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Evaluation of Saturated Hydraulic Characteristics and its Influence on Some Physical and Chemical Properties of Soils Developed on Coastal Plain Sands of Obufa Esuk Orok in Calabar, Cross River State, Nigeria

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Authors' contributions

This work was carried out in collaboration among all authors. Author EAA designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Authors AIA and OO managed the analyses of the study. Author OO managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

The study highlights the evaluation of saturated hydraulic characteristics and its influence on some physical and chemical properties of soils developed on coastal plain sands of Obufa Esuk Orok in Calabar, Cross River State, Nigeria. Sixteen grids designed in an experimental plot measured 6 m x 6 m were used for field studies and sixteen (16) soil samples were collected in each of the grid using

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a soil auger for particle size analysis, bulk density, particle density, total porosity and saturated hydraulic conductivity. The samples were analyzed using standard laboratory procedures. The result showed that the soils were predominantly high in sand content with a mean value of 860.6 g kg^{-1} and low in silt and clay contents with mean values of 56.1 g kg^{-1} and 83.3 g kg^{-1} respectively. The soil texture was predominantly loamy sand. The saturated hydraulic conductivity showed rapid with a mean value of 36 cm min^{-1}. Total porosity was high, a mean value of 52.4 %. Bulk density was low, a mean value of 1.21 Mgm^{-3} while Particle density was moderate, mean value of 2.55 Mgm^{-3}. The soil pH showed very strongly acid milieu (mean pH in water = 5.1). Organic carbon and Total nitrogen were low with mean values of 1.1 % and 0.09 % respectively. Available phosphorus was high with a mean value of 36.66 mg kg^{-1}. The exchangeable acidity and exchangeable bases were generally low with mean values of 2.54, 0.59, 0.08 and 0.053 cmolc/kg for calcium, magnesium, potassium and sodium and 0.261and 0.416 cmolc/kg for aluminum and hydrogen. The correlation coefficient (r) between the saturated hydraulic conductivity and texture showed that there was a positive relationship between saturated hydraulic conductivity and sand, silt and clay (correlation coefficient of r = 0.0013, 0.062 and 0.119) at $p\leq0.05$ indicating good relationship. There was also a positive linear relationship between the saturated hydraulic conductivity and bulk density, particle density and total porosity (correlation coefficient values of r = 0.224, 0.03 and 0.107) at $p\leq0.05$ respectively. Despite the positive relationship existed in their correlation, cultural practices such as minimum, zero, mulch tillage and other conservational practices should be adopted to help maintain the rapid condition of the saturated hydraulic conductivity to avoid restriction of water movement and other soluble nutrients in the soil.

Keywords: Soil; saturated hydraulic conductivity; coastal plain sands; physical and chemical properties.

1. INTRODUCTION

Soil is formed from different parent materials and of immense importance to man as it is the major resource for agricultural productivity. It serves as a habitat for organisms and medium for plant growth. Soil is known to contain pores that aid the movement of water, gases and other soluble substances through pore spaces. Soil is porous and the pores are the pathway through which water, air and other soluble substances move. According to Akpa et al. [1] hydraulic characteristics that determine the movement of water, nutrients and aeration of plant roots are hydraulic conductivity, pore space, infiltration rate, bulk density, particle density, porosity, soil texture and structure. Hydraulic conductivity is the force that drives water through the soil. Khire and Mukherjee [2] defined hydraulic conductivity as the volume of water passing through a unit cross sectional area of soil in a unit time, given a unit difference in water potential. Hydraulic conductivity depends on the size and continuity of the conducting pores. According to Amalu and Antigha [3] the number of pores in the soil and their size distribution are useful indicators of the physical condition of the soil with regards to their continuity and tortuosity that influence aeration, water movement and retention of nutrients as well as aid in root penetration in soils. Soil texture and structure, pore size distribution, type of vegetation and organic matter content have a direct effect on hydraulic conductivity. Hydraulic conductivity is important as it makes water and nutrients available to crops through conducting pores that will maintain moisture content well above the wilting point. According to Dixon and Jones, [4] hydraulic conductivity helps to ensure constant water and other soluble substances that aid crop production.

