Application of Geophysical and Geotechnical Methods for Mapping and Characterization of Sand and Gravel Deposits in Njaba Area of Imo River Basin, Nigeria.

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***Abstract*: Excavation of sand and gravel occurs along Njaba River bank for Civil engineering purposes which occasionally results to landslides that lead to casualties. Hence, Geoelectrical and Geotechnical techniques were adopted for mapping and characterizing the sand and gravel deposits and at the same time assess the slopes stability. Ten vertical electrical soundings (VES) were carried out at different locations, using OHMEGA-500 resistivity meter. The field data were interpreted using Advanced Geosciences Incorporation (AGI) ID resistivity inversion software and Schlumberger Automatic analysis version. The model results revealed that the sand and gravel layers have high resistivity values ranging from 1359Ωm to 7353Ωm. The geologic information, the borehole data and VES model were integrated to map the sand and gravel bed. The thickness of the beds ranges from 15.70m to 67.60m. Four samples collected at different locations were tested and analyzed in laboratory to determine basic geotechnical parameters. Average values obtained were: moisture content (10.7%), bulk density (2.10g/cm^3) maximum Dry density (1.73g/cm^2), California Bearing Ratio (24%). The particle size distribution obtained revealed that the coarse sand, medium sand, fine sand are 3.7%, 34.52%, 61.26% respectively, implying that they are of good grade and in conformity with civil engineering requirements. The slopes instability in the study area is as a result of the low shear strength.**

***Key words*: Sand, Gravel, Geoelectrical, Geotechnical, Civil engineering**

I. INTRODUCTION

The knowledge of the rock deposits in an area is not adequate if the deposits are not properly characterized. Also the location and quantity of the deposit are important in other to harness their potentials. The rock deposits form the basis for civil engineering projects ranging from conceptualization to commissioning. The rock material have played significant role in foundation design, material selections and cost control. In design, consideration is made of the stability of earth surfaces, in terms of their compressibility and load bearing capacity. The nature of the soil determines it's suitability for use in construction work. Slopes and erosion sites sometimes have caused great disasters, constituting menace to the environment. Apart from soil or rock application in civil engineering construction such as roads, bridges, buildings and structural works in general, they have vast uses in economic activities like agriculture, pottery, extraction, manufacturing and mining. Thus, the maintenance and safety consideration of the soil is a source of concern.

In this study, the aim is to locate, quantify and characterize the sand and gravel beds in the study area, relevant to civil engineering construction and at the same time assess the stability of the slopes. To achieve this, vertical electrical sounding (VES) was carried out in selected areas to map the sand and gravel beds and samples were also collected from different locations within the excavation site and then taken to the laboratory for determination of the geotechnical parameters.

Statement of The Problem

Commercial excavation or mining of sand and gravel has been going on along Njaba River Bank for civil engineering projects and this has resulted in the beehive of activities that goes on in the study area. These excavation activities have resulted in ecological problems ranging from gully erosions as observed at Amucha and landslides that have often claimed lives of miners and some persons that visit the sites especially the one at Njaba along Owerri-Orlu road, to building collapse due to landslides. The slope instability has often been attributed to superstitious belief that a certain goddess is responsible for it.

Another problem is the road failures and collapse of buildings which occur in the State in recent years and which have been suspected to be caused by either poor construction work or poor quality of building materials of which sand and gravel are components.

Previous Work

Several works have been done on the application of geophysical and geotechnical methods to map and characterize soil materials. Reference [1] studied the geotechnical parameters of Niger Delta soils in Warri and surroundings, Delta State to study geotechnical index properties of soils. Reference [2] combined both geophysical and geotechnical techniques for foundation design of site proposed for vocational skill/entrepreneurship centre at

Ibadan Polytechnic, South-western Nigeria to evaluate the competence of various foundation materials at near surface formation. Reference [3] carried out integrated geophysical and geotechnical methods to evaluate the structural disposition of the foundation beds around the University of Port Harcourt and evaluated the suitability of the near surface materials for the foundation of the structures. Reference [4] investigated using geotechnical method the road failure in Abakaliki area, Southeastern Nigeria to assess the extent of the effect of Abakaliki Shale on the frequent road and highway failures in the area.

Location Of The Study Area

The study area is located in Njaba and Orlu Local Government Areas in Imo State of Nigeria on latitudes and longitudes 5°30′N to 5°50′N and 6°50′E to 7°5′E. (Fig. 1)

Fig. 1: Location of VES stations in the study area.

