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Physico–Chemical and Mechanical Properties of Soils of Owukpa Lower Coal Measure Geological Formation of Anambra Basin-Nigeria

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Abstract: ***A study was undertaken to determine the physico – chemical and mechanical properties of soils of Owukpa Lower Coal Measure Geological Formation of Anambra Basin, Nigeria. The study was conducted using composite of the three land uses from different locations viz., forested, cultivated and residential. The physico – chemical and mechanical properties vary from one location to another. Soil moisture content ranges 11.84% to 16.82%, soil organic carbon 0.58% to 0.72%, which translated to organic matter content of 1.00% to 1.24% respectively, dry bulk density 1.25g/cm^3 to 1.34g/cm^3, particle density 2.49g/cm^3 to 2.77g/cm^3, porosity 46.93% to 52.81%, specific gravity 2.43 to 2.63 and hydrogen ion concentration 5.88 to 6.78 while permeability ranges from 9.45cm/h to 12.33cm/h with moderate permeability class and code 3. The soil grain size distribution were in the ranges of 45% to 65% for sand, 28% to 44% for silt, while clay soil percentages ranges from 8% to 16%. The mechanical properties such as Liquid limit was in range of 9.33% to 22%, Plastic limit 3.80% to 12.84%, shrinkage limit 1.19% to 3.33%, plastic index 2.43% to 8.45%, cohesion 9.67KN/M^2 to 73.67KN/M^2, angle of internal friction of 11 ^{0} to 18.33 ^{0}, and shear strength of 33.89 N to 185.70 N. The results show that Ipiga does not exhibit any of the mechanical properties carried out. The soils from the study area were classified as Loam and sandy loam suitable for all kinds of crops cultivation. This data on soils of Owukpa Lower Coal Measure Geological Formation of Anambra Basin area will be useful for land use classification and developing appropriate soil tillage practices, erosion control design criteria and geotechnical parameter for the study area.***

Key words; ***Soil, Physico – chemical properties, Mechanical properties, Owukpa Lower Coal Measure, Geological Formation, Anambra Basin.***

I. INTRODUCTION

Soil is the end product of the combined influence of climate, topography, organisms (flora, fauna and human) and parent materials (original rocks and minerals) over time (FOA, 2006)[1]. As a result, soil differs from its parent material in texture, structure, consistency, color, mechanical, chemical, biological and physical characteristics. Soil physico-chemical properties such as texture, structure, permeability, bulk density, porosity, specific gravity, particle size distribution, particle density, organic carbon, organic matter content and soil hydrogen ion concentration (pH) are of significant interest in describing its formation and its relevance to land use.

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The texture describes the proportion of three sizes of soil particles and the fineness or coarseness of a soil. The structure is the arrangement of particles and pores in soils.
A well-structured soil has adequate pore space for the storage and movement of water and air which classify it into granular, platy, blocky, prismatic, and columnar (Brady and Weil, 2005) [2]. Hence soil structure influences all processes that take place in the soil including water and nutrient movement within the soil (Eneje and Mbagwu, 2005)[3]. The permeability is a measurement of how easily liquid flows through a material (or soil). [4] O'Geen *et al*., (2006) defined Permeability as a measure of the rate at which water percolates through a soil. Permeability is a function of a texture, structure, and soil bulk density hence it has an important role on the properties and behavior of soil. Bulk density is the mass per unit volume and expressed in g/cm^3. High bulk density is an indicator of low soil porosity, compaction and soil health. [5] Price (2008) indicated that high bulk density of soil reduced vegetative cover, exposes the soil to erosion and leads to water logging in areas of flat surfaces. Porosity or pore space refers to the volume of soil voids that can be filled by water and/or air. It is inversely related to bulk density and it is influenced by the sizes, shapes and degree of packing of the soil particles. These properties are interrelated according to [6] Toy et al (2002) and [7] Morgan (2005). These relationships are;

$$\frac{\text{Bulk density}}{\text{Particle density}} \times 100 = \%\text{ Solid Space} \quad (1)$$

