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Assessment of Hydrogeophysical and Geotechnical Properties in Central Part of Anambra State, Nigeria

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Abstract

Both electrical resistivity and geotechnical investigations have been carried out in central parts of Anambra State in order to determine the depth to the subsurface water and the geotechnical properties of soil. Vertical electrical sounding (VES) curves were obtained across the area using the Schlumberger configuration. The data was interpreted using the conventional curve matching and computer iteration method. Tests were carried out on soil samples which include Particle Size Distribution Analysis and Atterberg Limits tests. The geo-electric results revealed eight different curve types namely; K, H, QH, HK, KH, QK, KQ and KHK-curve types. 54% of all the sounding curves belong to HK and H-types whereas the remaining 46% belongs to other six curve types within the study area. The results also revealed that depths to the water saturated sandstones (aquifer) within the study area range from 67.83m at Toll-Gate Onitsha to 225.03m at UNIZIK Science Village Awka with an average resistivity of 1205.12 Ohm-m. The water table map indicates multi flow direction and correlates favourably with the topography of the area. It was observed that the hydraulic conductivity obtained ranges from 2.84×10^{-3} to 3.37×10^{-1} m/day while the transmissivity ranges from 0.091 to 1.039m²/day within the study area. The result of sieve analysis reveals medium to coarse grained sand of 85% (by weight) of the soils, while the remaining 14% and 1% are fine grained sand and coarse silt. The Atterberg Limit Tests of the samples collected shows 63.45% liquid limit (LL), 19.13% plastic limit (PL), and 44.33% plasticity index (PI) indicates that the soil samples have good intergranular cohesive force. Based on the hydrogeophysical and geotechnical results, the aquifers are capable of yielding enough water that would serve the immediate environs as well as the soil nature encouraging soil erodibility.

1. Introduction

Potable water is the water which is usable for drinking and sanitary purposes. The availability to potable water is an essential matter all over the world and Anambra State is no exception. Groundwater constitutes the only reliable water supply for drinking and

irrigation purposes. It is exceptionally important as a source of relatively low-cost and high-quality municipal and domestic water supply in urban centers of the developing world [1, 2]. Nevertheless, current researches have shown that special care and skill are needed for its exploration and exploitation.

Consequently, electrical resistivity method which is one of the geophysical methods can now contribute substantially towards this initiative and can greatly reduce the number of necessary pumping tests, which are both, expensive and time consuming. The subsurface information inferred from this survey give a better knowledge of the aquifer systems and a more realistic picture of groundwater potential of any area [2, 3]. This method has been successfully used in investigating groundwater potential in different geological settings including sedimentary environment [4].

However, the geotechnical properties of lateritic soils are influenced by climate, drainage, geology, the nature of the parent rock and the degree of weathering or linearization of the parent rock. These factors also differentiate laterite from other soils that are developed in the temperate or cold regions [5]. Lateritic soils contribute to the general economy of the tropical and subtropical regions where they are in abundance because, they are widely utilized in civil engineering works as construction materials for roads, houses, landfill for foundations, embankment dams, etc. Lateritic soils are economically convenient in road construction, such that they are cheaper than other materials that can achieve comparable strength with them and they are more available than those materials. In Anambra State, laterite is a major road construction material that is used for the sub-grade and, occasionally, the sub-base and base courses of the roads.

This research describes the geo-electric investigation of groundwater potential and geotechnical properties of lateritic soil undertaken in Central parts of Anambra State. The primary objective of this investigation is to obtain from the geophysical characteristics of the study area, a meaningful delineation of the aquiferous units of the area as well as obtain adequate information on geotechnical properties of the lateritic soils of the area.

2. Geology of the Area

The study area falls within Anambra State, Nigeria and it is located between latitude $06^{\circ}00' N$ to $06^{\circ}55' N$ and longitude $006^{\circ}07' E$ to $007^{\circ}11' E$ (Fig. 1). The formations encountered in the study area were deposited in the Anambra Basin as a result of marine transgression that occurred during the Campanian-Maestrichtian sub-stages of second sedimentary cycle [2, 3, 6]. The formations that outcropped in the study area are Ameki Group (precisely Nanka Sands), Imo Shale and Ogwashi-Asaba Formation (Fig. 2).

