cm	%Sand	%Silt	% Clay	pH (H_2O)	Mg cmo/Kg	K cmo/Kg	Na cmo/Kg	H^+	Ca cmo/Kg	ECEC	CEC	%BS	% T.C	% T.N	P ppm	Mn ppm	Cu ppm	Fe ppm	Zn ppm
0-10	76.06	11.46	12.48	5.77	1.28	0.60	0.43	0.12	1.34	3.77	3.65	96.81	0.51	0.03	1.58	54.79	0.69	87.57	0.58
	72.06	13.46	14.48	4.77	2.26	0.59	0.28	0.66	2.12	5.91	5.25	88.83	0.61	0.03	1.57	49.32	1.15	71.31	0.88
29-58	72.06	9.46	18.48	4.93	1.98	0.66	0.28	0.58	1.45	4.95	4.37	88.28	0.60	0.04	1.58	50.01	0.91	66.69	1.14
58-106	56.06	19.46	24.48	6.13	1.11	0.57	0.27	0.10	2.26	4.31	4.21	97.44	1.23	0.12	5.28	29.83	0.27	132.09	0.94
106-154	54.06	11.46	34.48	6.08	1.09	0.32	0.34	0.11	3.03	4.89	4.78	97.75	0.54	0.05	3.85	36.57	0.37	95.53	0.98

Ahiara series (Middle slope)

Depth cm	% Sand	% Silt	% Clay	pH (H_2O)	Mg cmo/Kg	K cmo/Kg	Na cmo/Kg	H^+	Ca cmo/Kg	ECEC	CEC	%BS	% T.C	% T.N	P ppm	Mn ppm	Cu ppm	Fe ppm	Zn ppm
0-9	76.06	9.46	14.48	6.10	1.31	0.56	0.62	0.11	4.22	6.82	6.71	98.38	0.35	0.03	2.81	23.88	0.12	54.62	0.56
9-44	58.06	19.46	22.48	5.56	1.28	0.56	0.30	0.13	2.32	4.59	4.46	97.16	0.84	0.05	5.80	36.06	0.39	106.44	1.08
44-70	78.06	7.46	14.48	5.88	1.15	0.30	0.58	0.12	2.09	4.24	4.12	97.16	0.37	0.02	2.16	23.10	0.42	90.85	0.60
70-132	74.06	11.46	14.48	5.89	1.59	0.56	0.43	0.12	3.32	6.02	5.9	98.00	1.14	0.08	9.46	45.78	0.86	106.79	1.29
132-200	78.06	7.46	14.48	6.00	2.33	0.47	0.43	0.11	3.13	6.47	6.36	98.30	1.59	0.10	10.49	43.34	0.85	126.19	1.48

Mesan Series (Valley bottom)

Depth cm	% Sand	% Silt	% Clay	pH (H_2O)	Mg cmo/Kg	K cmo/Kg	Na cmo/Kg	H^+	Ca cmo/Kg	ECEC	CEC	%BS	% T.C	% T.N	P ppm	Mn ppm	Cu ppm	Fe ppm	Zn ppm
0-8	78.06	7.46	14.48	5.43	0.95	0.38	0.30	0.14	1.59	3.36	3.22	95.83	0.46	0.03	3.44	21.19	0.21	106.80	0.62
22-52	76.06	9.46	14.48	5.77	0.93	0.31	0.33	0.12	1.14	2,83	2.71	95.75	0.32	0.02	3.92	17.18	0.24	99.54	0.57
52+	80.06	5.46	14.48	6.01	1.26	0.56	0.35	0.11	1.27	3.55	3.44	96.90	1.05	0.09	5.57	41.24	0.22	174.89	0.72

Owode series (Middle upper slope)

