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Physical Properties, Potentials And Vulnerability Of The Soils Of Sombreiro Warri Deltaic Plain, Nigeria

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Abstract: *This paper evaluates the potentials and vulnerability of the Sombreiro Warri Deltaic Plain soils using physical properties. A total of 52 genetic horizon soil samples were studied in twelve soil profiles located in Akabuka, Obite, Obagi, Omoku, Okwuzi, Aggah and Umuoru-Ndoni areas. The soils have predominantly Loamy sand and sandy loam textures on the surface (about 80% of all the studied locations). Sand content had a range of 220 – 850g/kg with a mean of 515g/kg. Clay content in the area varied from 140 – 580g/kg, with a very gradual increase with depth in few pedons. The highest clay content was observed in the Umuoru / Ndoni 2 profile where clay had a range of 470 - 580g/kg followed by Umuoru/Ndoni 1 profile with a range of 210 – 270g/kg and a mean of 245g/kg. The range in particle density for the soils was 2.10 – 2.66gcm^{-3}. The highest profile mean particle densities were 2.53, 2.50 and 2.43gcm^{-3} for Umuoru/Ndoni 2, Aggah 2 and Umuoru 1 respectively while the lowest mean values were Obite 1 (2.33), Akabuka 2 (2.33) and Obagi 1 (2.30gcm^{-3}). About 50% of the soils had their particle density between 2.35 and 2.46gcm^{-3}. The lowest mean values for different pedons were obtained in Umuoro/Ndoni, Obiafu and Aggah pedons with 1.38, 1.42, 1.43 and 1.44gcm-3 respectively while the highest relatively higher values of 1.61, 1.62 and 1.64gcm^{-3} were obtained in Obite 1, Obagi 1 and Obagi pedons respectively. Surface horizons generally had lower bulk density values in most of the pedons. Aggregation in macro aggregate fraction was high in Obagi II, Omoku 1 and Okwuzi. Aggregate stability was low with Mean Weight Diameter (MWD) of water stable aggregates of 1.64, 1.36, and 1.23mm for Obagi II, Omoku 1 and Okwuzi respectively. Topsoil and subsoil permeability were very slow ranging from 4.92cmhr^{-1} to 14.18cmhr^{-1}. Mean soil permeability in the profiles were 4.81, 1.28, 8.66, 1.29 and 0.65cmhr^{-1} for Obite 1, Obrikom, Obagi 2 and Obuburu, respectively.*

Keywords: *Soil permeability, macro-porosity, Water stable aggregates, Water holding capacity, Soil Vulnerability*

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I. Introduction

Physical properties provide useful information on the characteristics and management of soils. Assessment of soils physical quality involves evaluating numerous properties, including bulk density, aggregate stability, infiltration rate, moisture retention, characteristics and pore size distribution, soil texture and structure, gravel content, etc. The key properties that determine soils physical quality differ among soils and eco-regions (Lal, 2001). Knowledge of structural stability and hydraulic conductivity of soil is a key factor for refining our understanding of water movement/retention in the soil. Water movement through soil is determined by complex interfacial reactions, i.e, attractive forces between bulk water and soil surfaces within soil matrices. Therefore, any factors affecting water affinity to the soil matrix can lead to a change in soil water movement. Soil water retention capacity is related to particle size distributions, and is essential for quantification of soil water and nutrient uptake by plants ((Vaz et al., 2005). Soil particle size distribution is of great importance in evaluating soil water movement, soil erosion risk and soil solute migration (Li and Zhang, 2009). It has been considered as an important soil physical parameter widely used to predict soil hydraulic properties (Saxton and Rawls, 2004). Knowledge of soil water retention characteristics is indispensable for many soil water related investigations such as soil water storage capacity. (Owusu-Bennoah *et al.*, 2000). Water storage capacity is an important soil parameter in relation to soil potential and can be used to facilitate the classification of soils for agricultural and other useful purposes (Gupta and Larson, 1979).

II. Materials And Methods

Description of study area and sample collection

The study was conducted in selected sites in Akabuka, Obagi, Obite, Omoku, Ebocha, Ndoni, Okwuzi and Aggah in ONELGA, Rivers State. Ten representative soil profiles were sited along six (6) transects. Fiftytwo (52) genetic horizons were sampled for particle size, bulk density, particle density, hydraulic conductivity, aggregate stability and total porosity.

Particle size distribution and organic carbon

Particle size distribution was determined by the method of Gee and Bauder (1996).