According to Eyong and Akpa [5] soil physical and chemical properties are important characteristics used to determine the texture and the fertility content of any soil which are of extreme important for crop production, project planning and design because they form the basis for many of the more costly operations that are required in project development. Sandy soils have higher saturated hydraulic conductivities than clay soils due to their large pore size distribution and low organic matter content.

According to Amalu and Antigha [3] permeability is directly related to hydraulic conductivity by the water moving force and coastal plain soils in terms of hydraulic conductivity are moderate to high and well drained. The soil of Obufa Esuk Orok is developed on coastal plain sand parent material which are mainly unconsolidated sediments defined by its unique geological substrates which consist of wind worked quaternary sand as reported by Kogbe [6]. Coastal plain soils are characterized by acidic conditions, low cation exchange capacity and multiple nutrient deficiencies due to factors such as intensive weathering, leaching and inappropriate agricultural activities as reported by Bulktrade [7] and FPDD [8]. FAO, [9] reported that **c**oastal plain soils cover an area of 480 km^2 in Cross River State, 3,470.32 km^2 in Benue State, 42.20 km^2 in Lagos State, 213.16 km^2 in Akwa Ibom State, 12.18 km^2 in Ogun State, 40.62 km^2 in Ondo State; and 5.435.92 km^2 in River State. In Cross River State, coastal plain soils are found mostly in Akpabuyo, Bakassi, Calabar and Odukpani Local Government Areas. Coastal plain soils have good agricultural potentials because they have moderate inherent fertility and availability of water during the dry season. The clay fraction of the soil is rich in kaolinitic clay minerals according to FPDD [8]; Chikezie et al. [10] and Ogban et al. [11]. The soils are highly leached and are therefore acidic in reaction probably due to high amounts of rainfall in the area according to Chikezie et al. [10] and Ogban et al. [11]. The objective of this study, therefore seeks to evaluate saturated hydraulic characteristics and its influence on some physical and chemical properties and to correlate these characteristics to physical properties of the soil.

2. MATERIALS AND METHODS

2.1 Location of the Study Area

The study was conducted in Obufa Esuk Orok community in Calabar, Cross River State, Nigeria. Obufa Esuk Orok is located between Latitude 4.5^0 N - 5.2^0N and Longitude 8.0^0E - 8.3^0E of the Greenwich meridian. Cross River State is located in the South Eastern part of the Federal Republic of Nigeria. Geographically, it lies between $5^0$32\` and $4^0$27\` North latitude of the equator and $7^0$50\` and $0^0$25\` East of the Greenwich Meridian. It is bounded by Ebonyi and Abia State in the West, Benue State in the North, Akwa Ibom State in the South, and Atlantic Ocean in the South-East and in the East by the Cameroon Republic. The total land mass of Cross River State is about 23,074,245 square kilometers. Cross River State has a population of 4.6 million people living in the state. The climate of the area is typical tropical humid. It is determined mainly by the direction of the North and South west winds known as distinct wet and dry seasons. The wet season is often intensive which starts from February/March and last to October/November with a short dry duration of one week or more usually in the month of July/August (August break). The annual rainfall ranges between 2500 mm and 4000 mm per annum. The dry season starts from November through February with a mean annual temperature range between 25°C – 29°C as reported by Iwena [12].

The area has moderately gentle slope. The vegetation is a tropical rain forest type but human interference through construction and farming activities have helped to modify the vegetation. The geology of the area is dominated by coastal plain loamy sand. According to SSS [13], the soils belong to the broad class of Ultisols in the USDA (1975) Soil Classification. The soils are yellowish red, gravelly and brown sandy soil derived from acid crystalline rock.

2.2 Field Studies/Collection of Sample

Sixteen grids designed in an experimental plot measured 6 m x 6 m were used for field studies and sixteen (16) soil samples were collected in each of the grid using soil auger. Samples for bulk density and saturated hydraulic conductivity were collected using a core sampler.