$$100\% - \%\text{ Solid Space} = \text{Percent Pores Space} \quad (2)$$

$$\text{Porosity} = 1 - \frac{\rho_d}{\rho_p} = \frac{e}{1+e} \quad (3)$$

Where;
ρ_d= Bulk density,
ρ_p = Particle density,
e = Void ratio

Particle density is not affected by pore space and therefore is not related to particle size or to the arrangement of particle (Soil structure).Specific gravity is the ratio of the mass of soil solids to the mass of an equal volume of water. According to [8] [Oyediran and Durojaiye (2011) specific gravity is a significant index property of soils that is closely connected with mineralogy or chemical composition, while [9] Tulcer and Lohnes (1977) opined that it reflects the history of weathering. It is comparatively significant as far as the qualitative behavior of the soil is concerned [10] (Raj, 2012) and beneficial in soil mineral classification. [11] (Bowles, 2012) establish that typical values of specific gravity of organic soil ranges from 1.00 to 2.60.
Soil organic matter (SOM) is an aggregating agent that binds mineral particles together to develop structure in the soil (O'Geen et al 2006)[4].

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The organic and chemical constituents of the soil are important because of their influence in stability of aggregates. Soils with less than two per cent (2%) organic carbon, equivalent to about3.5 per cent organic matter content can be considered erodible (Evans 1980)[12]. Soils with relatively low organic matter content are very vulnerable to water erosion (Brady and Weil, 2002) since organic matter increases the stability of soil. Un-decomposed organic residues present at the soil surface protect the soil against raindrop impact.

Highly decomposed organic material in the soil, called humus, acts as a glue to bind soil particles together into aggregates. Therefore, soils that are higher in soil organic matter are more resistant to erosion. Soil pH is a degree of acidity or alkalinity of soil and is the measure of hydrogen ions (H+) in the soil. Soil pH is one of the attributes sensitive to changes in the natural environment and soil management processes because of human activity. A high amount of H+ corresponds to a low pH value and vice versa. The pH scale ranges from 0 to 14 with 7 being neutral, below 7 acidic, and above 7 alkaline (basic). Soil pH can affect cation exchange capacity (CEC) and anion exchange capacity (AEC) by altering the surface charge of colloids.

The physical properties of soil affect tillage practices, soil erosion and other soil and water processes. [13] Lal, (2001) observed that soil with larger particles require a higher fluid drag (wind or water) than small particles. Large particles are resistant to transport because of the greater force required in entraining them and fine particles are less resistant to detachment because of their lack of cohesiveness.

[14] Kaniraj (1988) stated that the water contents corresponding to transition from one state to the next are known as the liquid limit, the plastic limit and the shrinkage limit. These indices are significant in terms of earth work and agricultural cultivation (Roy and Bhalla, 2017) [15]. According to Raj [10] (2012) plasticity index is used in soil classification and in various correlations with other soil properties as a basic soil characteristic. [16] Skempton (1953) observed that the plasticity index of a soil increases linearly with the percentage of the clay-sized fraction. [17] Laskar and Pal (2012) establish that plasticity depends on grain size of soil. The shrinkage limit is the maximum water content expressed as a percentage of oven-dried weight at which any further reduction in water content will not cause a decrease in volume of the soil mass (IS: 2720 – Part 6, 1972). Soil that has finer particles, has the greater amount of shrinkage. Soils that shrink and swell are characterized as expansive soils. According to [18] Prakash and Jain (2002), the value of shrinkage limit is used for understanding the swelling and shrinkage properties of cohesive soils. It is used for calculating the shrinkage factors which helps in the design problems of the structures made of the soils or/and resting on soil. It gives an idea about the suitability of the soil as a construction material in foundations, roads, embankments and dams. It helps in knowing the state of given soil. According to [19] Burland (2005) when the cohesive value of the soil is low, this shows low clay content and binding force and it is a sign that the soil is vulnerable to erosion. Akayuli *et al*. (2013) [20] establish that the friction angle is high for a sandy soil than its cohesion and vice versa for clayey soil. Shanyoug et al. (2009) [21] in their study finalized that there is a general increase in cohesion with clay content.

The inhabitants of Owukpa are mainly engaged in agrarian pursuits of cultivating arable crops and rearing livestock on a free-range and semi intensive basis. The coal deposit within the lower coal measures geological formation in Owukpa is over 60 million tons (Agagu *et al*., 1985)[22].To improve agricultural operations and food production in the area, soil characteristics of the precinct must be identified. The main objective of this work was to determine the physico – chemical and Mechanical properties of the soil of Owukpa district in other to classify the coal measure into appropriate land uses in terms of cultivation, forested for animal real and residential.

