PEDOLOGICAL EVALUATION OF SOILS ALONG RIVER KADUNA WATERSHED IN KADUNA, NORTH WESTERN NIGERIA

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ABSTRACT
This research was carried out along river Kaduna watershed in southern Kaduna to investigate the pedological properties of soils along the watershed for better management and increased productivity. Six profile pits were dug along the cropping soils of the watershed. Samples were collected according to the horizonations of the profile pits and analyzed for pedological evaluations. Structural composition of the investigated soils indicated that pit 1, pit 2 and pit 6 all had poorly formed indistinct peds on their surface horizons as their grade of structure. Pit 3 and Pit 5 had their grades as poorly formed indistinct peds while Pit 4 grade of structure had no observable aggregation. Almost all studied soils (pits 1, 2, 3, 5 and 6) had their textures ranged from Silt clay loam at the top horizons to silty loam or silt clay down the horizons. The investigated soils were very low in organic matter with the mean highest value appeared in pedon 1 (5.88 gkg^{-1}) while the lowest was found in pedon 6 with mean organic matter as low as 1.26 g kg^{-1}. The Available P status indicated that Pits 1, 2 and 3 had moderate P contents (5 -15 mgkg^{-1}) while low (< 5mgkg^{-1}) in Pits 4, 5 and 6. sand exhibited high variability (CV≥35%) except in pit 3 and 5 where it was moderate (CV≥15<35%). Clay exhibited mostly moderate variability (CV≥15<35%) except in pit 2 and 3 where it had low variability (CV≤15%) and pit 6 with high variability (CV≥35%). The silt content of the soils all indicated low variability (CV≤15%) except pit 4 where it varied highly (CV≥35%). Organic carbon and organic matter varied highly (CV≥35%) in all studied soils of River Kaduna watershed. Pits 1, 2, 3, 5 and 6 were classified as Aridic Ustifluvents while Pit 4 was classified as Aridic Ustipsamments.

Keywords: soil characterization, soil classification, pedological evaluations, soil variability, river Kaduna watershed.

INTRODUCTION
Pedological evaluation is very vital in soil characterization as it provides valuable information and knowledge on soil properties. The pedological characteristics of soils gives clear understanding of soil genesis, morphology, classification as well as spatial distribution of soils in a location (Kalala *et al.,* 2017). Pedological characterization involves the accumulation of soil information using systematic identification, grouping as well as delineation of different soils occurring in an area (Tan, 1995; Kebeney *et al*., 2015; Msanya *et al*., 2016). According to Munishi (2010), soil forming factors which include climate, parent material, biota, relief and time influence the morphological, physical, chemical and biological characteristics of soils.

Soils exhibit constant variation across different landscapes thereby influencing topographical features, types of vegetation, lithology, climate as well as land use; and these therefore may result in spatial and temporal variations in the soil physico-chemical properties (Msanya *et al*., 2003; Fantappiè *et al.,* 2011). Pedological characterization and evaluation provide valuable information and knowledge on soil physico-chemical properties and gives better understanding of soil morphology, genesis, classification and spatial distribution of soils in a location *(*Karuma *et al*., 2015; Kebeney *et al.,* 2015*)*. The information gathered through pedological characterization is needed by soil fertility specialists to carry out fertilizer trials and establish meaningful fertilizer recommendations (Msanya *et al*., 2003).

Soil characterization deals with providing information on the physical, chemical, mineralogical and microbiological properties of the soils which enable us to grow crops, sustain forests and grasslands which serve as home for the wildlife. Soil classification, on the other hand, helps to organize our knowledge, facilitates the transfer of experience and technology from one place to another and helps to compare soil properties. According to Eswaram (1977), some major uses of soil characterization data include to assist in the correct classification of the soil and enable other scientists place the soils in their taxonomies or classification systems.

Soil characterization can also serve as a foundation for more detailed evaluation of the soil as well as give preliminary information on nutrient elements, soil physical characteristics and or other limitations needed to produce a soil capability class. Akamigbo (2001) noted that soil classification usually means criteria based on soil morphology in addition to characteristics developed during soil formation. A soil characterization study, is therefore, a major building block for understanding the soil, classifying it and getting the best understanding of the environment (Esu, 2005).

Kaduna River, main tributary of the Niger River, in central Nigeria. It rises on the Jos Plateau 18 miles (29 km) southwest of Jos town near Vom and flows in a northwesterly direction to a bend 22 miles (35 km) northeast of Kaduna town. It then adopts a southwesterly and southerly course before completing its 340-mile (550-kilometre) flow to the Niger at Mureji (opposite Pategi). Most of its course passes through open savanna woodland, but its lower section has cut several gorges (including the 2-mile [3-kilometre] granite ravine at Shiroro) above its entrance into the extensive Niger floodplains. The Kaduna River is subject to great seasonal fluctuations and is navigable below Zungeru from July to October for light craft; it is used for fishing and for transport of local produce. Gbari (Gwari) people have utilized the Kaduna's upper floodplains for swamp rice cultivation, and in the southern plains, in Nupe tribal territory, rice and sugarcane production has become a major economic activity. Near Bida, the Edozhigi and Badeggi natural irrigation projects are major rice-growing ventures.

River Kaduna and its tributaries are very essential to the north central and north western Nigeria as they supply irrigation water for dry season farming and their floodplains makes farming possible all year round. Most soils within the river Kaduna watershed are used for irrigation farming due to their proximity to the source of irrigation water.

Most part of northern Nigeria receive less than 1000 mm rainfall in a normal year which is not sufficient for adequate rain-fed crop production in a region that have over a quarter of the country's population. River Kaduna watershed constitutes, of numerous uplands and ridges as well as floodplains where agricultural activities take place. Many cereal crops, legumes and vegetables are farmed on these regions as these crops may easily be irrigated from the river. The study of soil physical and chemical properties of River Kaduna watershed is necessitated by the fact that the country is struggling to feed its fast-growing population. There is also much pressure on the farmers, agricultural researchers and extension agents by the government and stakeholders to save the nation and world population by stepping up food production and farming generally.

However, only little soil information is available to the farmers, extension agents, researchers and students on the soils of River Kaduna watershed. The characterization of watershed soil of River Kaduna relating to elemental distribution in soil profiles will also provide useful information for assessment and monitoring of the behaviour and fertility status and help to predict the suitability of soils for agricultural uses. This research work will fill the information gap that is needed by stakeholders thereby enhancing agricultural productivity in the region as well as proper management and productivity of these soils. The major objective of this study is to evaluate some pedological properties of selected soils along River Kaduna, north western Nigeria for sustainable utilization and management.