Determination of Bulk Density, Total Porosity and Water Holding Capacity

Bulk density was determined by the method described by Black and Hartge (1986) as:

$$\text{Bulk density} = \frac{\text{Mass of oven – dried soil (g)}}{\text{Volume of bulk soil (cm}^3\text{)}}$$

Total porosity was calculated with core samples using the method of Flint and Flint (2002) as:

$$\text{\% total porosity} = \frac{\text{volume of water of saturation (cm}^3\text{)}}{\text{Volume of bulk soil (cm}^3\text{)}} \times \frac{100}{1}$$

Water holding capacity was calculated as:

$$\text{\% WHC} = \frac{Mw - Md}{Md} \times \frac{100}{1}$$

Where WHC is water holding capacity (%), Mw is mass of wet soil (g) and Md is mass of oven – dry soil (g).

Determination of Bulk Density, Total Porosity and Water Holding Capacity

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Water holding capacity was calculated as:

$$\text{\% WHC} = \frac{Mw - Md}{Md} \times \frac{100}{1}$$

Where WHC is water holding capacity (%), Mw is mass of wet soil (g) and Md is mass of oven – dry soil (g).

Determination of Structural Aggregates and Saturated Hydraulic Conductivity

Aggregate stability was measured by the mean weight diameter (MWD) of water stable aggregates as described by Kemper and Rosenau (1986). Water stable aggregates were measured by the mean weight diameter (MWD) by the following equation (Hillel,2004):

$$MWD = \sum_{i-1}^{n} Xi\ Wi \quad \ldots\ldots\ldots\ldots (1)$$

Where Xi is the mean diameter of any particular size range of aggregates separated by sieving and Wi is the weight of aggregates in that size range as a function of the total dry weight of the sample analyzed. Water-stable aggregate (WSA) was calculated as:

$$WSA = \frac{MR}{MT} \times \frac{100}{1} \quad \ldots\ldots\ldots(2)$$

Where, MR is the mass of resistant aggregate (g), and MT is the total mass of wet-sieved soil (g).

Saturated hydraulic conductivity was measured by the constant head permeameter technique as described by Klute and Dirksen (1986) as:

$$Ksat = \frac{Q}{AT} \times \frac{L}{\Delta H}$$

Where, K sat is saturated hydraulic conductivity (cm hr^{-1}), Q is volume of water that flows through a cross-sectional area (cm^3), A is cross – sectional area of core (cm^2),T is time elapse (s),L is length of core (cm),and ΔH is hydraulic head difference (cm).

III. Results

Particle Size Analysis

The soils of the Ogba-Egbema area of the SWDP are generally sandy (**Table 1**). Loamy sand and sandy loam textures dominate the surface soils of the area occupying about 80% of all the studied locations.

Sand content had a range of 220 – 850g/kg with a mean of 515g/kg. Clay content in the area varied from 140 – 580g/kg, with a very gradual increase with depth in few pedons. The highest clay content was observed in the Umuoru / Ndoni 2 profile where clay had a range of 470 - 580g/kg followed by Umuoru/Ndoni 1 profile with a range of 210 – 270g/kg and a mean of 245g/kg.

Particle Density, Bulk Density and Total Porosity

Data for particle density are given in **Table 2**. The range in particle density for the soils was 2.10 – 2.66gcm^{-3}. The highest profile mean particle densities were 2.53, 2.50 and 2.43gcm^{-3} for Umuoru/Ndoni 2, Aggah 2 and Umuoru 1 respectively while the lowest mean values were Obite 1 (2.33), Akabuka 2 (2.33) and Obagi 1 (2.30gcm^{-3}). Though there was no definite trend in particle density it generally seems to increase with depth of pedons. About 50% of the soils had their particle density between 2.35 and 2.46gcm^{-3}. Results obtained for particle density in the soils of the SWDP were similar to those (2.32 to 2.66gcm^{-3}) reported by Kamalu (1989) for the Meander Belt Deposits of the Niger Delta.

Bulk density is a measure of the volume of the dry soil as it naturally exists and includes air space and organic carbon but not soil moisture. Bulk density ranged between 1.38 and 1.74gcm^{-3} in the soils of the Ogba-Egbema area. The lowest mean values for different pedons were obtained in Umuoro/Ndoni, Obiafu and Aggah pedons with 1.38, 1.42, 1.43 and 1.44gcm-3 respectively while the highest relatively higher values of 1.61, 1.62 and 1.64gcm^{-3} were obtained in Obite 1, Obagi 1 and Obagi pedons respectively.