2.3 Laboratory Analysis

Soil samples from the site were air-dried, gently crushed with pestle and mortar and sieved through a 2.00 mm sieve to obtain the fine earth fraction for the analysis. Particle size analysis was determined by the hydrometer method elaborated by Day [14] using sodium hexametaphosphate VII (Calgon) as a dispersant. Bulk density was determined by the undisturbed core cylinder method as described by Blake and Hartge [15]. Particle density was determined by the use of a pycnometer. Soil pH was determined in 1:2 soils: water ratio using a glass electrode pH meter as described by IITA [16]. The hydraulic conductivity was determined by constant head method. The organic carbon was determined by the wet oxidation method of Walkley and Black [17]. The available phosphorus was determined by No 1 method of Bray and Kurtz as described by Bremmer and Mulvany [18]. The total Nitrogen was determined by sieving the sample in a 0.5 mm mesh using the macro-Kjeldahi method as described by Riley and Murphy [19]. Exchangeable $A1^{3+}$ and H^+ were determined by leaching the soil with KCL solution and the extract titrated with standard NaOH solution as described by the titration method of McLean [20]. Exchangeable Ca^{2+}, Mg^{2+}, K^+ and Na^+ were leached from the soil sample using NH_4OAC (pH 7) buffer. The Na^+ and K^+ were measured with a flame photometer while Ca and Mg were determined by EDTA titration method. Base saturation was determined by dividing the summation of exchangeable bases (Ca^{2+}, Mg^{2+}, K^+ and Na^+) by the effective cation exchange capacity and multiplies by 100. The formula is as follows:

$$\text{Base saturation} = \frac{\text{Total Exchangeable bases}}{\text{ECEC}} \times \frac{100}{1}$$

2.4 Data Analyses

Data obtained were subjected to simple descriptive statistics of mean and correlation analysis using GenStat software version 8.10.

3. RESULTS AND DISCUSSION

3.1 Physical properties

Table 1 shows the physical properties of soils developed on coastal plain sands in Obufa Esuk Orok.

3.2 Saturated Hydraulic Conductivity

The result showed that the saturated hydraulic conductivity had a mean value of 36.63 cm min^{-1}. This rate was rapid according to Blanco-Canqui and Lal [21]. This rapid content might be probably due to the high sand and low clay contents. This suggests that the soils are high in water movement when saturated with water which might be attributed to the high sand content.