Geology Of The Study Area

The geological setting of Imo River Basin of which the study area is part of (Fig. 2) reveals the following stratigraphic units: The Benin Formation which underlies greater part of the study area extends from the coastal area towards the hinterland. It is overlain by lateritic overburden. The Ogwashi-Asaba Formation which underlies the Benin Formation is in turn underlain by the Ameki Formation of Eocene to Oligocene age [5]. The earth materials are mainly coarse grained, pebbly and poorly sorted, containing fine sands ([6], [7]). The Benin Formation is one of the three recognized subsurface earth layer units in the modern Niger Delta. The formation has a high potential for fresh water with a thick continental sand and gravel deposit in an upper delta environment. The zone was formerly meant to be a Coastal Plain Sands [8]. Due to the sandy components which form more than 90% of the sequence of the layers, the permeability, transmissivity and storage coefficient are high [9]. The formation starts as a thin edge at its contact with Ogwashi-Asaba Formation in the north of the area and thickens seawards [10].

The Ogwashi-Asaba Formation is composed of varying deposition of clays, sands and grits with lignite. This formation which underlies part of the study area is underlain by greenish - grey clayey sandstones, shales and mudstones with inter-bedded lime stones of Ameki Formations. This formation then lies over the less permeable lmo Shale group with characteristic lateral and vertical variations in lithology. Under it lays Nsukka Formation, Ajali Sandstones and Nkporo Shales in the order.

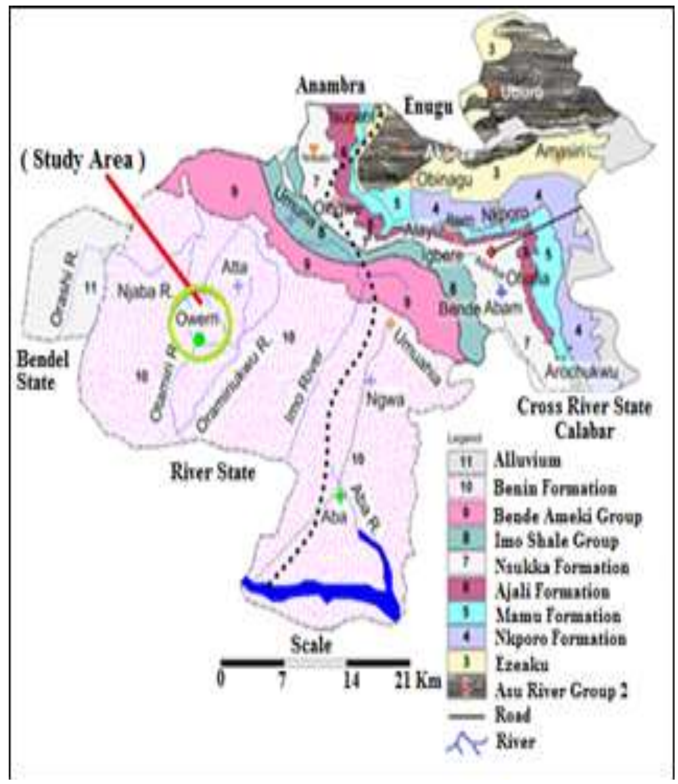

Fig. 2: The Geology Map of Imo River basin showing location of the study area (adapted from [11])

II. METHODOLOGY

Field Procedure: This study was carried out in two phases; the geoelctrical and geotechnical phases.

Geoelectrical Method: Ten vertical electrical soundings (VES) using the Schlumberger electrode configuration and Ohmega-500 resistivity meter were carried out in the study area. At each location, four electrodes consisting of two current electrodes A and B, and two potential electrodes M and N were placed along a straight line on the land surface such that the current electrode spacing AB is greater than or equals five times the potential electrode spacing MN. The values of the field resistance displayed on the resistivity meter were recorded against its corresponding electrode spacing. At each VES station, the Global Positioning System (GPS) was used to measure the coordinates and elevations.

After the initial manual computation to obtain the apparent resistivity, a computer based interpretation was done using the Advance Geosciences Incorporation (AGI) ID resistivity inversion software and Schlumberger Automatic Analysis Version.

Geotechnical Method: In the geotechnical phase, four samples of sand and gravel deposit were collected from four different locations within the excavation site and packaged in airtight sample bags to retain the moisture content and then transported to the laboratory for determination of the geotechnical parameters as follows:

Moisture Content Test: For each sample a dry crucible was accurately weighed and its weight recorded. Small quantity of the sample was placed in it, reweighed and then oven-dried completely for not less than 24 hours at temperature ranging from 105ºC to 110ºC. These oven-dried samples were thereafter weighed to determine the mass of both the container and dry sample.

The moisture content was calculated using equations 1.

$$M = \frac{\text{mass of water}}{\text{mass of solid soil}} \times 100\ \% \qquad 1$$

Bulk Density Test: Bulk density ρ_b which is also the wet density is the mass per unit volume of the deposit in addition to any moisture it contains. This parameter was determined in the laboratory following the standard procedure and obtained using equation 2

$$\rho b = \frac{w}{v} \qquad 2$$

where, *w* is the weight of sample and *v* is the volume

Particles Size Analysis (Sieve Analysis): For each of the samples, a reasonable quantity was poured into the crucible and placed in the oven to dry at a given temperature of 105ºC for one day in order to eliminate the moisture contained in the sample. The weight of sample before commencing sieving was determined using a weighing balance and sieving conducted on the samples following standard procedure.