The total porosity in the soils had a range of 18.6 – 45.1%. The highest profile means for total porosity were Umuoru 2, Aggah 2 and Umuoru 1 with 44.57, 42.4 and 40.8% respectively while the lowest profile means of 28.5, 30.5 and 31.4% were obtained in Obagi 2, Obite 1 and Akabuka 2 respectively. Total porosity was moderate in the top 0-25cm in Obagi 1 soil. Mean total porosity were 25, 27, 23, 25 and 27% for Obite1, Obite 2, Obagi 1, Obagi 2, Omoku and Okwuzi respectively (**Table 2**).

Saturated Hydraulic Conductivity and Water Holding Capacity

Data for saturated conductivity presented in **Table 3** showed a wide range of 0 – 98.0cmhr^{-1}. Saturated hydraulic conductivity was moderately rapid in the top 0 – 25cm soil in Obite 1 with mean distribution of 17.18cm/hr within 150cm depth. In Obite 2, Obagi 2 pedons permeability was moderately slow (14.18cm/hr and 15.64cm/hr respectively) at the top 0 – 25cm.

Water Stable Aggregates

Most soils of the Ogba-Egbema area are stable. Aggregate Stability measures the degree to which soil aggregates resist falling apart when wetted and hit by rain drops. The results for water stable aggregate of the soil are presented in **Table 4**. Okwuzi soils showed good stability of aggregates in terms of mean weight diameter (MWD) and macro aggregate stability throughout the profile. Mean Weight Diameter (MWD) of water stable aggregate was relatively high with 0 – 30cm soil in Obagi 1, Obagi 2, Omoku and Okwuzi (1.474, 1.638, 1.356 and 1.226 respectively).

Table 1: Particle Size Distribution in the Soils.

Horizon	Depth (cm)	Sand g/kg	Silt g/kg	Clay g/kg	Textural Class
	AKABUKA 2				
Ap	0 -23	810	30	160	Sandy loam
A2	23 – 60	760	60	180	Sandy loam
AB	60 – 97	780	80	140	Sandy loam
B2	97 – 125	720	110	200	Sandy loam
	Mean	***767.5***	***70***	***170***	
	OBITE 1				
Ap	0-25	840	20	140	Sandy loam
A2	25-40	770	50	180	Sandy loam
B21	40-65	790	50	160	Sandy loam
B22	65 - 150	770	40	190	Sandy loam
	Mean	***792.5***	***40***	***167.5***	
	Obite II				
Ap	0-20	820	40	140	Sandy loam
AB	20-36	820	30	150	Sandy loam
Bt21	36-86	760	50	190	Sandy clay loam
Bt22	86-150	750	50	200	Sandy clay loam
	Mean	**787.5**	**42.5**	**170**	
	Obagi 1				

Ap	0-20	800	50	150	Loamy Sand
A2	20-39	760	60	180	Loamy Sand
AB	39-47	740	60	200	Loamy Sand
B2	47-120	760	40	200	Sandy loam
BC	120-150	760	40	200	Sandy loam
	Mean	***764.0***	***50***	***186***	
	Obagi ll				
Ap	0-20	760	40	200	Sandy loam
B1	20-40	760	40	200	Sandy loam
B2	40-57	790	50	160	Sandy loam
B3	85-105	790	50	160	Sandy loam
BC	105-200	770	60	170	Sandy loam
	Mean	***774***	***48***	***178***	
	Omoku				
Ap	0-20	800	60	140	Sandy loam
A2	20-58	600	12	280	Sandy loam
BA	58-88	580	200	220	Sandy loam
B1	88-158	610	150	240	Sandy loam
	Mean	***647.5***	***132.5***	***220***	