Depth cm	% Sand	%Silt	% Clay	pH (H_2O)	Mg cmo/Kg	K cmo/Kg	Na cmo/Kg	H^+	Ca cmo/Kg	EC EC	CE C	%BS	% T.C	% T.N	P ppm	Mn ppm	Cu ppm	Fe ppm	Zn ppm
0-16	72.6	10.92	16.48	5.89	1.27	0.41	0.35	0.12	2.07	4.22	4.1	97.15	0.68	0.07	4.75	43.90	0.14	91.17	0.83
16-40	68.6	14.92	16.48	5.78	1.14	0.32	0.30	0.12	1.83	3.71	3.59	96.76	0.53	0.04	2.66	32.02	0.26	82.02	0.84
40-73	66.6	20.92	12.48	5.59	0.92	0.39	0.24	0.13	2.01	3.69	3.56	96.47	0.37	0.02	1.86	35.02	0.27	69.99	0.54
73-122	62.6	8.92	28.48	5.01	2.17	0.57	0.63	0.16	1.79	5.32	5.20	97.74	0.45	0.04	0.90	58.24	0.68	61.40	0.89
122-170	54.6	10.92	34.48	5.26	2.27	0.60	0.61	0.15	2.09	5.72	5.57	97.38	0.50	0.04	1.83	75.21	1.00	59.71	0.87

Morphological, physical and chemical description of the soil series

The morphological, physical and chemical properties (Table 1 and 2) of the soils series mapped were described. The pedogenetic factors that were responsible for their formation were discussed in order to understand effective management needed for sustainable land use.

Alagba series (Rhodic Hapludult)

Brown (7.5YR4/4) to yellowish red (5YR 4/6) sandy loam top underlain by red to dark red loamy clay to clay sub- soil. The soils occupy upper slope on the topography and usually on slope of 3-4 %. The crestal and gently undulating terrain must have led to in situ soil formation, the texture varied from sandy loam to clay at depth which was an evidence of clay movement down the profile and accumulation in situ. Thus the sandy top were attributed to lessiviation with accumulation of clay in the sub soils forming Kandic horizon (Table 2). The dominant red color was an evidence of ferruginsation. The pH was moderately acidic with very low CEC, %C, % total N and P. These parameters increased from A to B horizon and decreased down the profile. The retention of more nutrient at the B1 and also clay perticle have larger surface area for nutrient retention. The soil was classified as Rhodic Hapludult due to the Udic moisture regime, red hue and presence of Kandic horizon.

Kulfo series (Arenic Hapludult)

Dark brown (7.5YR 3/4) to dark reddish brown (2.5YR 3/4) loamy sand to sand from surface to subsoil, underlain by dark red clay sand to sandy clay loam in the C horizon. The soils were deep with depths greater than 150cm after which horizons of

Etinan series (Mid Lower slope)

Depth cm	% Sand	%Silt	% Clay	pH (H_2O)	Mg cmo/ Kg	K cmo/ Kg	Na cmo/ Kg	H^+	Ca cmo/ Kg	ECE C	CEC	%BS	% T.C	% T.N	P ppm	Mn ppm	Cu ppm	Fe ppm	Zn ppm
0-10	70.6	18.92	10.48	5.68	1.41	0.63	0.36	0.13	2.05	4.9	4.77	97.35	1.14	0.11	9.39	30.13	0.44	135.50	1.36
10-38	72.6	12.92	14.48	5.39	0.66	0.41	0.35	0.14	2.01	3.57	3.43	96.08	0.62	0.04	3.65	28.63	0.11	91.75	0.88
38-77	64.6	18.92	16.48	5.80	0.60	0.37	0.36	0.12	1.52	2.97	2.85	95.95	0.34	0.02	3.40	18.48	0.11	80.63	0.64
77-126	72.6	10.92	16.48	5.86	0.51	0.37	0.33	0.12	1.03	2.36	2.24	94.91	0.32	0.01	3.23	13.99	0.14	67.48	0.61
126-173	74.6	8.92	16.48	6.03	0.46	0.37	0.36	0.11	1.07	2.37	2.26	95.36	0.29	0.02	4.46	12.33	0.10	82.34	0.61