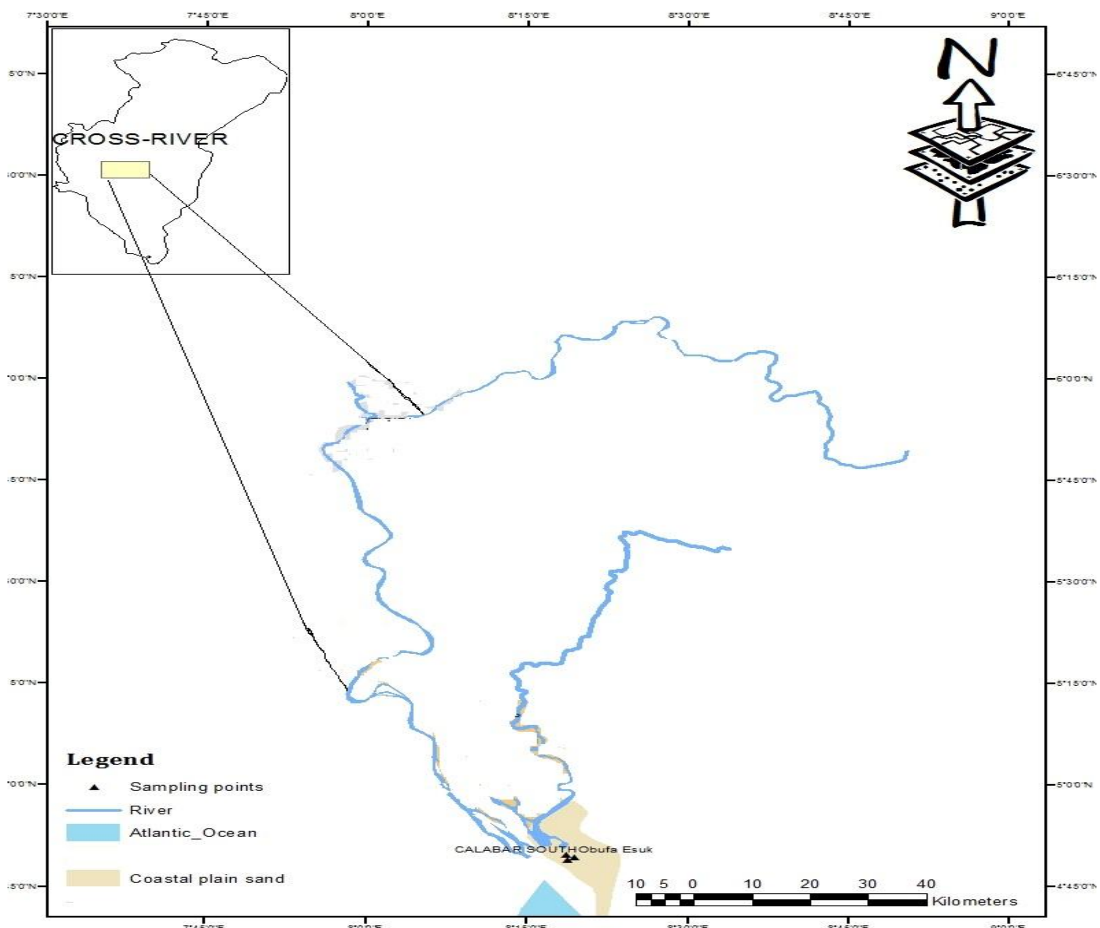

Fig. 1. Map of the study area
Source: Cartographic unit, Department of Geography, University of Calabar, Calabar

3.3 Particle Size Distribution

The particle size distribution had high proportion of sand, mean values of sand (861 g kg^{-1}) with low silt (83.3 g kg^{-1}) and clay (56 g kg^{-1}) contents. The texture was predominantly loamy loam. The texture of the soil contributes to the amount of nutrients the soil can hold for good crop yield. Sandy soils have loosed particles and so are unable to hold organic matter as well as nutrients, according to Lal [22]. They are also prone to leaching and erosion as reported by Vires et al. [23].

3.4 Bulk Density

The bulk density was low with a mean value of 1.21 Mgm^{-3}. This value was below the range of 1.49 - 1.83 Mgm^{-3} reported by Asadu et al. [24] for some yam growing soils in Southern Eastern Nigeria but were within the range of 1.00 – 1.60 Mgm^{-3}as reported by Wild, [25] for mineral soils elsewhere. The low bulk density value could be an indication of high pore space in soils of the area. This low bulk density is likely due to low levels of organic matter in the surface soils. Low levels of bulk density are capable of encouraging root penetration and development thereby increasing crop yield.

3.5 Particle Density

The particle density had a mean value of 2.55 Mgm^{-3} indicating low particle densities. This value was less than the mean values of 2.65 Mgm^{-3} particle densities reported by Don-Scott, [26]. The variation could be probably due to spatial variability of soil properties in coastal plain soils.

3.6 Total Porosity

The total porosity had a mean value of 52.4 % indicating fairly aerated soil. This value was within the range of 46-56% as reported by Asadu et al. [24] who work on soils of Atani in Abakaliki areas. Similarly, Durmusoglu et al. [27] reported that porosity increases as bulk density decreases; thus this high value of porosity was probably due to low bulk density. According to Ahn [28] top soils of soils form from coastal plain sands had a low porous bulk density than subsoil.

3.7 Chemical Properties

All the chemical properties are presented in Table 2.

The pH was 5.0 indicating strongly acidic. This might be attributed to the high rainfall in the area as reported by Akpa et al. [1]. The result corroborate with the work of Akpan – Idiok [29] who stated that the acidic conditions of the soils might be due to the high rainfall exceeding 3500 mm which could leach out basic cations from the soil solum in soils of coastal plain sands.

The Organic matter (OM) is rated low with a mean value of 1.14% as reported by FDALR, [30] and Landon, [31]. The low level of organic carbon is attributed to the slow decomposition of organic material due to low temperature and saturation of water in most part of the year. This agrees with the work of Bunemann et al. [32] who stated that intensive use of the land for agricultural activities without return of plant residue to the soils result to low organic matter.

The Total Nitrogen (N_T) is rated low with a mean value of 0.08% according to FDALR [30] and Landon, [31]. This agrees with the work of FMANR, [33] who observed low total nitrogen content in soils of acid sands of eastern Nigeria. Such levels of total nitrogen in soils might have serious negative implications on soil and crop productivity. These low values may be as a result of low organic matter content as well as leaching of nitrates from the soil; as is common in coastal plain soils. The slow rate of mineralization under anaerobic condition also accounted for the low level of nitrogen in the soils.