Horizon	**Okwuzi**				
Ap	0-14	850	30	120	Loamy sand
AB	14-37	820	40	140	Loamy Sand
B1	37-74	760	60	180	Sandy loam
B2	74-128	740	40	220	Sandy loam
	Mean	***792.5***	***42.5***	***165***	
	OBIAFU 1				
Ap	0 – 15	800	60	140	Sandy loam
AB	15 – 40	600	120	280	Loam
B1	40 – 65	580	200	220	Loam
B2	65 – 100	610	150	240	Loam
B3	100 – 120	760	60	180	Sandy loam
B4	120 - 200	740	70	190	Sandy loam
	Mean	***681.7***	***110***	***209***	
	AGGAH 1				
Ap	0 – 24	840	20	140	Sandy loam
B2	24 – 55	810	50	140	Sandy loam
B22	55 – 90	760	80	160	Sandy loam
B23	90 - 140	800	50	150	Sandy loam
	Mean	***802.5***	***50***	***147***	
	AGGAH 2				
Ap	0 -6	830	30	140	Sandy loam
AB	6 - 50	830	30	140	Sandy loam
B2	50 - 80	820	40	140	Sandy loam
BC1	80 - 130	830	30	140	Sandy loam
	Mean	***827.5***	***32.5***	***140***	
	UMUORU/NDONI 1				
Ap	0 – 18	480	250	270	Loamy sand
B21	18 - 36	510	240	250	Loamy sand
Bt1	36 - 62	520	270	210	Loam
Bt2	62 – 140	510	240	250	Loam
	MEAN	***505***	***250***	***245***	
	UMUORU/NDONI 2				
Ap	0 – 21	220	200	580	Silty Clay
B1	21 – 58	340	190	470	Silty Clay
BC1	58 – 90	280	190	530	Silty Clay
BC2	90 - 150	340	182	478	Silty Clay
	MEAN	***295.0***	***190.5***	***515***	

Table 2: Particle Density, Bulk Density and Total Porosity of the Soils.

Depth (cm)	Particle Density mgm^{-3}	Bulk Density mgm^{-3}	Total Porosity %
AKABUKA 2			
0 -23	2.42	1.52	37.2
23 – 60	2.50	1.54	38.4
60 – 97	2.22	1.62	27.0
97 – 125	2.16	1.66	23.1
MEAN	*2.33*	*1.59*	*31.43*
OBITE 1			
0-25	2.50	1.51	39.6
25-40	2.50	1.55	38.0
40-65	2.10	1.71	18.6
65 - 150	2.22	1.65	25.7
MEAN	*2.33*	*1.61*	*30.48*
Obite II			
0-25	2.35	1.52	39.6
25-60	2.50	1.56	37.6
60-90	2.50	1.61	35.6
90-150	2.50	1.67	33.2
MEAN	2.45	1.59	35.43
Obagi 1			
0-25	2.35	1.54	34.5
25-40	2.35	1.50	36.2
40-60	2.50	1.65	34.0
60-150	2.50	1.69	32.4
150-200	2.22	1.74	21.6
MEAN	*2.38*	*1.62*	*31.7*
Obagi ll			
0-30	2.35	1.54	34.5
30-45	2.35	1.63	30.6
45-70	2.22	1.67	24.8
70-105	2.35	1.67	29.0
105-200	2.22	1.70	23.4
MEAN	*2.30*	*1.64*	*28.5*
Omoku 2			
0-20	2.50	1.50	40.0
20-50	2.50	1.51	39.6
50-80	2.35	1.51	35.7
80-150	2.50	1.69	32.4

Depth (cm)	Particle Density mgm^{-3}	Bulk Density mgm^{-3}	Total Porosity %
Okwuzi			
0-20	2.50	1.48	40.8
20-70	2.35	1.49	36.6
70-120	2.50	1.44	42.4
120-200	2.50	1.61	35.6
MEAN	*2.46*	*1.51*	*38.9*
OBIAFU 1			
0 – 15	2.35	1.38	41.3
15 – 40	2.40	1.42	40.8
40 – 65	2.50	1.50	40.0
65 – 100	2.35	1.42	39.6
100 – 120	2.22	1.50	32.4
120 - 200	2.30	1.40	39.1
MEAN	*2.35*	*1.43*	*38.9*

AGGAH 1			
0 – 18	2.66	1.48	44.4
18 – 40	2.22	1.52	31.5
40 – 70	2.35	1.48	37.0
70 - 120	2.35	1.52	35.3
MEAN	*2.40*	*1.50*	*37.1*
AGGAH 2			
0 -6	2.35	1.40	40.4
6 - 50	2.50	1.42	43.2
50 - 80	2.50	1.46	41.6
80 - 130	2.66	1.48	44.4
MEAN	*2.50*	*1.44*	*42.4*
UMUORU/NDONI 1			
0 – 18	2.40	1.43	40.4
18 - 36	2.45	1.40	42.9
36 - 62	2.38	1.45	39.1
62 – 140	2.50	1.48	40.8
MEAN	*2.43*	*1.44*	*40.8*
UMUORU/NDONI 2			
0 – 21	2.64	1.45	45.1
21 – 58	2.55	1.40	45.1
58 – 90	2.53	1.42	43.8
90 - 150	2.60	1.45	44.2
MEAN	*2.53*	*1.42*	*44.57*