Katcha series

Depth cm	% Sand	% Silt	% Clay	pH (H_2O)	Mg cmo /Kg	K cmo/ Kg	Na cmo Kg	H^+	Ca cmo /Kg	ECEC	CEC	%BS	% T.C	% T.N	P ppm	Mn ppm	Cu ppm	Fe ppm	Zn ppm
0-23	68.06	3.46	28.48	5.89	8.12	0.69	0.84	0.12	5.89	15.66	15.54	99.23	1.57	0.18	1.33	57.44	2.17	178.19	0.66
23-47	58.06	25.46	16.48	5.73	1.17	0.43	0.35	0.12	2.20	4.27	4.15	97.18	0.70	0.05	3.78	52.38	0.39	137.79	0.81
47-76	52.06	15.46	32.48	5.82	1.60	0.47	0.19	0.12	2.37	4.73	4.53	95.77	2.00	0.15	6.49	77.99	0.42	148.97	1.10
76-120	53.60	14.46.	31.48	5.64	1.05	0.67	0.17	0.13	1.31	3.33	3.17	95.19	0.97	0.06	3.08	48.69	0.50	124.11	0.90

redox accumulation were encountered. They are usually situated on gently undulating terrain with multifaceted slope tending to plain terrain which probably resulted to soil formation in situ. Hence, formation of sandy top soil and accumulation of clay in the transitional BC sub soil. It seemed that the process of drying and wetting was predominant in these profiles giving rise to mottled and variegated color at depth with medium sub angular to angular blocky structure. The soils were moderately acidic, with low CEC, low %C and P. These parameters decreased down the profile except at the last horizon where they increased. These may be attributed to effects of roots which probably could not penetrate the hard firm BC horizon and thus their decomposition led to increase of these chemical parameters. Hence, the processes of soil formation were attributed to lessiviation, biodepostion, wetting and drying resulting to partial formation of fragipan at depth. It was classified as Arenic Hapludult due to sandy layers over Kandic horizon and Udic moisture regime.

Ahiara series (Rhodic Udipsamment)

Reddish yellow (7.5YR 6/6) to dark brown (7.5YR3/2) sand to silt loam top underlain by dark reddish brown to yellowish red sand sub- soil. The soils were deep with depth ranging from 165cm to 200^{c}m. The soil usually occupies middle slope on the topography with slope of 6% or greater. Soil formation were attributed to movement of soils from upper slope and deposition with time. Its pedogenesis include lateral movement of clay down slope and lessivage. The texture varied from sand to silty loam to sandy loam. This show probable difference in origin, while the sand might be a product of transported materials from upper slope, the silt might be a product of in situ weathering of remnant sand stone. The soil is moderately acidic to slightly acidic with low CEC (Table 1). The nutrient distribution showed evidence of various deposition time and active pedoturbation with higher content of N, %C and phosphorus at the surface. These decreased down the profile to the sub soils except at Emitachigi where these properties increased again in the last two horizons. Micronutrients were within the acceptable range for crop production. The soil was classified as Rhodic Udipsamment due to predominant hue of 2.5YR, absence of argillic horizon and general sandy texture of the soils.

Mesan series (Aquic Udipsamment)

This represents the major I land valley bottom soils but was not extensive enough to be represented at the scale the map was produced. The soil has dark brown (10YR 3/3) to yellowish brown (10YR 5/4) sand top soil underlain by brownish yellow (10YR 6/6) sand sub- soil. The soil was imperfectly drained with depth to groundwater table at 52cm. The pH was moderately to slightly acidic. The CEC was very low with low %C, N, and P. The micronutrient was within the limit for crop production. The area was geo-genetic in origin being zone of hillwash deposit. The soil was classified as Aquic Udipsamment due to high water table, sandy texture and Udic moisture regime.

Owode series (Rhodic Halpudult)

The surface soil was dark brown (7.5YR 3/4) to dark reddish brown (5YR 3/4) sandy. The color of the subsoils was reddish brown (2.5YR 4/4) to red (10R 4/6) color with loamy sand to sandy clay loam texture. The structure varied from weak sub angular blocky at the surface to medium sub angular blocky with pedogenetic mottles at the last horizon (122-170cm depth). There was Bt horizon within the profile, which indicates clay accumulation and well developed soil. The gently undulating multifaceted slopes that characterized its location could have encouraged better profile development. The profile was characterized with many micro and macropores which indicates good drainage and aeration. The chemical properties (Table 1) shows that the pH of the soil was moderately acidic with low CEC, low N, P and %C. The micronutrients were within the acceptable range for crop production. The nutrients generally decreased down the profile except in the last mottled B horizon. The soil has been classified as Rhodic Halpudult due to red hue, and presence of Kandic horizon, low base status and Udic moisture regime