2.0 Materials and Methods

2.1 Location

River Kaduna watershed is located on the Latitudes **10°36' and** 10° 60' N and Longitudes **7°25' and** 7° 40'E respectively and in Kaduna state, north western Nigeria**.** The study area has been characterized as a region where the rainfall is unimodal in pattern and between 900 – 1300 mm per annum (Uyovbisere and Lombin 1991). The region also has an undulating plain topography, with general elevation ranging from about 450 to 700 m, covered in highly sandy soils, which are usually very low in organic matter, may degrade rapidly under conditions of intensive rainfall. The region is characterized by high annual average temperature (28-32°C), short wet season and long dry season (6-9 months). Generally, soil moisture and temperature regimes in the area are inferred to be ustic and isohyperthemic respectively. During the rainy season however, mean temperature drops to 25°C – 28°C (June to September) and decreases to less than 20°C in the months between December and February (Gabasawa *et al.,* 2017). Tree cover varies from open woodland to light forest which has been reduced to bare land due to uncontrolled tree felling for fuel as well s farming activities (Carsky *et al.,* 1998) while abundant short grasses (<2 m) are also available (Sowunmi and Akintola, 2010).

Table 1: GPS Coordinates of Soils around River Kaduna

Location	Latitude	Longitude	Elevation (m)
Pit 1	10°.492267"	7 °.431442"	574
Pit 2	10 °.492842"	7 °.431392"	574
Pit 3	10 °.492200"	7 °.430547"	577
Pit 4	10 °. 493270"	7 °.429865"	579
Pit 5	10 °.493277"	7 °.429058"	577
Pit 6	10 °.492886"	7 °.477420"	583

2.2 Existing Information on Soil

Generally, soil such as that of dry land of northern Nigeria are named as 'Aridisols' by soil taxonomists (Soil Survey Staff, 1975) and are characterized by less than 1200 mm annual rains which are usually slowly permeable, leading to most of the water being lost to run-off (Fitzpatrick, 1980). Most of the rainfall received by the River Kaduna watershed drains to the river itself and this causes flooding along the watershed at the peak of rainy season around October in most years. The watershed soon experiences aridity as the dry seasons sets in between December and May. Soils along River Kaduna watershed might have been formed under aridity from wind-stored desert sands that accumulated over long periods of time. In addition, some soils within this region of north western Nigeria, in states such as Kaduna, Katsina, Kebbi, Sokoto and Zamfara have been also attributed to ferruginous tropic soils (D'Hoore, 1965) and characterized as having sandy texture, covering large areas of land with very low water-holding capacity and low organic matter, nitrogen and phosphorus content, neutral or moderately acidic in pH and also having a low cation exchange capacity. Large expanse of arable land exists within the River Kaduna watershed having the potential for the production of largely grain crops like maize, sorghum, millet, rice and wheat (Shehu *et al.,* 2015).

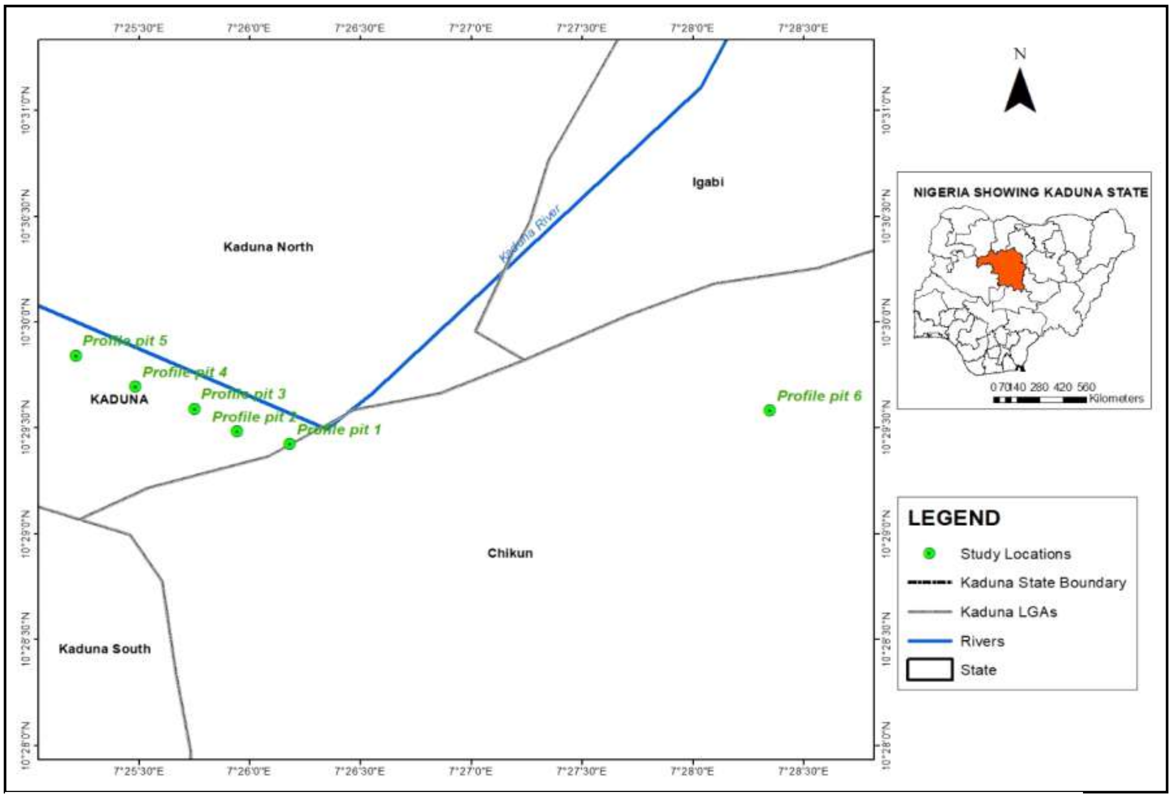

Fig. 1: Map of Study Area showing Sampling points

2.3 Vegetation

The vegetation around River Kaduna watershed is tropical guinea savannah located in north western Nigerian. The increased activities of man which include bush burning, and increased farming have apparently converted major part of the original vegetation to bare lands. Fitzpatrick (1980) showed that the vegetation in such desert areas is usually sparse and the surface is bare for long periods. This may contribute to soil degradation by wind erosion and, hence, cause soil fertility to decline in the area. Such a problem is one of the major contributing factors to soil and environmental degradation. However, few shrubs and grasslands are still available. The region has been occupied by some grasses such as; Elephant grass *(Pennisetum purpurem)*, Giant star grass *(Cynodon plectostachyus)*, Wild groundnut *(Calopogonium mucunoides)*, butterfly pea *(Centrosema pubescens)* and Goat weed *(Sida acuta)*.