II. THE STUDY AREA

Located in the Guinea Savannah ecological zone and in the middle belt of Nigeria, Owukpa in Benue State is geographically located within latitude 06°57’ and 07°00’N, and longitude 07°38’ and 07°42’E.It occupied an estimated land mass of about 350 square km and an estimated population of about 100,000 people (Isikwue *et al*., 2016) [23]. 95 % of the populace is Idoma speaking group.

The climate is a tropical type with distinct wet and dry seasons. According to [23] (Isikwe, *et al.,* 2016) rainfall usually starts around April when the inter-tropical convergence zone (ITCZ) shifts towards the Anambra Basin and stops in October with an average monthly precipitation of 4 – 1100 mm (0.2inches to 0.4 inches). The mean monthly temperature ranges from 16 ^{0}C to 36 ^{0}C in the area with the value of relative humidity ranges from 36 – 80%. The harmattan period is the coldest months which usually occur during December and January while the hottest months are in February and March, however, minor deviance may occur in their general pattern.

III. COLLECTION OF SAMPLES AND ANALYSES

A field experiment was conducted under three land uses viz., forested, cultivated and residential land uses and a composite of the land uses were form to determine the phsico – chemical and mechanical properties of the soil. A total of twenty-one (21) Soil samples were collected at a depth of 0 – 20cm from the three different land uses which were identified from topographic map of the area for the point locations from seven settlements using soil auger. The three samples from each settlement formed a composite sample for the particular settlement. 4kg was collected from the composite of each location and were labeled for ease of identification according to the location. The samples were sealed in clean black polythene bags to prevent moisture loss during handling and transportation to Federal University of Agriculture Makurdi Civil Engineering laboratory for analyses. ASTM D 422 – Standard Test Method for particle-size analysis of soils by hydrometer method to determine the percentage of different grain sizes contained within a soil. The percentage of silt, sand, and clay were determined by taking the reading from the Plot of the grain size curve D versus the adjusted percent finer on the semi logarithmic sheet.

Moisture content was determined by drying the sample to a constant weight. The water content is then expressed as the percentage, by weight, of the dry sample. Specific gravity was determined based on fine-grained soil by density bottle method as per Indian Standard: 2720 (part 111/sec 1) – 1980 G_s measured in room temperature. Particle density was determined using pycnometer method. Bulk density (ρd) was determined using core method. Soil pH was measured using pH meter.
Determination of soil organic content (SOC) was done using the Walkley-Black method (Walkley & Black, 1934) as modified by Allison (1965) and it was converted to organic matter content using OMC = 1.72OC. The soil permeability was also determined using constant head permeameter. Soil textural class was determined using soil textural triangle. Soil porosity was calculated using bulk density and particle density according to the equation

IV. RESULTS

Table 1 present the values of Physico-chemical properties, permeability rate, class and code results. Table 2 presents grain size analysis, soil class and soil structure results while Tables 3 presents the values of Mechanical properties.

Table 1 Values of Physico – chemical Properties, Permeability Rate, Class and Code Results

Location	MC %	OC %	OMC %	ρd g/cm^3	ρp g/cm^3	P %	G_s	pH	Pb Rate(cm/h)	Pb Class	Pb Code
Eupinobi	16.54	0.58	1.00	1.29	2.73	52.81	2.63	5.93	12.12	Moderate	3
Ipiga	11.84	0.72	1.24	1.30	2.72	52.34	2.43	6.05	11.79	Moderate	3
GSS Ukwo	14.42	0.67	1.16	1.33	2.58	48.32	2.48	6.78	12.24	Moderate	3
Eupi Coal Site	12.04	0.67	1.16	1.25	2.77	54.99	2.58	5.98	10.44	Moderate	3
Adu River	14.98	0.67	1.16	1.32	2.49	46.93	2.60	6.58	12.33	Moderate	3
Ekere	16.26	0.58	1.00	1.34	2.65	49.23	2.55	6.78	10.98	Moderate	3
Itabono	16.82	0.69	1.20	1.34	2.56	47.72	2.60	5.88	9.45	Moderate	3

MC = Moisture content, OC = Organic carbon, OMC = Organic matter content, ρd = Bulk density, Pρ = Particle density, P = Porosity, G_s = Specific gravity, pH = Hydrogen ion concentration and Pb = Permeability.