Compaction Test: This was carried out using standard procedure on each of the four samples, to obtain the Optimum Moisture Content (OMC) and Maximum Dry Density (MDD). Typical compaction curve obtained from which OMC and MDD were derived is shown in Fig 13.

California Bearing Ratio (Cbr) Test: CBR tests were carried out on the compacted samples in a soaked condition, in accordance with the procedure of [12]. However, the samples were soaked in a water-filled bathtub overnight as recommended by [13]. The California Bearing Ratio (CBR) machine was used in the experiment to determine the bearing capacity of the sample.

Direct Shear Box Test: This was also carried out on the four samples following standard procedure including [14] method. The shear strength of the sample material is defined as the point with the greater horizontal stress recorded. For every test, the horizontal shear stress is plotted against the shear displacement. Depending on the sample density, a different behaviour in terms of shear strength-shear strain is presented. Dense sand or over-compacted clay samples tend to give a maximum shear stress that subsequently drops reaching a fixed value known as residual strength.

III. RESULTS AND DISCUSSION

Typical model VES results are shown in Fig. 3 to Fig. 6 with corresponding analytical results displayed in Tables 1 to 4. Generally, the study area is underlain by multi-geoelectric layers with the sand and gravel layers having high resistivity values at each VES station. The average resistivity of sand and gravel beds ranges from 4178 Ωm to 12865 Ωm. The summary of the modelled result is shown in Table 5. The borehole data (Table 6) and the borehole lithologic log (Fig. 7) were used to design the lithology cross section of the area (Fig. 8), and as well used to assign the lithologic units on the analytical results.

Table 1: Amandugba Njaba VES Analytical Result

LAYER	DEPTH (m)	RESISTIVITY	LITHOLOGY	COLOR
1	0.40	770.0	Topsoil	Mixed Blue
2	5.09	4178	Silty-Sand	Orange
3	10.2	1812	Sand	Blue
4	16.6	2629	Shale	Green
5	21.3	12865	Sand/Gravel bed**	Yellow
6	47.7	115492	Shale-Lignite/Sandstone	Red
7	84.2	53077	Shale-Sandstone	Red
8	192	760	Sand (Prospective horizon)	Blue

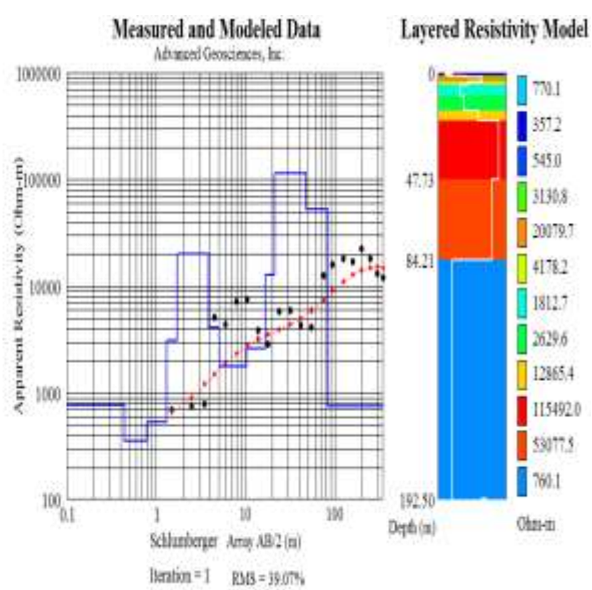

Fig 3: VES Model of Amandugba Njaba

Table 2: Mgbee VES analytical result

LAYER	DEPTH (m)	RESISTIVITY (Ohm-m)	LITHOLOGY	COLOR
1	3.195	7531.8	Topsoil	Red
2	8.7	934.8	Sand	Green
3	11.56	4754.7	Sand	Yellow
4	22.7	9816.6	Sand Gravel	Red
5	42.91	6258.3	Siltstone	Orange
6	57.45	2361.2	Sand	Green
7		37.5	Sand	Blue