2.4 Socioeconomic Activities

The major occupation of the people of Kaduna is subsistence farming with food crops dominating the practice. Cereals are the most important stable food crop in this region (Muhamman and Gungula, 2006). Aregheore, (2005) noted that farmers grow crops such as millet, sorghum, maize, cowpea, groundnut, and sometime soybean in parts of Katsina, Kano, northern Kaduna, Sokoto and Zamfara states. The cropping systems of cereals predominate in the farming systems with one or several other crops in mixture. The mixture mostly found in the region is sorghum, millet, cowpea; sorghum, millet; sorghum/groundnut and sorghum/cowpea (Muhamman and Gungula, 2006). However, millet and sorghum are frequently grown on the same plot in areas such as Kano, Kebbi and Sokoto states. Millet is sown with the first rains and sorghum is interplanted later when the rain become more reliable (Mortimore, 1989). According to Asadu *et al.,* (2004) crops that cover the soil, such as cowpea, are integrated in to different cropping system; crop rotation and mixed cropping. These systems include, maize, cowpea; yam, maize, cowpea; millet, cowpea; millet, sorghum, cowpea; and sorghum, millet, cowpea, okro, maize.

2.5 Field Work

A reconnaissance survey was carried out in the study location using the developed Digital Elevation Model (DEM). A region of the watershed was delineated into mapping units to represent some of the major cropping aspects of river Kaduna. Depending on the identified soil groups, Pedons were sunk in each of the delineated mapping units. A total six profile pits were dug cutting across the Kaduna River watershed. Soil samples were collected according to the profiles horizonation while morphological properties were analyzed in-situ. Core samplers were used to collect samples for bulk density while about 1kg samples were collected from the different horizons of each pedon. Samples were carefully packaged and labeled and transported to the soil laboratory of Ahmadu Bello University Zaria for analysis.

2.6 Laboratory Analysis

The sand, silt and clay contents of the soils was determined by hydrometer method using sodium hexametaphosphate (Calgon) as dispersing agent (Gee and Or, 2002). Bulk density (g cm^{-3}) was determined using the method described by Grossman and Reinsch (2002). Total porosity was calculated from particle and bulk densities of the soils. Moisture content was determined using gravimetric method (Obi, 1990). The silt clay ratio was calculated by dividing the value of silt with value of clay. The soil pH was determined using PH meter. Total nitrogen was determined by micro Kjeldahl method (Bremner and Mulvaney, 1982). Organic Carbon was determined by chromic acid wet oxidation method as described by Nelson and Sommers (1982). Available phosphorus was determined using Bray I method (Bray and Kutz, 1945). Total Exchangeable Acids (TEA) was determined by summing up all exchangeable acids (H^+ and Al^{+3}) while Total Exchangeable Bases (TEB) was determined by summing up all the exchangeable bases (Ca^{+2}, K^+, Mg^{2+}, Na^+).

2.7 Soil Taxonomic Classification

The results generated from the laboratory analysis of physical, chemical and morphological properties of the soil was used to evaluate the pedological properties of soil as well as classify them using USDA Soil Taxonomy and correlate results with World Reference Base for Soil Resources.

2.8 Statistical analysis

Coefficient of Variation (CV) was used to estimate the degree of variability existing among soil properties in the study site. Coefficient of variation (C.V.) ranked as follows; Low variation ≤15%, Moderate variation >15≤35%, High variation >35% was used as outlined (Wilding, 1985).

3.0 RESULTS AND DISCUSSION

3.1: Soil Morphological Properties

Soil morphological properties are as shown in Table 2. Structural composition of the investigated soils indicated that pit 1, pit 2 and pit 6 all had poorly formed indistinct peds on their surface horizons as their grade of structure. Structural form were crumbs indicating relatively porous, spheroidal peds, not fitted to adjoining peds and their sizes were however medium. Pit 3 and Pit 5 had their grades as poorly formed indistinct peds while Pit 4 grade of structure had no observable aggregation as there was no orderly arrangement of natural lines of weakness existing between the peds. Pit 3 form and size of structure were blocky and coarse respectively. The form of structure of Pit 4 and 5 were granular which show relatively non-porous, spheroidal peds not fitted to adjoining peds. The subsurface horizons of all profile pits had their grades of structure as mostly moderate were only strong in the last horizons of Pit 1, 4 and 5. Also, their forms and sizes at the subsurface levels were mostly blocky to subangular blocky as well as medium to coarse and very coarse respectively.

Soil consistence of all investigated soils was all slightly sticky when wet, loose when moist and soft when dry on the surface horizons.

However, down the horizons, soils were sticky when wet, friable when moist and hard to vey hard in the subsurface horizons for all pedons investigated. Also, roots were many and medium at the surface of horizons of all investigated pedons. The roots gradually reduce to few and their sizes becomes fine and very fine down the horizons of the pedons studied.

Table 2: Soil Morphological Properties

Pit 1	Structure	Consistence	Colour	Roots
0 – 11	1,cr,m	wss,ml,ds	D5YR7/4, W5YR7/2	many,medium
11 – 28	2,bk,m	wss,mfr,dsh	D5YR7/4, W5YR7/2	few,medium
28 – 56	2,abk,c	ws,mfr,dh	D5YR7/6, W5YR7/4	few,fine
56 – 82	3,sbk,c	ws,mfr,dvh	D5YR6/6, W5YR6/4	very few,fine
82 – 112	3,sbk,c	ws,mfr,dvh	D5YR7/6, W5YR7/4	very few,very fine
Pit 2				
0 – 8	1,cr,m	wss,ml,ds	D5YR6/3, W5YR6/2	many,medium
8 – 22	2,bk,c	wss,mfr,dsh	D5YR6/3, W5YR6/2	few,medium
22 – 46	2,abk,c	ws,mfr,dh	D5YR7/2, W5YR7/3	few,fine
46 – 73	2,sbk,c	ws,mfr,dvh	D5YR7/5, W5YR7/4	very few,fine
73 – 102	2,sbk,vc	ws,mfr,dvh	D5YR6/6, W5YR6/4	very few,very fine
Pit 3				
0 – 14	1,bk,c	wss,ml,ds	D5YR7/3, W5YR6/2	many,medium
14 – 33	2,abk,c	wss,mfr,dsh	D5YR7/6, W5YR7/4	few,medium
33 – 79	2,abk,vc	ws,mfr,dh	D5YR7/6, W5YR7/4	few,fine
79 – 105	2,sbk,vc	ws,mfr,dvh	D5YR6/6, W5YR6/4	very,fine
Pit 4				
0 – 10	0,gr,vf	wss,ml,ds	D5YR7/4, W5YR7/2	many,medium
10 – 25	1,cr,f	wss,mfr,dsh	D5YR7/4, W5YR7/2	few,medium
25 – 42	2,bk,m	ws,mfr,dh	D5YR7/6, W5YR7/4	few,fine
42 – 75	3,bk,m	ws,mfr,dvh	D5YR6/6, W5YR6/4	very few,fine
75 – 108	3,bk,m	ws,mfr,dvh	D5YR7/6, W5YR7/4	very few,very fine
Pit 5				
0 – 6	1,gr,m	wss,ml,ds	D5YR7/3, W5YR7/2	many,medium
6 – 18	2,cr,m	wss,mfr,dsh	D5YR7/4, W5YR7/6	few,medium
18 – 44	2,bk,c	ws,mfr,dh	D5YR6/6, W5YR6/4	few,fine
44 – 98	3,bk,c	ws,mfr,dvh	D5YR6/8, W5YR5/8	very few,fine
Pit 6				
0 – 15	1,cr,m	wss,ml,ds	D5YR5/6, W5YR5/4	many,medium
15 – 35	2,cr,m	wss,mfr,dsh	D5YR7/4, W5YR7/3	few,medium
35 – 74	2,pl,m	ws,mfr,dh	D5YR8/4, W5YR7/6	few,fine
74 – 104	2,bk,c	ws,mfr,dvh	D5YR6/6, W5YR6/4	very few,fine