The available phosphorus (P_A) is rated high with a mean value of 39.5 mg kg^{-1} as reported by FDALR, [30] and Landon, [31]. This agrees with the work of Enwezor, [34] who estimated an average value of 20 mg kg^{-1} of available phosphorus for the soils of coastal plain sands as high.

The exchangeable K^+ is rated very low with a mean value of 0.08 cmolc/kg as observed by Holland et al. [35]. The soil K status in the tropics is related to the parent material and the degree of weathering as reported by Ojo-Atere et al. [36] This contrasts with the mean value of 0.16 cmolc/kg obtained by Ewulo et al. [37] for the coastal plain soils of Uyo. The low value of K^+ which is below the critical level of 0.2 cmolc/kg according to Kyuma et al. [38] might be attributed to the high rainfall and leaching intensity normally often encountered in coastal plain soil.

The exchangeable Ca^{2+} is rated low with a mean value of 2.5 cmolc/kg as reported by FDALR, [30] and Landon, [31]. This could be attributed to the exchangeable bases, acidity clays and the type of soils.

The exchangeable Mg^{2+} is rated low with a mean value of 0.58 cmolc/kg as reported by FDALR, [30] and Landon, [31]. This agrees with Bulktrade, [7] that reported low to medium magnesium content in soils of South Eastern, Nigeria.

The exchangeable Na^{+} is rated very low with a mean value of 0.05 cmolc/kg according to Ewulo et al. [37]. High rainfall will result in extensive leaching of basic cations of which sodium is one of them. This conforms to the work of Ojo – Atere et al. [36] who observed that the deficiencies of sodium usually occur in very acidic soils with low cation exchange capacity in the tropics due to heavy rainfall in the area.

The exchangeable H^{+} and Al^{3+} were generally high with mean values of 1.70 cmolc/kg and 1.39 cmolc/kg as reported by FDALR, [30] and Landon, [31]. The high content of exchangeable H^{+} and Al^{3+} could be attributed to high rainfall in the areas resulting in soil acidity.

The ECEC was low with a mean value 6.32 cmolc/kg as reported by FDALR, [30] and Landon, [31]. Low ECEC has been attributed to strongly weathered soils. Agbede, [39] reported that tropical soils have low ECEC and SOM is the major source of ECEC in such soils with higher values in the top soils than the sub soils. The higher the ECEC, the more cationic nutrients the soil can retain against leaching forces.

The Base saturation was generally low with mean value of 49.0% as reported by FDALR, [30] and Landon, [31]. This is an indication of base poor nature of the soils resulting from high rainfall in the study area. The low level BS was related to the soil pH range and the level of the basic cations of the soils.

3.8 Hydraulic Conductivity with Texture

The saturated hydraulic conductivity with texture showed that sand, silt and clay had positive linear relationship with correlation coefficient (r) of 0.013, 0.062 and 0.119 at $p \leq 0.05$ respectively indicating good relationship. This means that saturated hydraulic conductivity increases with a corresponding decrease in sand, silt and clay contents. This means the relationship was linear and positive.

3.9 Saturated Hydraulic Conductivity with Bulk Density, Particle Density and Total Porosity

The saturated hydraulic conductivity with bulk density showed a downward movement and positive linear relationship with correlation coefficient value of 0.224. This means saturated

Table 1. Physical properties of soils of Obufa Esuk Orok

Sampling	Ksat	PSD			TC	Particle	Bulk	Total
Points		Sand	Silt	Clay		Density	Density	Porosity
	cm min^{-1}	←	g kg^{-1}	→		Mg m^{-3}	Mg m^{-3}	(%)
1	29.8	890	77	33	Sa	2.38	1.1	53.78
2	36.1	870	77	53	LS	2.37	1.1	51.23
3	49.5	860	67	73	LS	2.8	1.1	60.71
4	40.6	840	87	73	LS	2.81	1.2	52.68
5	34.1	880	77	43	Sa	2.32	1.1	51.67
6	39.6	880	67	53	Sa	2.82	1.2	57.45
7	40.5	860	77	63	LS	2.34	1.2	48.72
8	38.8	850	97	53	LS	2.33	1.1	49.12
9	39.1	860	87	53	LS	2.47	1.2	50.13
10	40.1	860	87	53	LS	2.46	1.2	51.22
11	35.7	870	87	43	Sa	2.61	1.4	50.22
12	36	850	77	73	LS	2.68	1.3	51.49
13	39.7	840	97	63	LS	2.45	1.2	49.71
14	33.4	870	87	43	Sa	2.64	1.2	55.55
15	33.6	840	97	63	LS	2.62	1.3	55.61
16	19.4	850	87	63	LS	2.62	1.4	49.77
Mean	**36.63**	**861**	**83.3**	**56**	**LS**	**2.55**	**1.21**	**52.4**