Table 3: Saturated Hydraulic Conductivity of the Soils of the Study Area

Depth (cm)	Ksat (cm hr^{-1})	Permeability Index	Permeability Class
AKABUKA 1			
0 - 30	15.51	3	Moderately slow
30 – 60	7.75	2	Slow
60 - 90	6.21	2	Slow
90 -150	5.17	2	Slow
Mean	8.66	2	Slow
OBITE 1			
0 -23	1.50	1	Very slow
23 - 70	1.55	1	Very slow
70 – 120	11.37	3	Moderately slow
Mean	4.91	2	slow
OBITE 2			
0 – 25	1.88	1	Very slow
25 – 50	1.04	1	Very slow
50 – 70	1.50	1	Very slow
70 – 100	2.00	2	Slow
100 - 150	0.00	1	Very slow
Mean	1.28	1	Very slow
Obagi 1			
0-16	18.10	4	Moderate
16 – 33	26.68	5	Moderately rapid
33 – 72	20.11	5	Moderately rapid
72 - 104	18.10	4	Moderate
104 -150	7.76	2	Slow
Mean	18.15	4	Moderate
Obagi 2			
0 -19	5.17	2	Slow
19 -54	0.00	1	Very slow
54 -144	0.00	1	Very slow
144 - 170	0.00	1	Very slow
Mean	1.29	1	Very slow
Omoku 1			

0 – 33	74.95	6	Rapid
33 – 70	25.85	5	Moderately rapid
70 -105	8.79	2	Slow
105 - 160	8.71	2	Slow
Mean	29.58	5	Moderately rapid
OMOKU OBRIKOM			
0 -15	2.59	2	Slow
15 – 35	0.00	1	Very slow
35 - 90	0.00	1	Very slow
90 – 150	0.00	1	Very slow
Mean	0.65	1	Very slow
OKWUZI			
0 – 20	79.61	6	Rapid
20 - 40	62.03	6	Rapid
40 - 70	36.19	6	Rapid
70 - 100	18.62	4	Moderate
100 - 140	3.10	2	Slow
Mean	39.91	6	Rapid
AGGAH 1			
0-24	98.00	6	Rapid
24 - 50	44.45	5	Moderately rapid
50 - 90	13.89	4	Moderate
90 - 120	4.37	2	slow
Mean			Moderately rapid
AGGAH 2			
0-20	54.76	6	Rapid
20 - 50	65.88	6	Rapid
50-100	26.99	5	Moderately rapid
100-120	5.24	2	Slow
Mean			Rapid
EBOCHA 1			
0-15	84.13	6	Rapid
15 - 40	64.29	6	Rapid
40-100	10.71	3	Moderately slow
100-120	19.45	4	Moderate
Umuoru/Ndoni 1			
0-20	0	1	Slow
20-40	0	1	Slow
40-60	0	1	Slow
60-120	0	1	Slow
Mean	0	1	Slow

.Table 4: Water Stable Aggregates (%) of the Soils

Depth (cm)	**Aggregates sizes (mm)**					**MWD (mm)**
	4.75 – 2	**2 – 1**	**1 – 0.5**	**0.5 – 0.25**	**< 0.25**	
OBITE 1						
0-25	10.50	8.50	20.03	30.00	41.47	0.843
25-40	6.33	7.51	8.00	31.06	49.10	0.626
40-65	4.79	8.00	9.14	30.00	49.07	0.586
65-150	5.11	10.46	15.02	28.75	40.66	0.652
Mean	6.68	8.62	13.05	29.95	45.08	0.677
OBITE 2						
0-25	10.15	3.75	2.10	40.00	44.00	0.675
25-60	5.16	4.19	9.05	41.50	40.10	0.561
60-90	3.11	5.63	6.74	40.02	44.50	0.502
90-150	6.06	4.97	9.45	30.30	49.32	0.587

Mean	6.12	4.64	8.12	37.96	44.48	0.581
OBAGI 1						
0-25	36.50	4.30	3.30	10.70	45.2	1.474
25-40	10.20	3.84	7.29	61.13	58.8	0.701
40-60	3.20	9.68	2.83	32.3	51.99	0.670
60-150	8.41	2.75	1.16	40.22	47.46	0.603
150-200	1.67	8.31	10.48	21.11	58.43	0.485
Mean	12.00	5.21	5.01	33.13	52.38	0.787