Soil colour was determined under Dry and Wet status of the soil as shown in Table 2. Pit 1, 3, 4 and 5 all had colour notations indicating pink when dry, and pinkish gray when wet or moist respectively on the top horizons. While down the horizons the colour graded reddish yellow to light reddish brown from dry to wet respectively. In pedon 2 soil colour under dry and wet condition were light reddish brown to pinkish gray at the surface. Down the horizon, colour ranged from reddish yellow to light reddish brown. Pedon 6 under dry and wet condition on the surface were yellowish red and reddish brown while down the profile, colour ranged from reddish yellow to light yellowish brown under dry and wet conditions respectively.

Jackson (2020) explained that color of soil is determined by its mineral makeup, as well as its water and organic content. Soils rich in calcium are white, those rich in iron are reddish, and those rich in humus are dark brown to black. When moist, soil requires only around 5% organic content to appear black. Soil color also reflects its age as well as the climate's temperature and moisture levels. Cooler locations contain grayish to black topsoil due to humus formation. Soils in moist, warm areas tend to be yellowish-brown to red, depending on the hydration of ferric oxide and the extent of weathering of the parent mineral. Because of the rapid mineralization of organic content in warm, damp environments, humus formation is insufficient to have a significant impact on soil color. Arid soils are often light in color (due to low organic content) and largely express the color of their mineral composition. The investigated soils were very low in organic matter with the mean highest value appeared in pedon 1 (5.88 gkg^{-1}) while the lowest was found in pedon 6 with mean organic matter as low as 1.26 g kg^{-1}. Other factors responsible for the colour matrix of the studied soil include soil mineral composition as well as moisture distributions of the soil.

Table 3: Physical properties of studied soil

Horiz. Depth	0 BAR	0.3 BAR	15 BAR	GRAV MOIST CONT (g.g-1)	B.D. ($g.cm^{-3}$)	Particle Size Distribution (%)				
Pit 1						Sand	Clay	Silt	Silt/ clay	Text. Class (USDA)
0 – 11	0.588	0.243	0.210	0.025	0.96	6	26	68	2.62	Silty Clay Loam
11 – 28	0.483	0.230	0.180	0.105	1.14	4	42	54	1.29	Silty Clay
28 – 56	0.494	0.231	0.188	0.128	1.14	6	42	52	1.24	Silty Clay Loam
56 – 82	0.434	0.234	0.190	0.151	1.31	2	44	54	1.22	Silty Clay Loam
82 – 112	0.406	0.214	0.162	0.153	1.22	2	50	48	0.96	Silty Clay
Mean	0.481	0.230	0.186	0.112	1.154	4	40.5	55.2	1.36	
CV (%)	14.5	4.55	9.34	46.81	11.19	50	21.81	13.70	44.86	
Pit 2										
0 – 8	0.493	0.188	0.161	0.016	0.89	11	27	62	2.29	Silty Clay Loam
8 – 22	0.417	0.185	0.153	0.103	1.00	6	32	62	1.94	Silty Clay Loam
22 – 46	0.377	0.204	0.144	0.138	1.49	9	28	63	2.25	Silty Clay Loam
46 – 73	0.373	0.160	0.116	0.145	1.31	4	30	66	2.20	Silty Clay Loam
73 – 102	0.384	0.189	0.151	0.195	1.32	20	22	58	2.64	Silty Loam
Mean	0.409	0.185	0.145	0.119	1.20	10	27.8	62.2	2.24	
CV (%)	12.27	8.58	11.94	55.68	20.66	62.05	13.55	4.60	11.07	
Pit 3										
0 – 14	0.468	0.226	0.193	0.022	0.97	2	32	66	2.06	Silty Clay Loam
14 – 33	0.413	0.236	0.176	0.114	1.22	4	38	58	1.53	Silty Clay Loam
33 – 79	0.373	0.216	0.161	0.167	1.24	4	35	61	1.74	Silty Clay Loam
79 – 105	0.293	0.188	0.149	0.178	1.14	4	40	56	1.40	Silty Clay Loam
Mean	0.387	0.216	0.169	0.120	1.14	3.5	36.25	60.25	1.66	
CV (%)	19.04	9.55	11.21	59.22	10.75	28.57	9.66	7.29	17.12	
Pit 4										

0 – 10	0.408	0.179	0.159	0.022	1.33	18	15	67	4.47	Silty Loam
10 – 25	0.504	0.229	0.161	0.058	1.10	28	22	50	2.27	Silty Loam
25 – 42	0.455	0.252	0.188	0.105	1.05	28	26	46	1.77	Silty Loam
42 – 75	0.480	0.238	0.176	0.087	1.07	52	21	27	1.29	Sandy Clay Loam
75 – 108	0.324	0.113	0.085	0.018	1.39	67	12	26	2.17	Sandy Loam
Mean	0.434	0.202	0.154	0.058	1.19	38.6	19.2	43.2	2.25	
CV (%)	16.38	28.17	26.16	66.47	13.42	52.38	29.32	39.74	51.09	
Pit 5										
0 – 6	0.499	0.241	0.206	0.038	1.23	4	24	72	3.00	Silty Loam
6 – 18	0.346	0.140	0.114	0.100	1.29	2	30	68	2.27	Silty Clay Loam
18 – 44	0.512	0.240	0.215	0.166	1.10	5	34	61	1.79	Silty Clay Loam
44 – 98	0.452	0.141	0.109	0.113	1.20	4	36	60	1.67	Silty Clay Loam
Mean	0.452	0.191	0.161	0.104	1.21	3.8	31	65.25	2.10	
CV (%)	16.67	30.31	35.60	50.44	6.59	33.55	17.07	8.79	40.76	
Pit 6										
0 – 15	0.309	0.107	0.078	0.010	1.44	4	30	66	2.20	Silty Clay Loam
15 – 35	0.281	0.083	0.045	0.015	1.59	9	28	63	2.25	Silty Clay Loam
35 – 74	0.308	0.104	0.070	0.061	1.47	22	16	62	3.88	Silty Clay
74 – 104	0.297	0.126	0.088	0.065	1.33	16	14	70	5.00	Silty Loam
Mean	0.299	0.105	0.070	0.038	1.46	12.8	22	65.25	2.97	
CV	4.36	16.77	26.15	77.54	7.33	62.25	37.11	5.51	27.65	