PSD= Particle size distribution; Ksat = Saturated hydraulic conductivity; TC = Textural class; Sa = Sand; LS = Loamy sand hydraulic conductivity increases as the bulk density decreases. However, saturated hydraulic conductivity with particle density and total porosity showed upward movement and a positive linear relationship (correlation coefficient values of 0.03 and 0.107) at p≤0.05 respectively, indicating that the saturated hydraulic conductivity decreases as the bulk and particle density and porosity increases. This means that the movement of water and other soluble nutrients into the soil would be restricted according to Khire and Mukherjee, [2].

Table 2. Chemical properties of soils of Obufa Esuk Orok

Sampling Points	pH	Org. C (%)	Total N (%)	Avail. P Mg/kg	Ca^{2+}	Mg^{2+}	K^+	Na^+ (cmol/kg)	Al^{3+}	H^+	ECEC	BS (%)
1	5.1	1.17	0.1	33.8	3.2	0.8	0.1	0.08	1.08	1.52	6.78	61.7
2	5.2	1.07	0.09	60.8	2.6	0.8	0.08	0.06	1.04	2.36	6.94	51.0
3	5.0	0.89	0.07	50.3	1.0	0.2	0.07	0.05	1.02	1.92	4.26	31.0
4	4.8	0.79	0.05	32.5	1.2	0.2	0.06	0.04	1.35	1.65	4.50	33.3
5	5.0	1.39	0.11	43.0	2.8	0.2	0.09	0.06	1.16	1.32	5.63	56.0
6	4.9	0.84	0.06	39.3	2.0	0.2	0.08	0.05	1.28	1.28	4.89	47.6
7	4.9	0.59	0.04	51.0	1.4	0.2	0.07	0.05	1.80	1.70	5.22	33.0
8	4.9	1.03	0.07	46.5	1.6	0.6	0.08	0.05	1.24	1.80	5.37	43.4
9	5.0	1.05	0.08	33.5	2.8	0.8	0.08	0.04	1.16	1.74	6.22	59.8
10	5.0	1.15	0.09	24.5	2.8	0.4	0.08	0.04	1.24	1.67	6.23	53.3
11	5.0	0.94	0.07	35.0	1.4	0.8	0.07	0.03	1.28	1.40	4.98	46.4
12	4.9	0.79	0.06	38.8	1.0	0.8	0.07	0.04	1.72	1.60	5.23	36.5
13	4.9	1.49	0.11	18.3	5.4	0.4	0.10	0.06	1.40	1.45	8.81	67.7
14	5.9	2.31	0.18	32.8	6.2	1.0	0.11	0.07	1.98	1.89	11.25	65.6
15	5.3	1.77	0.13	53.5	3.8	1.2	0.1	0.07	1.79	1.79	8.75	59.1
16	5.2	1.03	0.08	39.0	1.4	0.8	0.08	0.06	1.80	1.92	6.06	38.6
Mean	**5.0**	**1.14**	**0.08**	**39.5**	**2.5**	**0.58**	**0.08**	**0.05**	**1.39**	**1.70**	**6.32**	**49.0**

Correlation coefficient (r) between hydraulic conductivity and texture, bulk density, particle density and total porosity