Depth (cm)	Aggregates sizes (mm) 4.75 – 2	2 – 1	1 – 0.5	0.5 – 0.25	< 0.25	MWD (mm)
OBAGI 2						
0-30	40.02	7.63	3.28	20.02	29.05	1.638
30-45	8.46	5.11	5.08	40.01	41.34	0.655
45-70	9.69	2.77	9.40	40.04	38.10	0.685
70-105	9.51	2.18	8.31	50.10	29.90	0.679
105-200	19.05	10.3	10.1	30.2	30.4	1.063
Mean	17.35	5.60	7.23	36.07	33.76	0.944
OMOKU						
0-20	29.62	10.80	4.07	20.00	35.51	1.356
20-50	20.70	10.00	11.52	23.11	34.67	1.109
50-80	15.00	9.89	18.11	20.07	32.90	0.948
80-150	3.94	25.63	13.97	20.30	36.16	0.789
Mean	17.32	14.07	11.92	20.62	34.81	1.051
OKWUZI						
0-20	17.3	30.94	10.44	13.32	20.00	1.226
20-70	28.00	19.51	10.60	11.89	30.00	1.412
70-120	16.10	18.11	18.68	20.00	32.89	1.269
120-200	8.43	10.00	11.10	30.32	40.15	0.732
MEAN	17.46	19.64	12.71	18.88	30.78	1.160

Depth (cm)	Aggregates sizes (mm) 4.75 – 2	2 – 1	1 – 0.5	0.5 – 0.25	< 0.25	MWD (mm)
AGGAH 1						
0-18	12.21	0.404	0.472	2.675	4.239	0.4423
18-40	8.774	0.676	2.073	7.670	0.807	0.3526
40-70	2.871	1.716	2.388	12.71	5.315	0.2012
70-120	0.107	0.846	4.904	13.06	6.083	0.1173
Aggah 3						
0-15	12.77	0.527	1.116	4.973	5.614	0.4497
15-55	3.591	0.477	1.056	4.121	5.755	0.2094
55-100	2.013	0.898	2.680	11.38	13.029	0.1778
100-120	0.154	1.015	3.337	6.243	4.251	0.0794
Ebocha 1						
0-15	17.88	0.611	0.540	3.046	2.923	0.6370
15 - 65	7.945	6.375	7.778	29.13		0.5003
65-100	7.878	3.189	3.973	3.494	31.557	0.4363
100-120	0.196	1.502	3.653	13.925	15.724	0.1709

120-200	0.455	1.072	2.354	7.953	18.168	0.1251
EB/ND 1						
0-20	5.002	0.116	0.218	1.647	2.25	0.2465
20-40	0.061	0.242	0.549	1.951	7.197	0.0542
40-60	0.383	0.313	0.643	1.753	11.908	0.0599
60-100	0.212	1.421	2.425	5.135	0.807	0.0717

IV. Discussion

Particle Size, Particle Density, Bulk Density, Total Porosity

Generally, the soils were sandy throughout the entire matrices of the different pedons with observable increase in clay with soil depth obtained in some profiles. This buildup of clay in the B-horizon observed in few pedons (Obiafu, Omoku 1, Obagi2 and Obite 1) was an indication of active illuviation and evidence of soil stability and development (Arocena and Sanborn, 1999). The soils are usually sandy loam to sandy clay loam in texture. A change in texture from loamy sand to sandy clay loam was observed only in three pedons (Obite 2, Omoku 2 and Ebocha 1). Generally, the surface soils were more sandy than the subsurface. Change in texture with depth was also minimal usually between loamy sand and sandy loam. The predominantly sandy loam to loamy sand texture in the area enhanced rapid infiltration and drainage.

Generally, particle density seems to be relatively lower on the surface. This agreed with the findings of Ahmed (2002) who attributed increasing particle density with soil depth to the inverse relation between organic matter and increasing soil depth. The mean particle density of most mineral soils is about 2.60 to 2.75g/cm3, but the presence of iron oxide and heavy minerals increases the average value of particle density and the presence of organic matter lowers it (Hillel, 1980).