Etinan series (Pellic Dystrochrept)

Very dark grayish brown (10YR 3/2) to dark grayish brown (10YR 4/2) sand top soil underlain by pale brown (10YR 6/3) to light gray (10YR 7/3) sandy sub- soil with high silt content. The structure varied from crumbs to fine weak sub angular blocky with many micro pores. Table 1 shows that the pH was moderately acidic to slightly acidic at depth. The CEC was low with low %C, % Total Nitrogen and P. The micronutrients were within the acceptable ranges for crop production. The soil is the pale variation of Ahiara series. This finding is cn contrast to the report of Moss 1957 that the soils were confined to wetter soils in Southern Nigeria. The soil is associated with Owode series on the same transect occupying the middle slope in a multifaceted landscape. The landscape could have resulted to micro environment that favoured retention of water such that the process of iron reduction was encouraged given rise to pale soils. The soil was classified as Pellic Dystrochrept due to low nutrient, little horizon development and low chroma resulting to pale colouration. This kind of soil formation has been attributed to clay destruction in a subsurface horizon due to process of ferrolysis (USDA, 2014). Ferrolysis causes loss of clay from the upper horizons by decomposition from the upper layers. The process consists of a sequence of repetitive cycles involving an oxidative phase and a reductive phase. During the reductive phase, the ferrous iron displaces exchangeable cations, which are then removed by leaching.

During the oxidative stage, oxidation of exchangeable ferrous iron produces exchangeable hydrogen, part of which attacks the phyllosilicate. In every cycle, cations are removed by leaching and part of the phyllosilicate is destroyed. With continued ferrolysis, a seasonally wet soil, even if base saturated, can develop a gray, silty or sandy horizon with low clay content and a low cation exchange capacity.

Katcha series (Typic Plinthudults)

Very dark brown (10YR 2/2) to dark grayish brown (10YR4/6) sandy clay loam top soil underlain by dark yellowish brown (10YR4/6) clay sub- soil with reddish brown (5YR3/4) mottles. The surface soil has medium sub angular structure, no gravel and clear smooth boundary. The clay sub soil was characterized with high content (>80%) of iron manganese concretions, quartz gravels and stones. The soil is located in the transition horizon between sand stone and Precambrian basement complex parent materials. The pH was moderately acidic. CEC was higher at the surface (15.54cmol/kg) and very low in the subsoils (4.15-3.17cmol/kg). % C and N were moderately high while P was low (1.33-6.49g/kg). Micronutrients were within the acceptable range for crop production. The higher CEC and % C at the surface could be attributed to effects of landuse which include cover crops and legumes. It has been reported that legumes has potential to increase soil organic matter which is a store house with capability of storing nutrients (Ande *et al.,* 2014). The clayey texture of the profile at the surface must have also enhanced nutrient retention. The soil was classified as Typic Plinthudults due to low base saturation, high stone, gravel and Fe/Mn content (>80%).

Pedogenesis

The soils formed from sand stone parent materials usually gives rise to soils with sandy texture at the surface and are generally low in nutrients (Moss 1957). The soils identified follow this trend with sand to sandy loam texture at surface. The soils had high base saturation varying between 88.28 -98.38% based on extraction by Ammonium acetate at neutral pH. Soil acidity correlated with %base saturation (BS) such that pH below 5 usually have % BS less than 90% while soils with pH above 5 recorded %BS greater than 90%. This shows that the soil acidity controls amount of nutrient on the exchange site. The higher pH at the surface and higher fertility could be attributed to the effects of land use and cultural practices. Plant residues are usually left on the farm and incorporated back to the soils during the next planting season. However high rate of mineralization due to high temperature did not allow adequate accumulation of organic matter in the soils. Leaching and lateral movement of nutrients must have resulted to poor fertility, since sandy soils dominated the surface soils extending to sub soils in Ahiara series.