Nanka Sands (Eocene) forms the dominant geologic formation in the study area. The Nanka Sands is approximately 305m at its type locality [1, 2, 6, 7]. It is a lateral equivalent of Ameki Formation. The Nanka Sands consist of fine to coarse grained sands with abundant intercalations of calcareous shale and thin shaly limestone below, and of loose cross-bedded white or yellow sands, with bands of fine-grained sands and sandy clay above [1, 3]. The sand member of the formation constitutes the aquifer system.

Afterwards, Nnaka Sands is underlain by thick Imo Shale (Paleocene), which is characterized by thick clayey shale with occasional admixture of clay ironstone and thin sandstone bands [1, 3]. The formation is fine textured and dark grey to bluish grey in colour. Its major lithology is the Shale which is impermeable to water and also is generally described as an aquitard however; the sand member of the formation constitutes the aquifer system.

The Ogwashi-Asaba Formation was deposited on top of the Ameki Formation in the Oligocene-Miocene. The Ogwashi-Asaba Formation is composed of alternating bands of sandstone and shale [8]. The sandstone unit exhibits colours that range from yellow, whitish, red, to reddish brown. It is also mainly ferruginized and indurated, although sometimes friable. The base of the sandstone consists of poorly sorted pebbly to very coarse grained sandy particles with mixture of some fine sand [9].

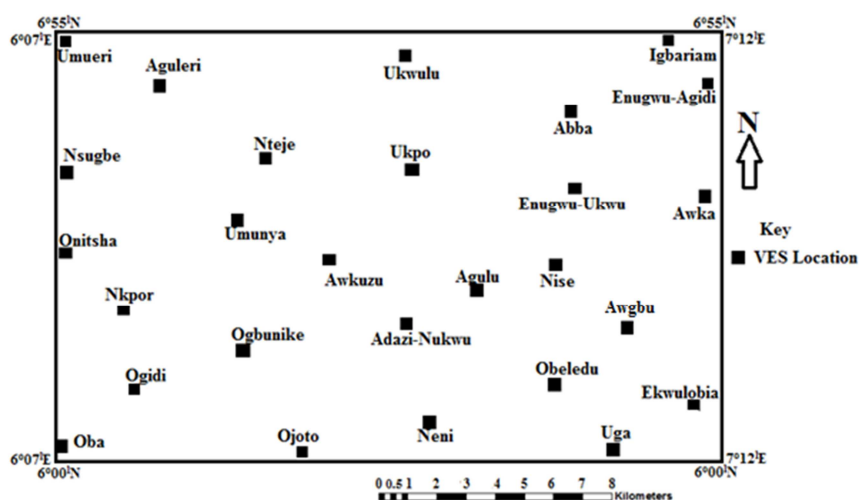


Fig. 1. Map of the study area showing towns and VES locations.