3.2: Soil Physical Properties

3.2.1: Soil Moisture

The physical properties of the studied soils were as displayed in table 3. At different pressure levels of 0, 0.3 and 15 bars as well as gravimetric moisture contents of the soils of the watershed; mean values of 0.481, 0.230, 0.186 and 0.112g.g^{-1} were recorded in pit 1; 0.409, 0.185, 0.145 and 0.119 g.g^{-1} in pit 2; 0.387, 0.216, 0.169 and 0.120 g.g^{-1} in pit 3; 0.434, 0.202, 0.154 and 0.058 g.g^{-1} in pit 4; 0.452, 0.191, 0.161 and 0.104 g.g-1 in pit 5 and 0.299, 0.105, 0.070 and 0.038 g.g^{-1} in pit 6 respectively. The soil moisture levels at 0 bar of the respective locations (pits 1-6) represents the initial moisture content of the soil without any applied pressure or suction. It's relatively high, indicating a significant amount of free water in the material. When a suction pressure of 0.3 bar is applied, the moisture content decreases. This indicates that the material is losing some of its free water.

Along River Kaduna watershed, this level of suction pressure may represent conditions similar to the water table depth or a shallow groundwater condition. With a much higher suction pressure of 15 bar, the soil's moisture content decreases even further. This suggests that the soil has a significant ability to retain water against suction, indicating that it has good moisture retention properties. Gravimetric moisture content is usually expressed as a percentage of the mass of water in a given mass of soil. The values obtained suggests that this is the water content as a fraction of the total soil mass, without considering the applied suction pressure. It is lower than the initial moisture content at 0 bar in all investigated soils, indicating that the soil has lost water.

These results can help assess soil moisture conditions along river Kaduna watershed, which are crucial for crop growth and irrigation planning. The higher moisture content at 0 bar indicates that the soil is relatively wet initially, but it can be used for certain crops. The moisture content at 15 bar suggests the soil's ability to retain moisture against roots' suction. The moisture content of river watersheds is vital for understanding the health and sustainability of the ecosystem. It can be used to monitor changes in water availability and the impact on aquatic life and ecosystems. Equally, watersheds soils are vulnerable; leading to loss of basic cations, soil erosion through the agency of water, loss of aggregate stability, resulting to increased soil acidity and decreased soil quality (Onwudike and Mbonu 2018).

3.2.2: Particle Size Distribution

Soil particle size distribution also known as soil texture of River Kaduna Watershed were as shown in Table 3. Sand, clay and silt were; 4, 40.5 and 55.2 % in pit 1; 10, 27.8 and 62.2 % in pit 2; 3.5, 36.25 and 60.25 % in pit 3; 38.6, 19.2 and 43.2 % in pit 4; 3.8, 31 and 65.25 % in pit 5; 12.8, 22 and 65.25 % in pit 6 respectively. The studied soils were dominated by soil texture class of silt clay loam. Almost all studied soils (pits 1, 2, 3, 5 and 6) had their textures ranged from Silt clay loam at the top horizons to silty loam or silt clay down the horizons. The only exception to this was the pit 4 which was dominated with sand and with its lower horizon as Sandy loam.

The trend of distribution of sand showed a decrease in Pit 1, 2, increased in pit 3, 4 and 6 with no defined trend in Pit 5. The clay content of the investigated soils showed an increase in all Pits (1 – 5) with exception of Pit 6 where clay rather decreased down the profile. Silt content had a decrease in Pit 1, 3, 4 and 5 while it increased in Pit 6 and Pit 2 which later decreased. The increasing clay content observed in most of the profile Pits (Pit 1 – 5) suggests that illuviation (clay movement down the profile) is taking place. These results clearly show that pit 1, 2, 3, 5 and 6 were in the Backswamp depositional area of the watershed. This is evident by the very low sandy (4, 10, 3.5, 12.8 and 4 % respectively) content of these locations. Profile pit 4 with relatively higher sand content (38.6 %) was located in the terrace area of the watershed. In these Backswamp soils, there was evidence of huge depositions of clay and silt. The dynamics of variability in the investigated soils using coefficient of variation suggests that; sand exhibited high variability (CV≥35%) except in pit 3 and 5 where it was moderate (CV≥15<35%). Clay exhibited mostly moderate variability (CV≥15<35%) except in pit 2 and 3 where it had low variability (CV≤15%) and pit 6 with high variability (CV≥35%). The silt content of the soils all indicated low variability (CV≤15%) except pit 4 where it varied highly (CV≥35%).

According to Smith *et al.* (1998), there is a high correlation between specific surface area, soil compatibility, compressibility, and measurements of particle size distribution specifically, the percentage of silt and clay and organic matter. These factors all have an impact on the productivity of soils. Thus, except in oxide soils, soil fertility within a mineralogical class correlates with clay content. This conclusion indicates that there will probably be less plant development, particularly for annual crops, in the Backswamp due to its high clay content, which was caused by debris deposited by the river Kaduna due to the occasional flooding activities in most years. This is due to clay's interacting effect on the water and nutrient condition of the soil (Scholes *et al,* 1994; Iheka *et al.,* 2015). The availability of these nutrients is dependent on the activities of the clay in the soil. Because clay soils have the capacity to hold and trap specific nutrient elements in their colloidal surfaces, they are appropriate for heavy tuber crops and perennial crops whose roots naturally have the capacity to absorb nutrients.

The silt:clay ratios as shown on Table 3 were 1.36, 2.24, 1.66, 2.25, 2.10 and 2.97 for pits 1, 2, 3, 4, 5 and 6 respectively. The trend of the ratios indicated that there was a decrease in most of the profile pits investigated such as pits 1, 3, 4 and 5 while Pit 2 showed no particular distribution patterns, Pit 6 rather increased down the horizons. This silt: clay results suggest that this soils under investigation are young soils with low degree of weathering. Young soils such as Entisols or Inceptisols are mostly recently formed soils usually known to exhibit high silt: clay ratios (>1.0) (Obasi *et al.,* 2015). The consistent deposition of materials of clay and silts transportation from the river flows, especially during the intense rainy seasons led to the formation of such soils. Occasional flooding of the banks of River Kaduna watershed had contributed to the formation of the prevalent soils in the location. Profile pit 1, 4 and 5 had high variability (CV≥35%), Pit 2 low (CV≤15%) variability and Pit 3 and 6 had moderate variability (CV≥15<35%).