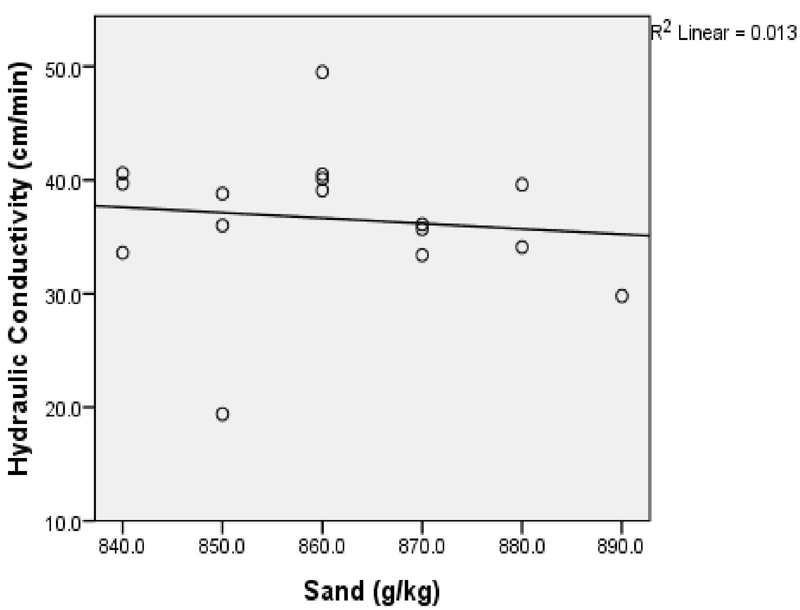

Fig. 1. A graph of Hydraulic Conductivity (cm min^{-1}) versus Sand content (g/kg)

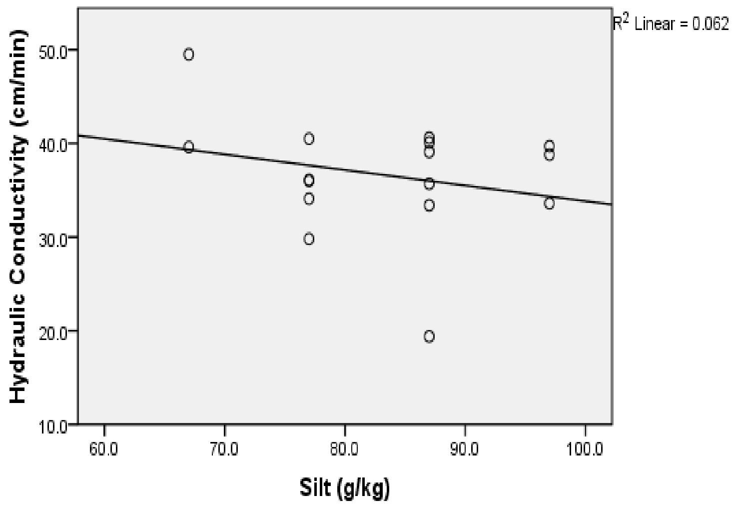

Fig. 2. A graph of Hydraulic Conductivity (cm min^{-1}) versus Silt content (g/kg)

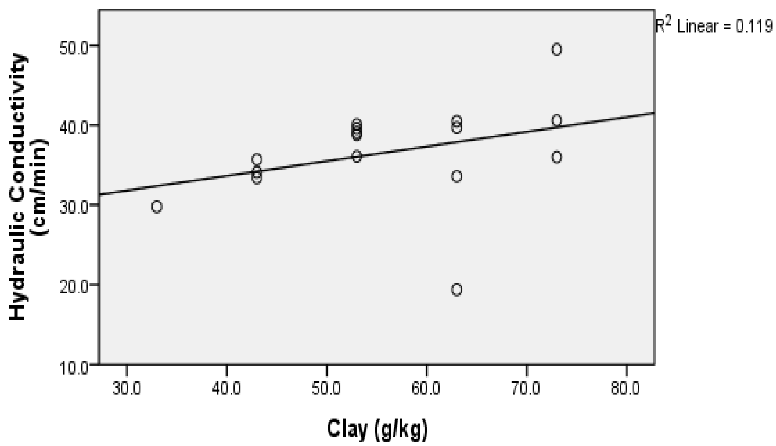

Fig. 3. A graph of hydraulic conductivity (cm min^{-1}) versus clay content (g/kg)

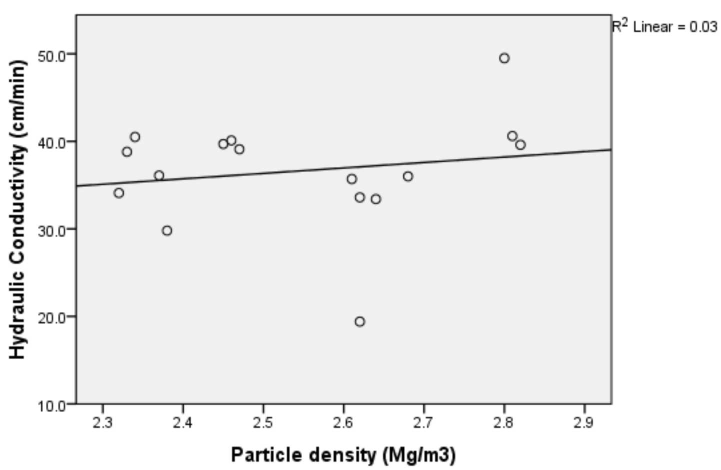

Fig. 4. A graph of Hydraulic Conductivity (cm min^{-1}) versus Particle density (g/cm^3)