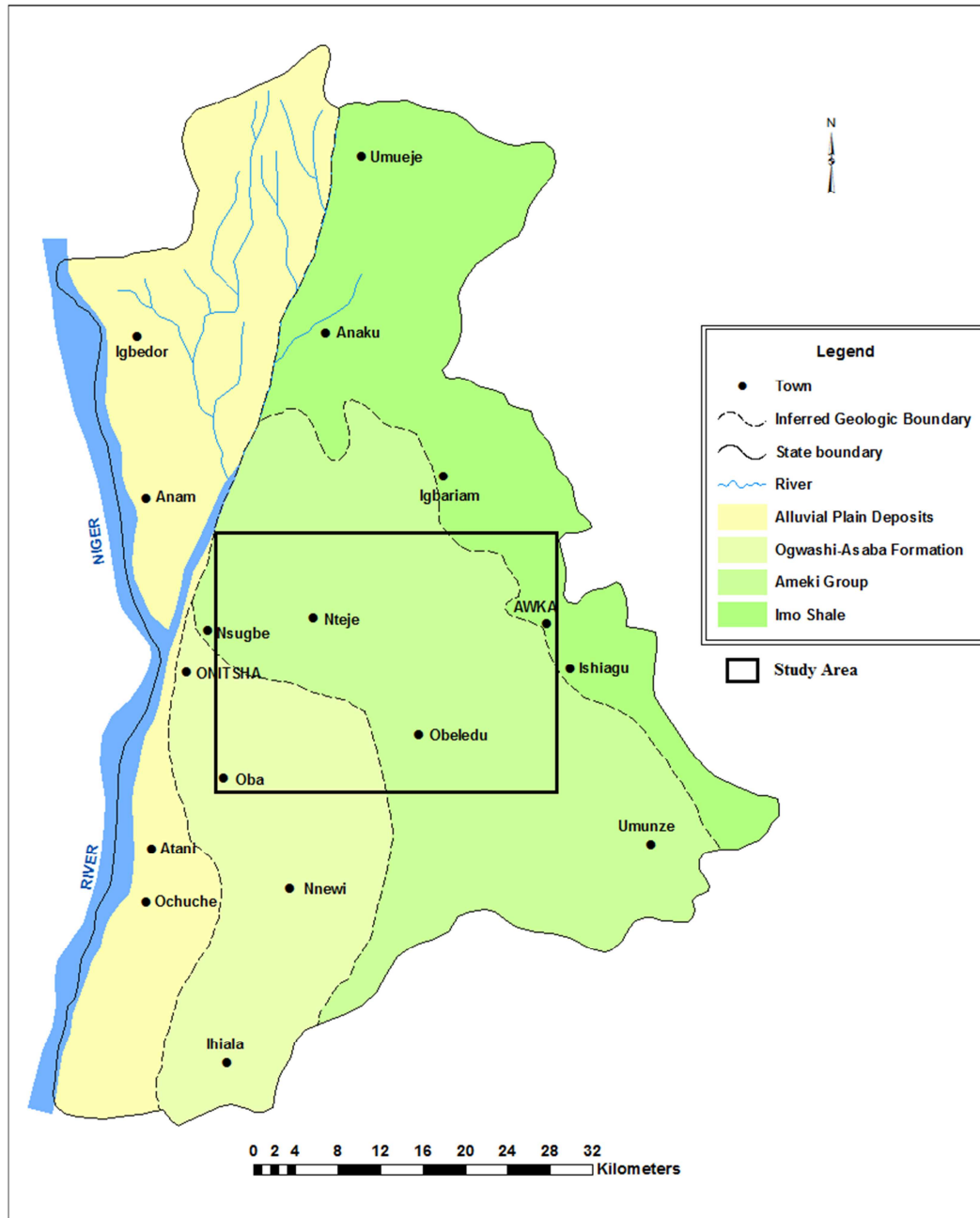


Fig. 2. Geologic map of Anambra State showing the study area.

3. Methodology

The vertical resistivity sounding (VES) was carried out at thirty VES locations within the study area (Fig. 2) using ABEM Terrameter SAS 1000 model for groundwater investigation purposes. During the vertical resistivity sounding (VES), electrodes are distributed along a line, centered about a midpoint that is considered the location of the sounding. The Schlumberger electrode configuration having a maximum current electrode spread of 300 m was used. For a Schlumberger survey, the two current electrodes A and B and the two potential electrodes M and N are still, placed in line with one another and centre on some location, but the potential and current electrodes are not placed

equidistant from one another. To acquire the resistivity data in the field, current is introduced into the ground through current electrodes and the potential electrodes are then used to quantitatively measure the voltage pattern on the surface resulting from the current flow pattern of the first set of electrodes. The geometry scheme for this array is shown in Fig. 3. The apparent resistivity values obtained from the measurement were plotted against half the current electrode spacing on a bi-logarithmic graph in order to determine the apparent resistivities and thicknesses of various layers penetrated. This technique has been utilized in groundwater exploration by various researchers [such as, 1, 2, 3, 4, 7, 8, 10, 11, 12, 13, 14]. The resistivity curves were interpreted quantitatively by matching small segments of the field curves

using two-layer model curves and the corresponding auxiliary curves. The resistivity data were interpreted manually using partial curve matching method as well as using IXID that was developed by Interpex Limited [15].

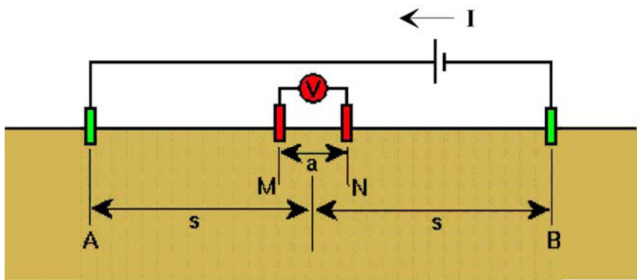


Fig. 3. Schlumberger array.