Other dominant pedogenic activities include hydrolysis due to acidic precipitation, high intensity rainfall, high soil temperature which could have caused disintegration of minerals by release of H^+ and displacement of cations from clay minerals. The process of braunification and desilication was observed in red hues and accumulation of Fe-Mn in some profiles. It has been reported that high warm soil temperature and extreme leaching encourages marked dissolution of soil water, build up of hydrogen ions, rapid desilication, and accumulation of iron. immobilized in ferric oxide forms (Ojanuga, 1979). The major pedogenesis includes ferruginisation, leaching, lessivage, redoximorphic cycles in soils and cyclic change of climate.

Sustainable land use

Sustainable soil management of the soils except Katcha series should include minimum tillage in order not to destroy further the sandy loose fragile nature of the soils. Effective management of the soils would require limited use of mechanical clearing while on large commercial farms, it is recommended that the soils be ploughed once. Conventional mechanical land clearing involving ploughing and harrowing would pulverize the soils exposing it to erosion, leaching, degradation and compaction. Due to method of land preparation practice of which encourages no-till and/or minimum tillage, observations have shown reduced incidence of erosion,i mproved soil structure, increase in microbial activities especially earthworm cast formation, improved organic matter contents, as well as increase in infiltration rate and reduced bulk density (Aina *et al.*, 1991, Adesodun *et al.,* 2007). Residue management is recommended to increase organic matter status of all the soils. Incorporation of crop residue will also help in structural stability and nutrient retention as it will enhance organic matter content. Land should also not be left bare after cultivation, introduction of control fallow, which include legumes and plants that yield high biomass will help build up organic matter and improve water holding capacity, nutrient retention by improving structural stability.

Leguminous cover crops have the additional benefit of contributing some N to the soil for subsequent crops (Kang *et al.*, 1996, Ibewiro *et al.,* 2000). There are considerable results available as to the potential of leguminous cover crop in soil amelioration. They produce abundant mulch, which protect the soil against erosion and favour infiltrability, transmissivity and soil water sorptivity (Lal, 1989). Also, they recycle nutrient elements especially through the fixation of nitrogen and subsequent release to crops (Kang *et al.,* 1996). Cover crops smother some notorious weed species such as *Striga hermonthical* and *Imperata cylindica* (Chikoye *et al.,* 2002) and they help increase the organic matter content of the soil, improve soil structure and reduce bulk density. Some of the leguminous cover crops produce reasonable amount of grains for human consumption thereby removing the non-adoption by farmers of some of these technologies.

Lime application will be necessary to control the acidity nature of some of the sub soils. Use of inorganic fertilizers should be encouraged to supplement low exchangeable base levels in the soils and as basal treatment on Katcha series. Sustainable management of Katcha series will include maintaining the nutrient levels, prevention of surface ponding due to high clay content.

Alagba, Owode and Kulfo series were classified as moderately suitable (S2) for arable crops (maize, yam, ground nut and cowpea) due to sandy nature and low nutrient levels. Although the legumes can fix N from the atmosphere while there is still need for addition of P to ameliorate the low levels. Ahiara and Etinan were classified as marginally suitable (S3) for these crops due to sandy nature, slope (6%), low nutrient level and high susceptibility to erosion. Mesan was not suitable for these crops due to high water table. Katcha series in spite of medium texture, good structure, and moderate nutrient status was classified as moderately suitable for maize, yam, cowpea and groundnut due to presence of abundant or quartz gravels, stones and iron manganese concretions within 50cm of the profile. Continuous cultivation can result to loss of top soils and exposure of stony concretion subsoil at the surface.

Conclusion

Seven soils (Alagba, Kulfo, Owode, Ahiara, Etinan , Mesan and Katcha series) derived from sedimentary and basement complex origin in upland areas of Katcha Local Government Areas were characterized, classified and their genesis discussed. The soils were generally moderately acidic. The soils derived from sand stone origin have moderate to low inherent natural fertility with low exchangable basic cations, organic Carbon, cation exchange capacity, total Nitrogen but moderate levels of micronutrients (Cu, Fe, Mn and Zn). Soils of quartz schist origin (Katcha series) were observed to be more fertile than those derived from sand stone. Recommendations for sustainable use of these soils include minimum tillage, proper residue management, combine use of organic fertilizers, inclusion of legumes in cropping system and control fallow. The major pedogenetic processes include lessivage, ferrolysis, pedoturbation, ferruginisation, illuviation, gleization and decomposition.

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