Bulk densities were as shown in Table 3 with means of 1.15, 1.20, 1.14, 1.19. 1.21 and 1.46 gcm^{-3}. The bulk density of the studied soils increased down the profile in Pits 1 – 3 of the studied soils although it later decreased in these locations. There was an irregular distribution of bulk density in locations with Pits 4 – 6. Bulk density is important physical properties of soils which is used as a measure of soil compactness and hence root penetration, soil structure and soil aeration (Massawe *et al.,* 2017). Hazelton and Murphy (2007) noted that topsoil is rated as being somehow too compacted when it exceeds critical value of 1.4 g cm-3 for root growth. Therefore, soils under investigation had their bulk densities less than the critical limits above which roots penetration, structure and aeration of soils are adversely affected. All investigated soils had low coefficient of variation (CV≤15%) with the exception of Pit 2 which exhibited moderate variability (CV≥15<35%).

Table 4: Chemical Properties of studied soils

	Soil Reaction (pH)		($g.kg^{-1}$)		Primary Nutrients		Exchange Bases (Cmo1.kg-1)				Exch. Acidity (H+Al) (Cmol.kg-1)	ESP %	ECEC (Cmol .kg-1)	Base Saturat. (%)
	H_2O	0.01 N $CaCl_2$	O.C	O.M	TN ($g.kg^{-1}$)	Avail. P ($mg.kg^{-1}$)	Ca	Mg	K	Na				
	6.90	5.80	2.94	5.07	0.42	15.26	9.40	2.54	0.61	0.90	0.10	5.24	13.35	99.25
8	6.30	6.00	2.55	4.39	0.36	6.69	4.60	1.24	0.19	0.22	0.20	3.41	6.45	96.90
6	6.30	5.90	7.64	13.18	1.09	8.75	10.0	2.70	0.21	0.10	0.20	3.54	13.55	98.52
2	6.50	4.10	1.37	2.37	0.20	4.97	2.80	0.76	0.21	0.10	0.10	2.53	3.96	97.47
12	6.10	5.70	2.55	4.39	0.36	5.12	5.20	1.40	0.15	0.10	0.40	1.38	7.25	94.48
	6.42	5.50	3.41	5.88	0.49	8.16	6.40	1.73	0.27	0.28	0.20	3.22	8.91	97.34
	4.73	14.37	71.5	71.5	35.2	52.1	49.16	49.2	69.1	122	61.24	44.14	48.44	1.88
	6.30	7.70	2.35	4.06	0.34	32.93	6.00	1.44	0.29	0.11	0.20	1.40	7.84	97.45
	6.10	5.60	3.33	5.74	0.48	4.63	6.00	1.80	0.17	0.21	0.60	2.39	8.78	93.17
6	5.90	4.80	4.52	7.77	0.64	4.80	4.20	1.13	0.12	0.10	1.20	1.48	6.75	82.22
3	5.80	5.00	2.25	3.87	0.34	3.09	6.20	1.86	0.13	0.39	1.20	3.99	9.78	87.73
02	6.00	5.60	3.92	6.76	0.56	4.12	3.20	0.86	0.16	0.11	0.80	2.14	5.13	84.41
	6.02	5.74	3.27	5.64	0.47	9.91	5.12	1.42	0.17	0.18	0.80	2.28	7.66	89.00
	3.19	20.08	36.1	36.0	28.2	130.0	26.29	30.3	39.1	67.2	53.03	45.84	23.56	7.05
	6.80	6.10	2.87	4.95	0.41	4.97	9.20	2.76	0.12	0.09	0.10	0.73	12.27	99.19
3	6.90	6.10	1.57	2.70	0.22	18.01	5.00	1.35	0.26	0.16	0.10	2.33	6.87	98.54
9	6.50	5.80	0.98	1.69	0.14	3.26	12.40	3.35	0.11	0.18	0.10	1.12	16.14	99.38
05	6.30	5.50	1.18	2.03	0.17	2.92	4.00	1.08	0.07	0.16	0.20	2.90	5.51	96.37
	6.63	5.88	1.65	2.84	0.24	7.27	7.65	2.14	0.14	0.15	0.13	1.77	10.20	98.37
	4.16	4.89	51.5	51.6	51.6	98.8	50.8	51.3	59.2	26	40	57.38	48.26	1.40
	5.70	4.80	0.97	1.67	0.14	2.40	4.40	1.13	0.20	0.43	0.60	6.53	6.58	90.88
5	6.20	5.60	5.29	9.12	0.76	8.75	4.00	1.08	0.11	0.16	0.40	2.78	5.75	93.04
2	4.90	4.10	3.08	5.31	0.44	5.48	6.80	1.84	0.16	0.10	1.20	0.99	10.10	88.12
5	5.80	4.70	0.59	1.01	0.08	2.74	3.20	0.86	0.10	0.16	1.20	2.90	5.52	78.26
08	6.20	5.40	0.78	1.35	0.11	2.57	5.40	1.46	0.09	0.28	0.40	3.67	7.63	94.76
	5.76	4.92	2.14	3.69	0.31	4.39	4.76	1.27	0.13	0.23	0.76	3.37	7.12	89.01
	9.24	12.14	94.6	94.7	95.4	62.6	29.17	30.0	35.3	58.2	53.93	59.85	26.17	7.31
	5.90	4.90	2.16	3.72	0.31	3.09	5.20	1.38	0.08	0.19	1.20	2.36	8.05	85.09
	6.30	5.30	0.97	1.67	0.14	2.40	6.60	1.78	0.18	0.40	0.40	4.27	9.36	95.73
4	6.20	5.40	4.51	7.77	0.64	7.89	5.40	1.46	0.17	0.17	0.40	2.24	7.60	94.24
8	5.90	5.00	0.95	1.64	0.14	4.63	4.80	1.30	0.09	0.02	1.40	0.26	7.61	81.60
	6.08	5.15	2.15	3.70	0.31	4.50	5.50	1.48	0.13	0.20	0.85	2.28	8.16	89.17
	3.39	4.62	77.9	77.9	76.7	54.3	14.08	14.2	40.2	80.2	61.88	71.76	10.18	7.74
	6.20	5.60	0.20	0.34	0.03	2.92	5.20	1.41	0.18	0.07	0.40	0.96	7.26	87.28
5	6.40	5.70	1.18	2.03	0.17	2.40	6.60	1.79	0.11	0.18	0.20	2.03	8.88	97.75
4	6.30	5.80	0.78	1.35	0.11	2.92	2.20	1.33	0.10	0.16	0.20	2.36	6.79	97.05
04	6.50	5.70	0.77	1.33	0.11	7.03	3.40	0.92	0.12	0.03	0.20	0.64	4.67	95.72
	6.35	5.70	0.73	1.26	0.11	3.82	4.35	1.36	0.13	0.11	0.25	1.50	6.90	94.45
	2.03	1.43	55.0	55.1	54.7	56.5	44.64	26.2	28.2	65.1	40	55.22	25.15	5.14