Meanwhile, six soil samples were obtained from borrow pits in Awka, Igariam and Enugwu-Agidi respectively. The choice of these sites and soil is justified by the fact that it is a borrow pit from where various construction companies get

their material for road construction in Anambra state. The natural moisture content was determined by the oven drying method. Specific gravity of soils, particle size distribution, plasticity characteristics were determined in accordance with procedures outlined in BS 1377 (1990) [16].

4. Results and Discussion

4.1. Qualitative Interpretation of VES Curves

Thirty geo-electrical sounding curves obtained from the study area (Fig. 4) were interpreted qualitatively. The result revealed four to seven geo-electrical layers. Eight different curve types namely; K, H, QH, HK, KH, QK, KQ and KHK-curve types were revealed [2, 3, 14, 17]. 54% of all the sounding curves obtained within the study area belong to HK and H-types whereas the remaining 46% belongs to other six curve types within the study area ((Fig. 5 and Table 1).

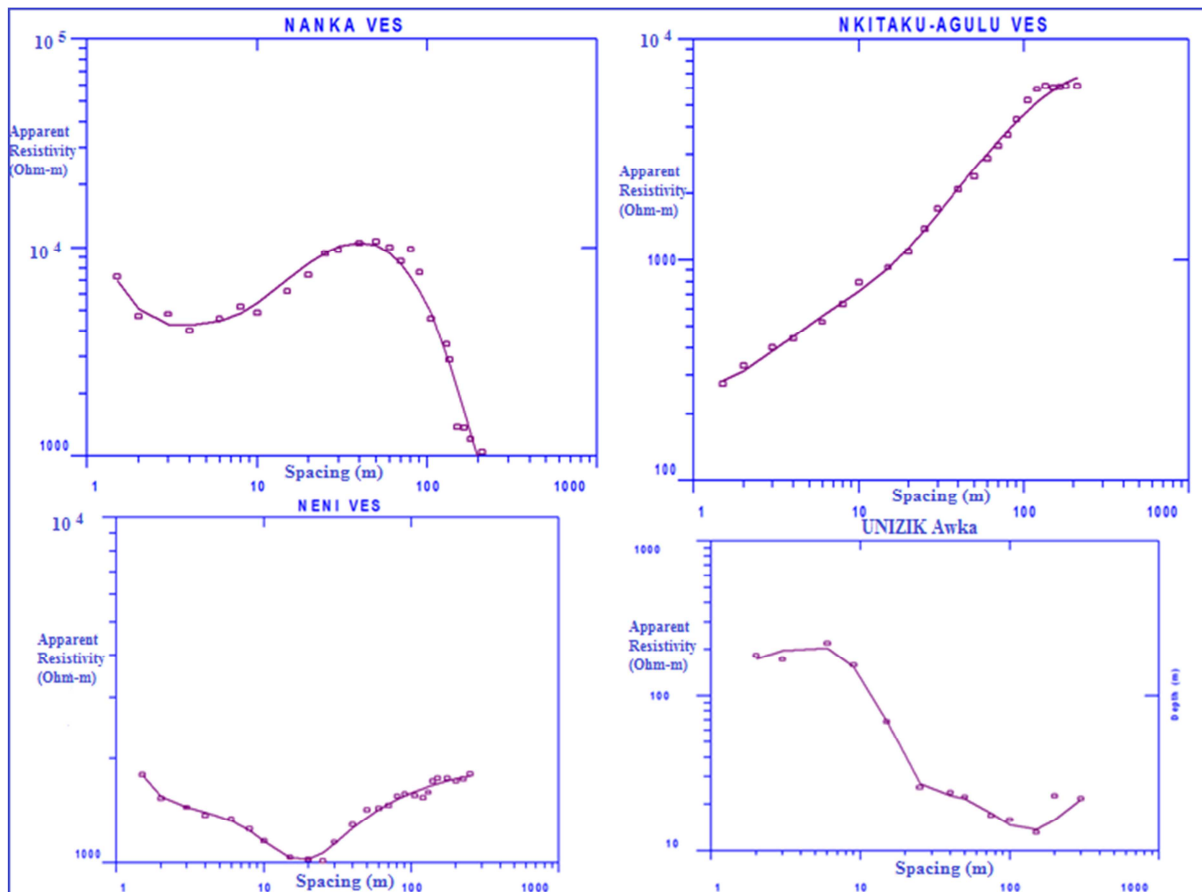


Fig. 4. Representative geo-electric curves within the study area.