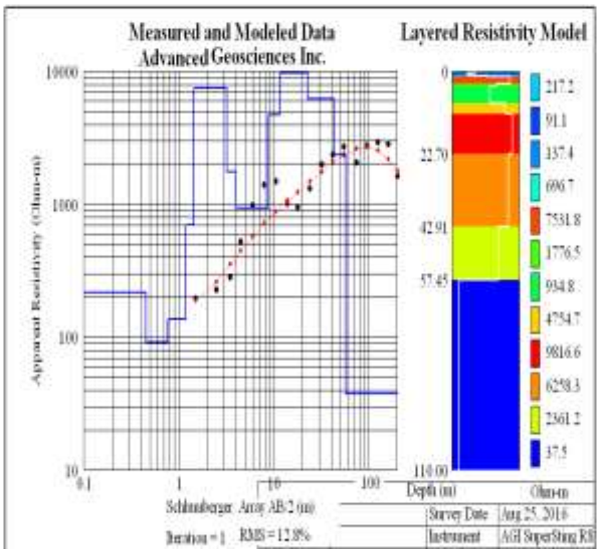

Figure 4: VES Model of Mgbee

Table 3: Umuaka-Njaba VES Analytical Result

LAYER	DEPTH (m)	RESISTIVITY (Ohm-m)	LITHOLOGY	COLOR
1	0.60	291.5	Topsoil	Blue
2	2.14	161.7	Silty-Sand	Light Blue
3	6.4	1111	Mixed sand	Orange
4	10.521	8925	Sand/Gravel bed	Red
5	18.1	214	Sand	Blue
6	23.6	1090	Clay-Shale	Green
7	41.44	6960	Sandstone	Off-Red
8	95.34	3702	Siltstone	Red-Brown
9	192.50	9.7	Sand (Prospective	Blue

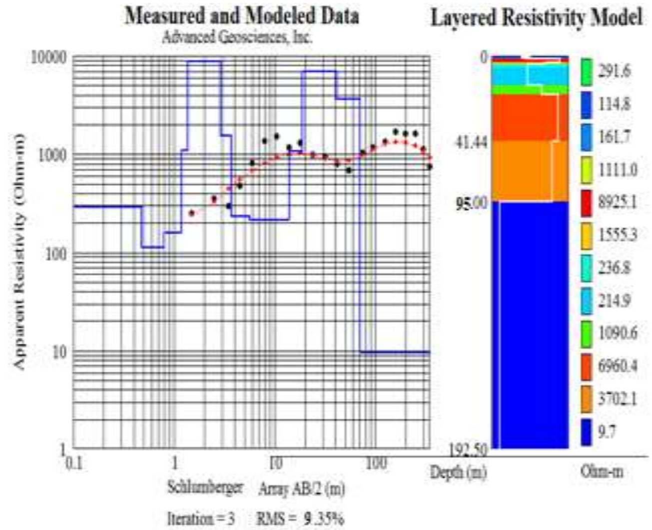

Figure 5: VES Model of Umuaka-Njaba

Table 4: Njaba River Bank Excavation Site VES Analytical Result				
Layer	Ohm-m	Thickness (m)	Bottom Depth (m)	Lithology
1	2534.77	0.014	0.592	Topsoil
2	74.57	2.969	6.091	Sandy clay
3	4312.83	1.210	17.300	Sand Gravel
4	2581.89	21.772	39.072	Siltstone
5	951.88	13.379	52.451	Mixed sand
6	0.03	Prospective Aquifer unit		

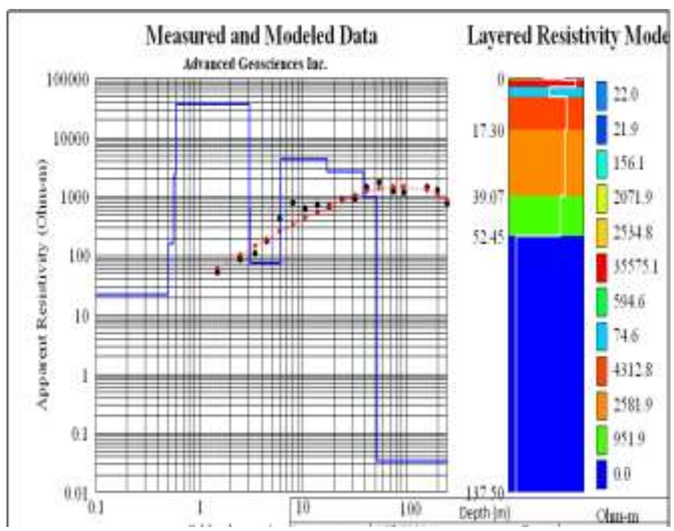

Fig 6: VES Model of Njaba River Bank Excavation Site.

Table 5: Summary of the Modelled VES Results for the Study Area

VES NO	Location	Elevation	Latitude (^{0}N)	Longitude (^{0}E)	Average Resistivity of Sand/Gravel bed (Ωm)	Depth to Sand/ Gravel bed (m)	Thickness of Sand/ Gravel bed (m)	Water Table (m)
1	Amandugba	154m	5.6710	7.0710	4178 – 12865	5.09	41.62	84.21
2	Amucha erosion site	100m	5.7270	7.0589		0.80	67.60	32.33
3	Mgbee	59m	5.8003	7.6432		3.20	39.79	32.24
4	Njaba River Bank excavation site	48m	5.7304	7.0605		6.09	32.98	52.24
5	Umuaka Njaba	136m	5.6603	7.0102		2. 14	15.86	95.00
6	Njaba 3	134m	5.6510	7.6265		1.24	19.63	36.21
7	UBA Umuaka	136m	5.8003	7.6432		4.97	59.03	64.37
8	Ugwu Mgbee	164m	5.7464	7.6451		3.40	33.60	57.45
9	Ubakala Njaba	141m	5.7746	2.0079		1.80	15.70	74.56
10	UmuduruibeAmakor	137m		5.6749		3.42	17.30	31.00