The high mean bulk density (1.61gcm^{-3}, 1.67gcm^{-3}, 1.74gcm^{-3} and 1.64g/cm^{-3}) in Obite 1, Obite 2, Obagi 1, Obagi 2 respectively are capable of restricting plants roots within 65cm depths. Arshad *et al*. (1996) reported that bulk density between 1.60gcm^{-3} and 1.75gcm^{-3} affected root growth of most cultivated crops in sandy clay loam soils. They further reported threshold values for loamy sands, sandy loam and clay loams as 1.69 -1.80gcm^{-3}, 1.63 -1.80gcm^{-3}, and 1.49 -1.58gcm^{-3} respectively. Bulk density did not have a definite trend in most of the pedons, though it was generally lower within 0-65cm depth of the soils and increased with depth beyond 100cm in most of the pedons. Using bulk density of equal to or greater than 1.65gcm^{-3} ($\geq$1.65gcm^{-3}) as a soil quality benchmark in the study area, more than 80% of the soils have very good physical property and as such are of high soil quality. Bulk density was relatively lower and closer to the ideal value of 1.3gcm^{-3} for optimal plant growth in the northern part of the study area (ie around Egbema). The mean value in this area was 1.42 – 1.51gcm^{-3}. Reynolds *et al*., (2007) reported that the optimal bulk density for crop production ranges from 0.9 to 1.3gcm^{-3} for fine-textured soils. The land use in the Egbema area was less perturbed and was dominated by thick vegetation (forestry). Surface horizons generally had lower bulk density values in most of the pedons. This was attributed to their relatively higher content of organic matter and uncompacted nature. Generally bulk density values increased with depth of pedons. This increase with depth may be due to compaction which resulted from overburden and less disturbance (Baver, 1956; Brady and Weil 2002; Marshall and Holmes 1979). Total porosity was moderate in the topsoils of the southern end of the study area. Mean total porosity were 25, 27, 23 and 25% for Obite1, Obite 2, Obagi 1, Obagi 2 and Omoku respectively (**Table 2**). Water holding capacity of the soils at saturation were low with non-significant ($P > 0.05$) difference between the profile in Obite 1, Obagi 1, Obagi 2, and Omoku. These imply that the soil cannot retain water for a long period of time. It also indicates that the tendency of the soil to flooding, crusting and cracking is high in this area. Similar observation has been reported by Sharma and Bhagat (1993) on studies on both water storage and residual porosity of soil under intensive agricultural land use. The soils in Obite and Obagi would be easily flooded and eroded under heavy rainfall. Topsoil water holding capacity in Omoku and Okwuzi were relatively higher. However, with adequate soil management, and tillage at appropriate soil moisture content the soil quality can be improved to sustain agricultural production.

Saturated Hydraulic Conductivity, Water Stable Aggregates and Permeability

The saturated hydraulic conductivity had a very wide range from slow (0cm/hr) to rapid (98cm/hr). Saturated hydraulic conductivity was moderately rapid in the top 0 – 25cm in Obite 1 with mean distribution of 17.18cm/hr within 150cm depth. In Obite 2, Obagi 2 soils, permeability was moderately slow (14.18cm/hr and 15.64cm/hr respectively) at the top 0 – 25cm (**Table 4**). In Obagi 1 Pedon where there has been intensification of industrial activities (oil and gas activities) the saturated hydraulic conductivity was very slow in the top 0 – 25cm, while Omoku and Okwuzi pedons have rapid permeability generally with means of 36.52cm/hr and

38.10cm/hr respectively. The relatively lower hydraulic conductivity in the Obagi area are associated with increased overburden created by traction in relation to several construction activities of oil and gas field operations. Consequently Obagi and Obite soils have impeded drainage, while Omoku and Okwuzi soils are well drained and support plants roots.

Okwuzi soils showed good stability of aggregates in terms of Mean Weight diameter (MWD) and macro aggregate stability throughout the profile. MWD of water stable aggregate was relatively high within 0 – 30cm soil depth in Obagi 1, Obagi 2, Omoku and Okwuzi (1.47, 1.64, 1.36 and 1.23mm respectively). However, the relatively high MWD of water stable aggregate observed in the 0 – 30cm soil in Obagi 1 and Obagi 2 did not translate to improved permeability and water holding capacity which is generally reported (Pagliar *et al* 2004, Lal et al 1994 and Pagliar et al 2000). In Omoku and Okwuzi macro aggregate stability was 46% and 59% respectively in the topsoil with mean weight diameter (MWD) of 1.36 and 1.23mm respectively. The improvement in water stable aggregate led to concomitant improvement in saturated hydraulic conductivity, bulk densities and water holding capacity in these soils.