Table 2 Values of Grain Size Analysis, Soil Class and Soil Structure

Location	Sand (%)	Silt (%)	Clay (%)	Soil Class	Soil Structure
Eupinobi	45	44	11	Loam	Fine granular
Ipiga	65	28	8	Sandy Loam	Fine granular
GSS Ukwo	62	30	8	Sandy Loam	Medium to C.G
Eupi Coal Site	55	32	13	Sandy Loam	Medium to C.G
Adu River	53	34	13	Sandy Loam	Blocky
Ekere	47	39	14	Loam	Blocky
Itabono	46	38	16	Loam	Blocky

Table 3 Values of Mechanical Properties

Location	LL (%)	PL (%)	PI (%)	LS (%)	C (KN/M^2)	$\emptyset$ (°)	δ (N)
Eupinobi	14.17	5.92	8.25	1.19	9.67	13.33	41
Ipiga	-	-	-	-	-	-	-
GSS Ukwo	9.33	6.72	2.62	2.14	16.33	6.33	33.89
Eupi Coal Site	12.67	3.40	2.43	1.19	43	11	61.13
Adu River	22.0	11.52	6.99	3.33	73.67	10.33	100.78
Ekere	16.17	12.80	3.14	2.38	48	18.33	155.72
Itabono	19.17	12.94	6.23	3.09	64	17.67	185.70

LL = Liquid limit, PL = Plastic limit, PI = Plastic index, LS = Shrinkage limit, C = Cohesion,
$\emptyset$ = Angle of internal friction, δ = Shear strength.

V. DISCUSSION

A. Moisture Contents:

The moisture content of the soil from the study area (Table 1) ranges from 11.84% to 16.82% with Itabono recording the highest (16.82%) while the lowest Ipiga 11.84%. High moisture content in the Itabono could be attributed to high clay content in the area. The low moisture content 12.04% observed at Eupi Coal Site might due to generated heat by overburden helping the Coal-making process that evaporate the water from the surface or due to high porosity observed in the area which allow easily percolation of the water down into the ground water. Lowest moisture content in Ipiga is due to high percentage of sand in the area. Moisture brings about cohesion of soil particles which jointly with other soils components like organic matters form aggregates that can resist fluid drag. Hence the Itabono soil based on moisture content are less vulnerable to erosion compare to other soil in the study area. This finding agrees with Andreassian *et., al* (2004) who revealed that a drier soil is generally more vulnerable to wind and water erosion than a wet soil.

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B. Soil Organic Carbon and Organic Matter Content:

The soil organic carbon and organic matter content are same for GSS Ukwo, Eupi Coal, and Adu River 0.67 % and 1.16% each respectively (Tables 1). While Ipiga has little bit high Organic carbon of 0.72 % among the area with organic matter content of 1.24 % follow by Itabono 0.69 % and 1.20 % respectively. The low organic carbon and organic matter content was observed in Eupinobi and Ekere 0.59% and 1.00 % each respectively.

The soil in the study areas has low organic carbon and organic matter content hence the soils in the study area are erodible which are in agreement with [24] Evans (1980) who stated that any soil with less than 2% organic carbon or 3.5 % organic matter content is considered erodible.

C. Dry Bulk Density (g/cm3):

The dry bulk density ranges from 1.25 g/cm^3 to 1.34 g/cm^3 (Table 1). The dry bulk density was low in Eupi coal site (1.25 g/cm^3) compared to Ekere and Itabono (1.34 g/cm^3) each. The low values of the dry bulk density observed in the Eupi coal site indicate that the natural deposits (coal) in the area are loose and accounts for the high void ratio, while that of Ekere an Itabano might as a result of low porosity and high clay content in those areas. The dry bulk density in the study area was bit passable compared to the average standard value of 1.33 g/cm^3 as given by Esu (1999) [25].

D. Particle Density:

The results show that the particle density ranges between 2.49 g/cm^3 to 2.77 g/cm^3 (Table 1). The highest particle density was observed in Eupi Coal Site while the lowest was observed in Adu River. The high particle density observed in the coal site might due to the densities of various constituent solids present in the area. The particle density in Eupi Coal Site is high compared to the average standard value of 2.66g/cm^3 soil particle density recorded by Nyle and Ray, (1999) [26].

E. Porosity:

The porosity results of soils in the studies area ranges from 46.93 % to 52.81 %. The highest porosity was recorded in Eupinobi (52.81%) and the lowest was recorded at Adu River (46.93%) (Table 1). The high number of pores in Eupinobi might due to high percentages of silt and clay in the area.