Table 6: Existing Borehole/Pumping Test Data in the Study Area (Source: [15])

VES No.	Location	DD (m)	Casing Diameter (m)	Screen Diameter (m)	Casing Depth (m)	Screen Length (m)	Static Water Level (m)	Well Discharged or Yield (m^3/day)	Draw down (m)
1	Amandugba BH	1095	0.300	0.20	90.00	12.00	51.00	3633	22.30
2	Njaba BH	1200	0.313	0.20	93.00	18.00	60.00	3270	18.60
3	Mgbee BH	1200	0.338	0.20	123.00	21.00	64.50	3815	15.00

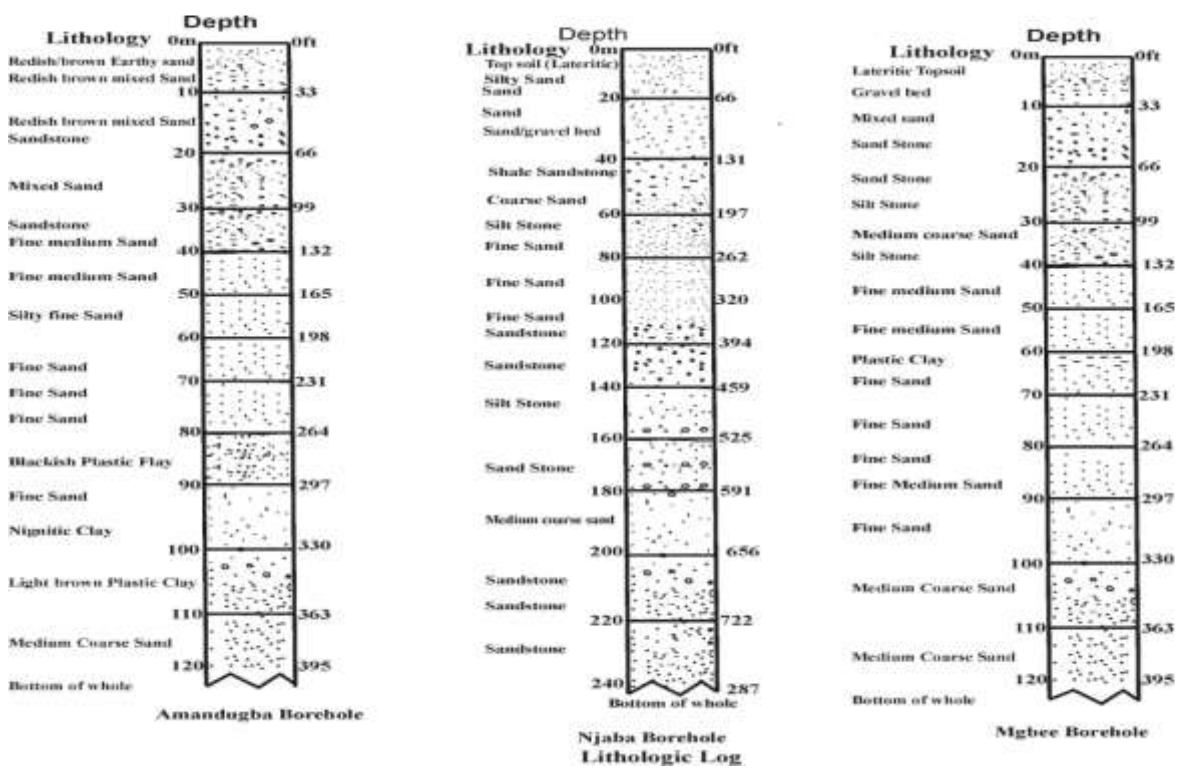

Fig. 7: Borehole Lithology of the Study area

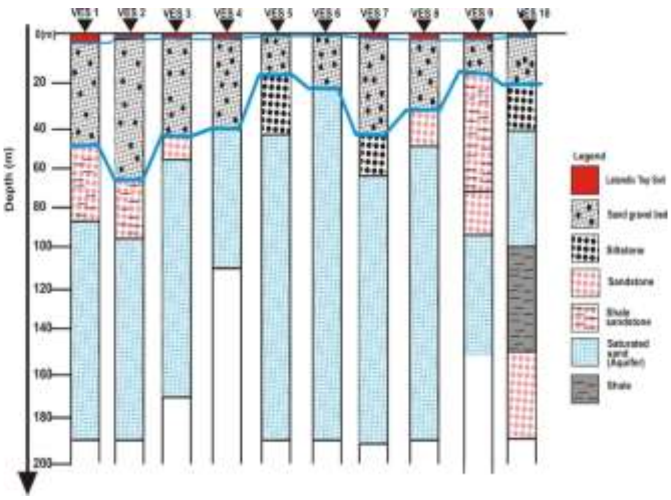

Fig. 8: The Lithologic cross section of the Study area showing Sand and Gravel beds

The results obtained were further explained using digital maps. The Average resistivity of sand and gravel bed in the study is fairly high (Fig 9).