OC = Organic Carbon, OM = Organic Matter, TN = Total Nitrogen, Ca = Calcium K = Potassium, Mg = Magnesium, P = Phosphorus, Al = Aluminum, ECEC = Effective cation exchange capacity

3.3. Soil Chemical Properties

3.3.1 Soil Reaction

Soil pH was investigated in water and in 0.01N $CaCl_2$ as shown in Table 4. The trend of distribution of pH across horizons was not in any particular form as it either decreased or increased within the horizon in all investigated profile pits. Mean soil pH in water and $CaCla_2$ for the different pits are; Pit 1; 6.42, 5.50; Pit 2; 6.02, 5.74; Pit 3; 6.63, 5.88; Pit 4; 5.76, 4.92; Pit 5; 6.08, 5.15 and Pit 6; 6.35, 5.70 as measured in water and $CaCl_2$ respectively. Soil pH in water was mostly slightly acidic (pH≥ 6.0) and moderately acidic (pH > 5.0< 6.0) when measured in $CaCl_2$. The exception to this trend was observed only in Pit 4 where pH was more acidic; 5.76 and 4.92 in water and $CaCl_2$ respectively. This higher pH when compared to other locations may be attributed to a higher degree of weathering taking place in this location. It is worthy to note that this location has the highest sand content (38.6%) which will possibly encourage the leaching of exchangeable cations which predisposed the soil to acidic condition.

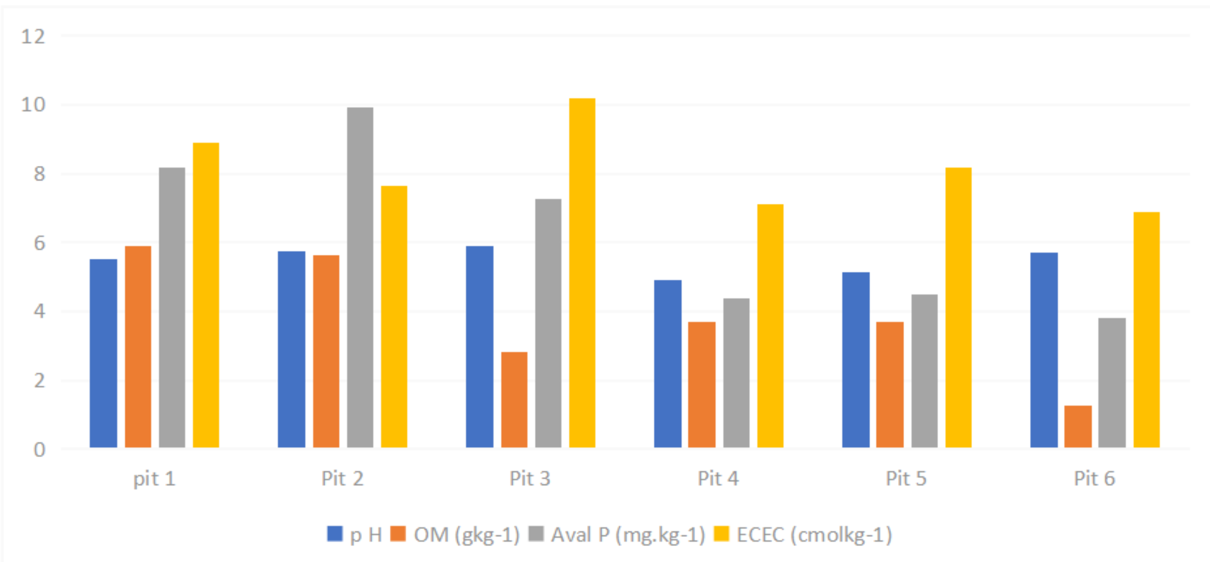

Fig. 2: Patterns of Distribution of Selected Soil Chemical Properties

3.3.2: Soil Organic Carbon, Organic Matter and Total N.

Soil organic carbon and organic matter were as shown in Table 4. Pit 1 recorded OC and OM as 3.44 and 5.88 $g.kg^{-1}$ and 3.27, 5.64; 1.65, 2.85; 2.14, 3.69; 2.15, 3.70 and 0.73, 1.26 $g.kg^{-1}$ respectively. Organic carbon and organic matter distribution displayed an irregular pattern in virtually all the profile pits studied, concentrating more towards the middle of the horizons in each profile pit examined. A deviation from this trend was observed in Pits 3, 4 and 6 where there was a consistent decrease of OC and OM down the profile although the surface horizons of Pit 4 and 6 were lower than the horizon immediately after it. Organic C and OM are product of dead and decayed organic materials (liters) on the surface of the soil and these products decrease down the profile in a normal soil. These Organic C and OM content of these soils are very low and poor (<5.0; <20 gkg^{-1}). Tabi *et al,*. (2012) recognized OC of < 5gkg^{-1} and OM of <20 gkg^{-1} as low. The reason for this may be due to the fact that these locations have been under intense farming activity which takes organic substances from the soil without adequate restoration or rejuvenation. The soils under investigation have equally been affected by continual overflow of the river Kaduna leading to the high silt and clay presence observed in most of the studied soils. This situation has altered the physical and chemical properties of the soil as observed by the irregular distribution of soil OC and OM. Organic carbon and organic matter varied highly (CV≥35%) in all studied soils of River Kaduna watershed.

Total Nitrogen distribution as shown in Table 4 indicated that means were 0.49, 0.47, 0.24, 0.31, 0.31 and 0.11 g.kg^{-1} in Pits 1 – 6 respectively. It is worthy to note that N distribution had no particular trend down the profile across the locations examined. The N content of these soils is quite low (<0.5 gkg-1) according to Obasi *et al.,* (2015). Nitrogen and many other primary nutrients in the soils are a function of organic matter content and should normally decrease down the profile pits. Nutrient elements travel down the soil through the process of eluviation/illuviation and tend to concentrate more where there is argillation or accumulated clays. This process leads to the formation of kandic horizons in highly weathered soils. However, the soil under investigation have had their physical and chemical properties highly altered by the activity of consistent over flow of the Kaduna River within the watershed. Coefficient of variation (CV) indicated that all investigated soils varied highly (CV≥35%) in their total nitrogen content except in Pit 2 where total nitrogen varied moderately (CV≥15<35%).