Soil permeability in Obite 1 and 2, Obagi 2 Omoku/Obrikom and Umuoru catchment were generally very slow ranging from 0.0 to 11.37$cmhr^{-1}$ with mean distribution within the profile of 4.91, 1.28, 1.29, 0.65 and 0$cmhr^{-1}$ for Obite 1, Obite 2, Obagi 2, Omoku/Obrikom 2 and Umuoru/Ndoni 1 respectively. Subsoil permeability was essentially very slow due to high water table and high clay content and manganese concretion of the profiles. This indicates that there is drastic reduction in the macro-porosity. If the soil receives high rainfall or irrigation, the swelling of the clay will result in reduced permeability, but during drying periods, the soil will shrink, resulting in initial rapid permeability (Curtin *et al*., 1994). This implies that the soil quality is low because of the catchment area is prone to limiting nutrient uptake, water infiltration and redistribution, seeding emergence and root development (Sharma and Bhagat, 1998; Arvidcon, 2001). However, soil water storage in the subsoil will be high enough to sustain plant crops for a long period of time after rainfall or irrigation. However, the very low permeability of the soil can be improved through adequate tillage practices that will balance the ratio of macro-porosity to micro-porosity (Udom, *et al.,* 2011). Adequate drainage will improve the water movement in and out of the soil. The Omoku soils varied from slow to rapid. The top soil permeability was generally rapid indicating good drainage at the top soil.

Potential and Vulnerability of the Soils

The soils in Obite and Obagi would be easily flooded and eroded under heavy rainfall as a result of low total porosity. Similar observation has been reported by Sharma and Bhagat (1993) and Langmack (1999) on studies on both water storage and residual porosity of soil under intensive agricultural land use. Topsoil water holding capacity in Omoku 1 and Okwuzi were relatively higher. However, with adequate soil management, and tillage at appropriate soil moisture content the soil quality can be improved to sustain agricultural production. The general relationship between bulk density and root growth for these soils showed that more than 70% of the horizons studied belong to moderate to ideal range for the growth of plants. The bulk density values obtained in the area would not impair the ability of plant roots to penetrate the soils. The combining impact of the predominantly sandy loam texture with bulk density and porosity further enhances the performances of plants in the area and are indicative of moderate to high inherent soil quality.

High proportion of macropores brings about a high value of saturated hydraulic conductivity and expected low unsaturated hydraulic conductivity. These facts have implications for infiltration of water into the soils and the availability of water to plant roots and leaching losses. Water percolation on the surface of Obite 2 and Obagi 2 areas is therefore low and drainage is impeded. In the Obagi 1 pedon where there is intensification of developmental activities, hydraulic conductivity in the top 0 – 25cm was very slow. Omoku 1 and Okwuzi pedons have rapid permeability generally with means of 36.52cm/hr and 38.10cm/hr respectively. This implies that Omoku and Okwuzi soils are well drained and have relative greater potential to support plants roots. Obagi and Obite soils have impeded drainage, which may lead to low oxygen transport for both plants and microorganisms. Water movement through sands is both rapid under saturated conditions and slow under unsaturated conditions. This has a bearing on the pore size distribution and moisture retentivity. The general relationship between bulk density and root growth for these soils showed that more than 70% of the horizons studied belong to moderate to ideal range for the growth of plants. The bulk density values obtained in the area would not impair the ability of plant roots to penetrate the soils. The combining impact of the predominantly sandy loam texture with bulk density and porosity further enhances the performances of plants in the area and are indicative of moderate to high inherent soil quality.

V. Conclusion

The soils have predominantly Loamy sand and sandy loam textures on the surface (about 80% of all the studied locations). Sand content had a range of 220 – 850g/kg with a mean of 515g/kg. Clay content in the area varied from 140 – 580g/kg. The range in particle density for the soils was 2.10 – 2.66gcm^{-3}. Surface horizons generally had lower bulk density values in most of the pedons. Aggregation in macro aggregate fraction was high in Obagi II, Omoku 1 and Okwuzi. Aggregate stability was low with Mean Weight Diameter (MWD) of water stable aggregates of 1.64, 1.36, and 1.23mm for Obagi II, Omoku 1 and Okwuzi respectively. Topsoil and subsoil permeability were very slow ranging from 4.92$cmhr^{-1}$ to 14.18$cmhr^{-1}$. The physical properties of most of the pedons reflect deep and very productive setting and are suitable for agricultural land uses. However, poor drainage and periodic flooding in four of the pedons are limiting factors in the soils. The soils in the area have low aggregate stability, slow permeability and low quality. Six of the ten pedons studied and their catchment areas are suited for agricultural use, while four (4) pedons have varying levels of limitations due to their vulnerability to flooding and erosion.

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