The variation in depth to sand and gravel bed in the study area (Fig 10) revealed that Amandugba (VES 1) has the highest value of 5.09m while Amucha (VES 2) has the least depth of (0.8m). This could be responsible for the gully erosion that occurs there. Other shallow beds were identified at some communities at VES 5, 6 and 9. The sand and gravel beds are thick enough at VES 1, VES2, VES3, VES4, VES6, VES7 and VES8 (Fig. 8 and 11). This can therefore encourage commercial excavations or mining in some of these locations.

Commercial mining can therefore be sited in some of these communities as alternatives to reduce ecological hazards. These communities include Amandugba, UBA Umuaka, Mgbee and Ugwu Mgbee. The mapped sand and gravel beds agreed with the result obtained in a previous study of the area [16].

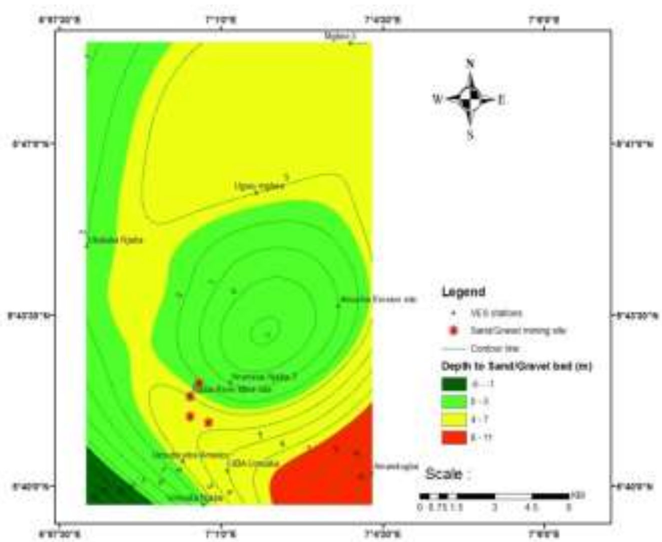

Fig 9: Resistivity Sand/ Gravel Bed Map

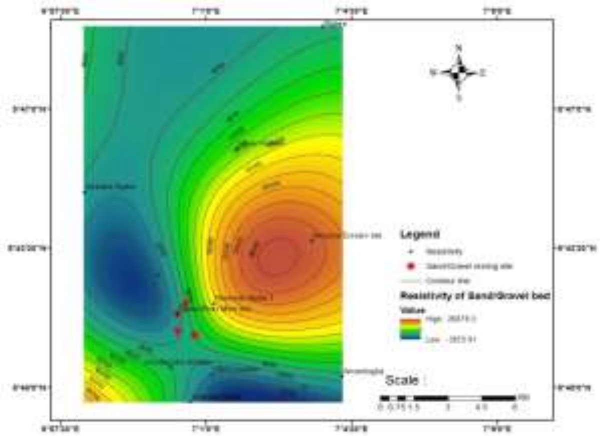

Fig 10: Depth to Sand / Gravel Bed Map

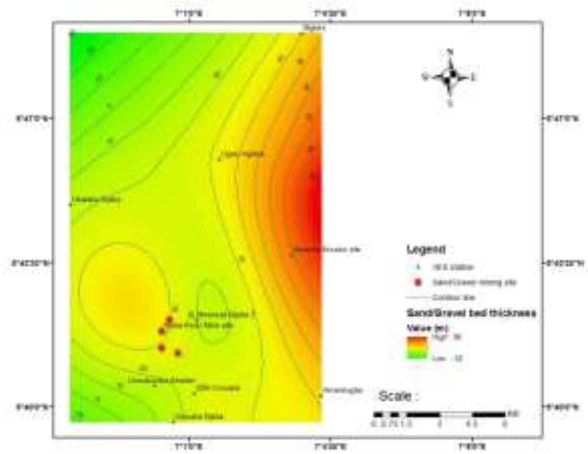

Fig 11: Thickness of Sand / Gravel Bed Map

The summary of the laboratory tests carried out according to British Standard Code of practice (BS1377:1990) method of testing soils for civil engineering purposes is shown in Table 7.

The moisture content ranges from 9% to 12.1% with an average value of 10.7%. This value could be due to the absence of clay minerals that hold water. The percentage of water present in any earth material would determine the strength of the material. The low value of moisture content in the sample indicates that the sample would hardly undergo expansion and would exhibit little or no shrinkage when moisture is removed from its pore spaces [1].