3.3.3: Available Phosphorus

The available P content of the studied soils had no particular trend of distribution down the horizons in most of the studied soils although it ultimately decreased in Pits 1 – 3 and increased in Pits 4 – 6. Decrease in P with depth can be due to decrease in organic matter content with depth. Organic matter plays a key role in P availability due to its ability to coat aluminum and iron oxides, which reduces P sorption (Debicka *et al.,* 2015). Mean available P distribution as shown in Table 4 were 8.16, 9.91, 7.27, 4.39, 4.50 and 3.82 mg.kg^{-1} in Pits 1 – 6 respectively. The Available P status indicated that Pits 1, 2 and 3 had moderate P contents (5 -15 mgkg^{-1}) while low (< 5mgkg^{-1}) according to Tabi *et al.,* (2012) in Pits 4, 5 and 6. Among the factors which affect P availability is the pH status of the soil. When the pH too low (high acidity) or too high (high alkalinity), the available P may be fixed under any of these circumstances. All studied soils had pH suggesting slightly to moderately acidic. Locations within Pits 4 and 5 had pH 4.92 and 5.15 respectively indicating more acidity compared to other locations. This may have caused the low available P obtained these locations. Available P varied highly (CV≥35%) in all investigated soils along river Kaduna watershed.

3.3.4: Exchangeable Cations

The exchangeable bases were major nutrient cations and includes Ca, Mg, K and Na as shown on the Table 4. The distributions of means of exchangeable bases are as follows; Calcium (Ca) – 6.40, 5.12, 7.65, 4.76, 5.5 and 4.35 for Pits 1 – 6. For Magnesium (Mg) – 1.73, 1.42, 2.14, 1.27, 1.48 and 1.36 in Pits 1 – 6. Potassium (K) – 0.27, 0.17, 0.14, 0.13, 0.13 and 0.13 for Pits 1 – 6. Also, Sodium (Na) – 0.28, 0.18, 0.15, 0.23, 0.20 and 0.11 for Pits 1 – 5 respectively. There was no particular trend of distribution of exchangeable bases across different profile pits although most of the profile pits had highest concentrations in their third and fourth horizons. However, Ca distribution was moderate (5 – 10 cmolkg^{-1}) in Pits 1, 2, 3 and 5 and low (<5 cmolkg^{-1}) in Pits 4 and 6 when Ca critical limits were considered according to (Tabi *et al.,* 2012). Furthermore, Pit 1 had a moderate (1.5 – 3.0 cmolkg^{-1}) Mg content while the Pits 2 – 6 all had low (< 1.5 cmolkg^{-1}) Mg concentrations. Potassium and Na were low across their respective horizons having ranges of < 0.3 cmolkg^{-1} in all studied locations. The low exchangeable bases observed may have been caused by excessive leaching taking place in the studied soils.

Obasi *et al.,* (2015) noted that most tropical soils are prone to leaching. Also, the dynamics of moisture within river Kaduna watershed and continuous farming activities may have depleted the exchangeable basic cations by leaching, leading to their low availability. Effective Cation Exchange Capacity (ECEC) was moderate (6 – 12 $cmolkg^{-1}$) in all studied soils from Pits 1 – 6. The ECEC distributions were as follows as shown in Table 4. 8.91, 7.66, 10.20, 7.12, 8.16 and 6.90 $cmolkg^{-1}$ in Pits 1 – 6 respectively. Landon (1991) pointed critical ECEC as follow; low (<6 $cmolkg^{-1}$), medium (6 – 12 $cmolkg^{-1}$) and high (>12 $cmolkg^{-1}$). The percentage base saturations were high in all the locations - 97.34, 89.00, 98.37, 89.01, 89.17 and 94.45% in pits 1 – 6 of the studied soils. The coefficient of variation of Effective cation exchange capacity (ECEC) indicated high (CV≥35%) in Pits 1 and 3, moderate (CV≥15<35%) in Pits 2 and 4 while low (CV≤15%) in Pit 5. Base saturation exhibited low (CV≤15%) variability in all investigated soils.

3.4 Taxonomic Classifications

The diagnostic criteria for classification of Pits 1 - 6 according to the USDA Soil Taxonomy (Soil Survey Staff, 2014) include soil temperature regime which is hyperthermic: in which mean annual soil temperature is 22 °C or higher, and the difference between mean summer and mean winter soil temperatures is 6 °C or more either at a depth of 50 cm below the soil surface. Soil moisture regime is Ustic; the ustic (L. ustus, burnt; implying dryness) soil moisture regime is intermediate between the aridic regime and the udic regime. the soil moisture control section in areas of the ustic soil moisture regime is dry in some or all parts for 90 or more cumulative days in normal years. It is moist, however, in some part either for more than 180 cumulative days per year or for 90 or more consecutive days. Silt-clay ratios were high (>1.0) signifying very low degree of weathering taking place in the studied soils. This situation equally suggests a young soil such as Entisols. All investigated soils had irregular organic carbon distributions in their horizons which ultimately decreased. Pit 4 had loamy sand texture. Pits 1, 2, 3, 5 and 6 were classified as Aridic Ustifluvents while Pit 4 was classified as Aridic Ustipsamments.

Conclusion

Structural form of the studied soils were crumbs indicating relatively porous, spheroidal peds, not fitted to adjoining peds and their sizes were however medium. The bulk density of the studied soils increased down the profile in Pits 1 – 3 of the studied soils although it later decreased in these locations. There was an irregular distribution of bulk density in locations with Pits 4 – 6. The clay content of the investigated soils showed an increase in all Pits (1 – 5) with exception of Pit 6 where clay rather decreased down the profile. Silt content had a decrease in Pit 1, 3, 4 and 5 while it increased in Pit 6 and Pit 2 which later decreased. The trend of distribution of pH across horizons was not in any particular form as it either decreased or increased within the horizon in all investigated profile pits. Organic carbon and organic matter distribution displayed an irregular pattern in virtually all the profile pits studied, concentrating more towards the middle of the horizons in each profile pit examined. A deviation from this trend was observed in Pits 3, 4 and 6 where there was a consistent decrease of OC and OM down the profile although the surface horizons of Pit 4 and 6 were lower than the horizon immediately after it. The available P content of the studied soils had no particular trend of distribution down the horizons in most of the studied soils. Pits 1, 2, 3, 5 and 6 were classified as Aridic Ustifluvents while Pit 4 was classified as Aridic Ustipsamments. Activities that will improve the organic matter status of the soils should be adopted while burning and grazing should be avoided for increased productivity and proper management of the river Kaduna watershed soils.

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