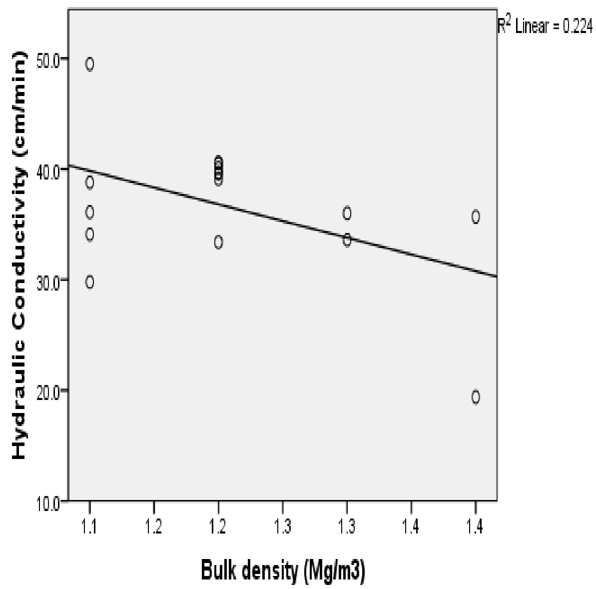

Fig. 5. A graph of Hydraulic Conductivity (cm min^{-1}) versus Bulk density (Mg/m^3)

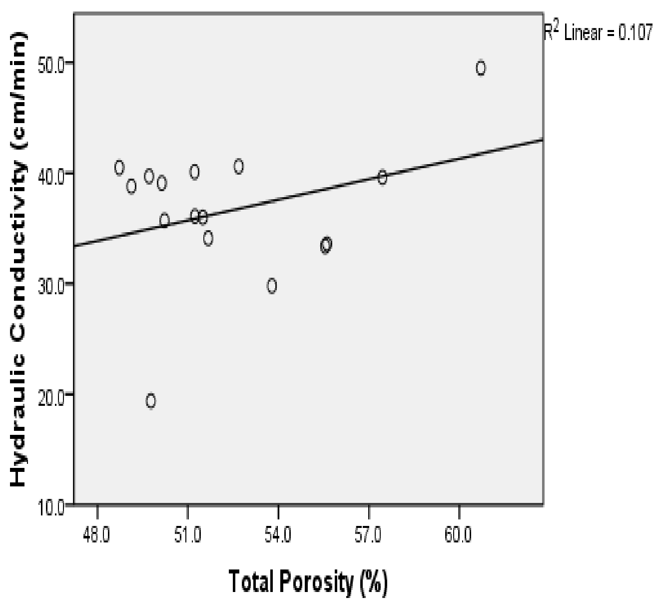

Fig. 6. A graph of Hydraulic Conductivity (cm min^{-1}) versus Total porosity (%)

4. CONCLUSION

The study affirmed that the evaluation of saturated hydraulic characteristics and its influence on some physical and chemical properties of soils developed on coastal plain sands of Obufa Esuk Orok in Calabar are high in sand content with predominantly loamy sand texture. The soils are poor and generally low in nutrients. The saturated hydraulic conductivity with texture showed that sand and silt have positive linear relationship while clay has negative linear relationship contents indicating good relationship. Saturated hydraulic conductivity with bulk density, particle density and total porosity showed a positive linear relationship indicating that saturated hydraulic conductivity decrease as the bulk and particle density and porosity increases. For proper use of this soil for agricultural purpose, the application of organic matter and other crop residues may be help in stabilizing the soil. Some cultural practices like minimum, zero, mulch tillage and other conservation practices could be encouraged to maintain the rapid condition of the saturated hydraulic conductivity and to improve other physical and chemical properties of the soil in the area.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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