The bulk density is 2.0g/cm^3 which include the solid particle, the void and water. According to the USDA specification (1951), the sample can be classified as silt and sand material.

The grain size analysis was carried out for the grading of the sample. Using the [17], the analysis reveals a well graded sample soil of 3.7% coarse sand, 34.5% medium sand and 61.26% of fines. The particle size distribution curves (Fig. 12) represent the distribution of particles of different sizes in the four samples mass. The distribution of the different grain size influences the suitability of the earth material for road construction.

The results obtained from compaction test (Fig. 13) reveal Maximum Dry Density (MDD) value of 1.74g/cm^{3,} 1.73g/cm^3,1.71g/cm^{3}with and 1.73g/cm^3 at Optimum Moisture Content (OMC) of 8.0%, 10.5, 8% and 10%. According to [18] and Federal Ministry of Works and Housing specification for building of Roads and Bridges, the value should be between 1.75 and 2.165mgm. Hence, based on the AASHTO soil classification under A-2po8 [19], the material is good to be used as pavement material. Also the Nigerians specification for Road and Bridge Materials (Nigeria Federal Ministry of Works and Housing, 1994) recommends that for a material to be used generally as fills, it should possess MDD greater than 0.004 mg/m and OMC less than 18%.

For California Bearing Ratio (CBR), the soaked CBR values of the samples are 19%, 12%, 24% and 22% as deduced from the CBR graph in Fig. 14, which has the highest moisture content of 10.5% out of the four CBR tests carried out. This is in accordance with the BS1377 (1990) specification. Reference [20] recommended soaked CBR for sub-grade and sub-base material not less than 5% and less than 30%. According to specification of [21] as shown in Table 4.19, the results show that the material is suitable for sub-grade and sub-base course which are materials for road construction. The direct shear box test was done at least three times for each sample at different normal stresses. The maximum shear stresses derived at each experiment was plotted against the normal stresses and the best line of fitness determined the optimum Mohr-Coulomb Failure Envelope. The cohesion and friction angles were derived in Fig. 15. The cohesion and friction angle where deduced as in the range 26KN/m^2 to 30KN/m^2 and 0^0 respectively. The cohesion is very low and the materials are loosely bound and can amount to a high instability [1]. This could be responsible for landslides experienced at some slopes or gullies within the study area. Table 7 shows the summary of the geotechnical results as compared to other standards.