Specific Gravity: Results of the specific gravity of the soil samples from the study area vary from 2.43 to 2.63. The low specific gravity was observed in Ipiga (2.43) (Table 1). This might due to the high organic matter content present in the location than any other locations. Generally, the study area has a low specific gravity this an indication of organic soil based on Bowles, (2012).

F. Hydrogen ion concentration (pH):

The pH value recorded in the study area varies from 5.88 to 6.78 which are somewhat acidic in nature. The pH was close to neutral 6.78 in GSS Ukwo and Ekere soils (Table 1). Hence the pH in the study area indicates that the soil has low concentration of salt.

D Permeability:

Result from Table 1 shows that the permeability rate ranges from 9.45cm/h to 12.33cm/h with moderate class and code 3 for all the locations. These indicate that the amount, distribution, and movement of water in soil which have an important role on the properties and behavior of soil are moderate for all locations.

G. Soil Structure/Textures:

Soil structure consist of fine granular, medium to coarse granular and blocky (Table 2). Soil texture is a soil property that shows proportional distribution of soil particles. The percentage of sand, silt and clay were determined. The percentage of sand ranges from 45% to 65%. Ipiga has the highest sand while Eupinobi has the lowest sand while the silt percentages ranges from 28% to 44% with Eupinobi has the highest percentage of silt while Ipiga has the lowest. Clay percentages ranges from 8% to 16% with lowest percent at Ipiga and GSS Ukwo (8%) each and the highest was in Itabono (Table 2).The result from table 2 shows that the soil class from the study are were predominantly Loam and Sandy loam.

H. Liquid, Plastic, Shrinkage limits and Plastic index:

The results show that Ipiga has no liquid, plastic, shrinkage limits and plastic index this might due to high content of sand while other location’s liquid limit ranges from 9.33% to 22%, plastic limit ranges from 3.40% to 12.84%, while shrinkage limit ranges from 1.19% to 3.33% and plastic index ranges from 2.43% to 8.25% (Table 3). The low value of liquid limit might due to decrease in clay content which results into decrease in inter molecular attraction force or it might be attributed to low amounts of fine fraction. This indicates that the soil in the study area can change from one state of consistency to another at a minimum change in Water content. Due to decrease of attraction force, liquid limit of the soil decreases and thus plasticity index decreases. The high plastic limit observed at Itabono might due to increase in clay content in the location as clay increases inter molecular attraction force, thus plastic and liquid limit increases. The highest shrinkage limit was observed in Adu river while the lowest were in Eupinobi and Eupi Coal site. Clay soil from Adu river and Itabono may be classified as montmorillonite clay mineral soil since the shrink more.

K Cohesion, Angle of internal friction and Shear strength:

The results indicate that the cohesive value of the soil ranges from 9.67 KN/M^2 to 73.67 KN/M^2, angle of internal friction ranges from 11^0 to 18.33^0 and shear strength ranges from 33.89N to 185.70N (Table 3). Ipiga has no cohesion, angle of internal friction and shear strength this might due to high sand and low clay contents.

VI. CONCLUSION

This work described the physico – chemical and mechanical properties of soils of Owukpa Lower Coal Measure Geological Formation of Anambra Basin, Nigeria.

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The parameters studied include Moisture content, organic carbon, organic matter content, soil hydrogen concentration (pH), bulk density, particle density, porosity, specific gravity, grain or particle size, permeability, liquid limit, plastic limit, plastic index, cohesion, angle of internal friction and shear strength. Results from this analysis showed that:

1. The soils from the study area were predominantly sandy soil and classified as Loam and sandy loam and with soil structure of fine granular, medium to coarse granular and blocky.
2. Generally, soils from the study area have low moisture content, organic carbon and organic matter content hence low fertility. The dry bulk density in the study area is a bit passable compared to the average standard value of 1.33 g/cm^3 as given by Esu (1999).
3. Particle density were low compare to average standard value of 2.66g/cm^3 as recorded by Nyle and Ray, (1999) except Eupi Coal site that has particle density of 2.77g/cm^3. The specific gravity values show that the soil in the study area is more of organic soil and sand. The pH obtained shows that the soils from the study area were slightly acidic in nature. The soils permeability was moderately permeable with class code 3.
4. The liquid limit, plastic limit, plastic index from the study area is low. The cohesion, angle of internal friction in some location is low while in other it was high whereas the soil shear strength is high in all locations exception of Ipiga which has no consistency limits.

These findings can go along way in classifying the soil within the study area into different land uses as recommendation for further studied.

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