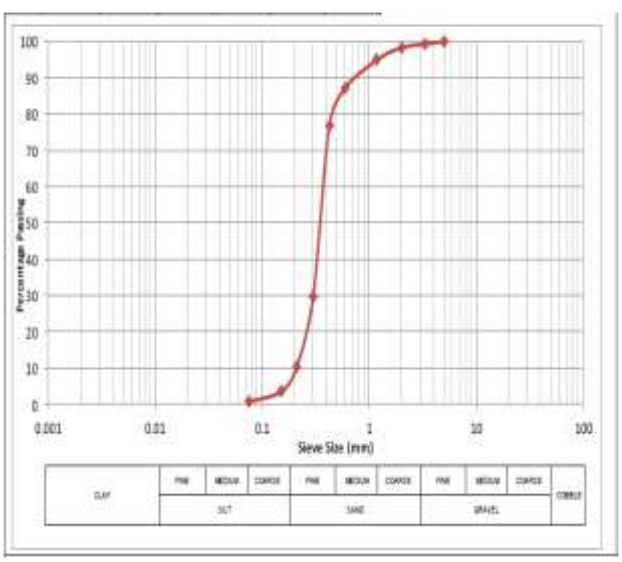

Fig 12: Graph of Particle Size Analysis of Sample 1

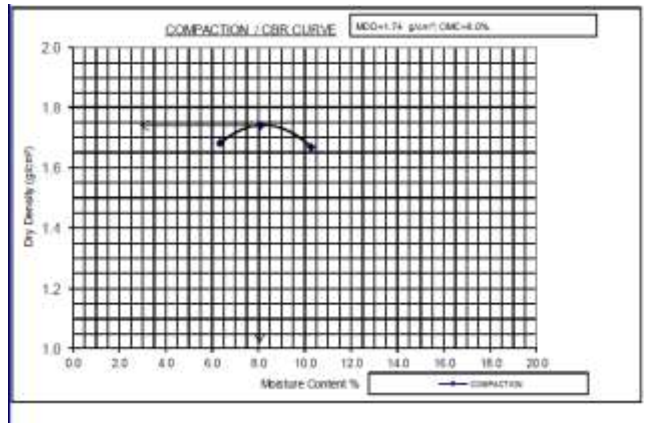

Fig 13: Graph of dry density against moisture content for sample 1

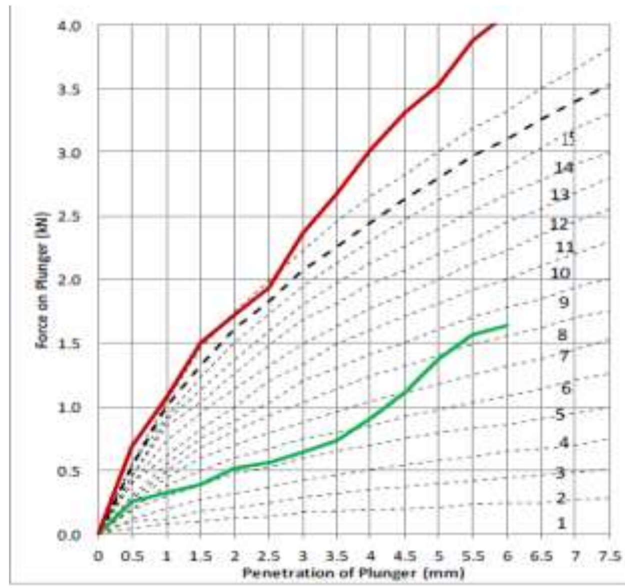

Fig 14: Graph of CBR of 8% moisture content (sample 1)

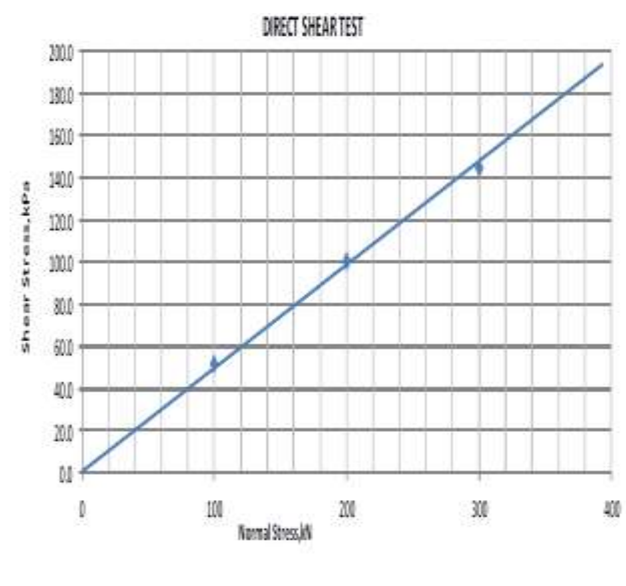

Fig 15: Mohr-Coulomb failure envelope for sample 1

Table 7: Summary of Geotechnical Results Compared with Other Standards

S/N	Geotechnical property	Quality Sample 1	Quality Sample 2	Quality Sample 3	Quality Sample 4	Quality (Average)	Classification standard compared with	Description/qualifying
1	Moisture Content	12.10%	10.0%	90%	11.6%	10.7%	(Oghonyon et al., 2015)	Negligible expansion and plastic
2	Bulk density	2.14g/cm^3	2.12 g/cm^3			2.10g/cm^3	USDA	Presence of sand
3	Particle Size Distribution	Coarse Sand=1.73% Medium Sand=21.5% Fines=76.63%	Coarse Sand=4.94% Medium Sand=39.5% Fines=54.34%	Coarse Sand=6.8% Medium Sand=584% Fines=34.8%	Coarse Sand=1.43% Medium Sand=18.61% Fines=76.27%	3.7% 34.5% 61.26%	Unified Soil Classification (USC)	Well graded soil (SW)
4	Compaction						AASHTO	Presence of Sand
	Maximum Dry Density (MDD)	1.74 g/cm^3	1.73 g/cm^3	1.71 g/cm^3	1.73 g/cm^3	1.73g/ m^3		
	Optimum Moisture Content (OMC)	8.0%	10.5%	8.0%	10%	9.1%		
5	California Bearing Ratio	19%	12%	24%	22%	24%	Federal Ministry (1994)	Good for sub-grade and sub-base materials
6	Direct Shear Strength	27 KN/m^2	27 KN/m^2	30 KN/m^2	26 KN/m^2	27.5	(Oghonyon et al., 2015)	Presence of Sand

IV. SUMMARY AND CONCLUSION

The mapping and characterization of sand and gravel deposits in the study area were carried out using geophysical and geotechnical methods. The results were able to identify potential sites for sand and gravel excavation for building roads and other engineering structural constructions. The sites are located at Amandugba, Amucha, Mgbee, Njaba River Bank, Nnenasa Njaba 3, Uba Umuaka and Ugwu Mgbee. The result of the study also showed that the sand and gravel are recommended for civil engineering works.

V. RECOMMENDATIONS

1. Since the shear strength of the sand and gravel sample is low, it is advised that structures should not be built at proximal distances from any gully as the formation has high porosity and permeability and naturally flow with sea page or undergo solifluction.
2. Ecologically, the existing mining sites can be relocated to areas where there is less population.
3. The slope in the area should be protected with vegetation covers, pitch stones or concrete in order to curb the menace of gully erosion as the formation is highly susceptible to erosion.

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