4.2. Quantitative Interpretation of VES

Depth to Aquifer

Four to seven geo-electrical units with their corresponding thicknesses and resistivities were interpreted in the area (Fig. 4 and Table 1). The units from top to bottom include the top soil, shally-sandstone, sandstone, shale, sandstone, water

saturated sandstone (second aquifer) and shale. The results also revealed that depths to the water saturated sandstones (aquifer) within the study area range from 67.83m at Toll-Gate Onitsha to 225.03m at UNIZIK Science Village Awka with an average resistivity of 1205.12 Ohm-m (Table 1). The water table map also indicates multi flow direction and correlates favourably with the topography of the area.

Table 1. Summary of VES Interpretation with respect to Aquifer.

S/N	VES Location	No. of layer	Curve Type	Aquifer thickness (m)	Depth to Aquifer (m)	Aquifer Resistivity (m)	Hydraulic Conductivity (m/day)	Transmissivity (m ² /day)
1	Ifite-Awka	4	KHK	46.04	204.08	896.66	0.02677	1.02323
2	Unizik Awka	6	QK	31.26	225.03	26.04	0.32166	1.03911
3	Temp. Site Awka	5	K	46.29	31.65	1186.22	0.02023	0.93654
4	Amaenyi Awka	5	H	36.08	89.01	1209.15	0.01985	0.71615
5	Nkwelle Awka	6	H	21.58	86.4	1069.15	0.00284	0.48443
6	Ngozika Housing Estate Awka	6	HK	37.01	70.08	407.18	0.05894	1.01814
7	Ichie Ajator Site Agu-Oye	5	KH	21.18	86.92	2810.09	0.00854	0.1809
8	Ifite-Nibo	5	QH	25.07	69.03	3259.33	0.00736	0.18459
9	Prisons Amawbia	5	KQ	21.18	70.46	4072.11	0.00589	0.12483
10	Nise Micro Fiance	6	HK	36.24	73.18	769.84	0.03117	1.01298
11	Agwu Square	4	H	40.11	98.43	2051.04	0.0117	0.46933
12	Nkwo Agulu	5	K	37.65	128.77	8014.03	0.00299	0.11276
13	Nanka Market	6	HK	32.99	130.06	4723.07	0.00508	0.16762
14	Ekwulobia	7	QH	27.55	154.78	6211.02	0.00386	0.10645
15	Umuoru Uga	6	HK	31.02	173.05	5297.35	0.00453	0.14055
16	Oba-Nnewi Road	4	KH	28.06	125.21	7308.52	0.00328	0.09115
17	Nkpor	5	HK	28.02	101.42	4950.26	0.00641	0.13584
18	Ojoto	5	QH	26.12	76.68	4950.26	0.00484	0.12663
19	Ogbunike Old Road	5	HK	33.74	91.03	4950.26	0.00522	0.16357
20	Toll gate Onitsha	6	HK	30.11	67.83	4149.33	0.00578	0.17416
21	Umunya Market	4	HK	41.08	75.11	2611.03	0.00919	0.37761
22	Nkwo Market Igbariam	5	KH	29.91	86.52	1637.44	0.01465	0.43839
23	NTA Enugwu-Agidi	6	QH	35.03	78.99	2119.07	0.01132	0.39675
24	Ezi-Alias Enugwu-Ukwu	5	K	24.95	80.22	1183.22	0.07284	0.50609
25	FBN Abagana	6	HK	29.03	77.25	1942.51	0.01235	0.35867
26	Neni Town	4	QH	37.73	68.07	3107.05	0.00772	0.29143
27	Ununachi Road	5	HK	24.77	89.05	2226.01	0.01078	0.26707
28	Afor Igwe Umudioka	5	HK	26.05	90.76	3092.44	0.00776	0.20217
29	Nawfia market	5	HK	30.11	88.27	4108.42	0.00584	0.1759
30	Aguleri	6	HK	28.04	92.11	5022.93	0.00477	0.13398

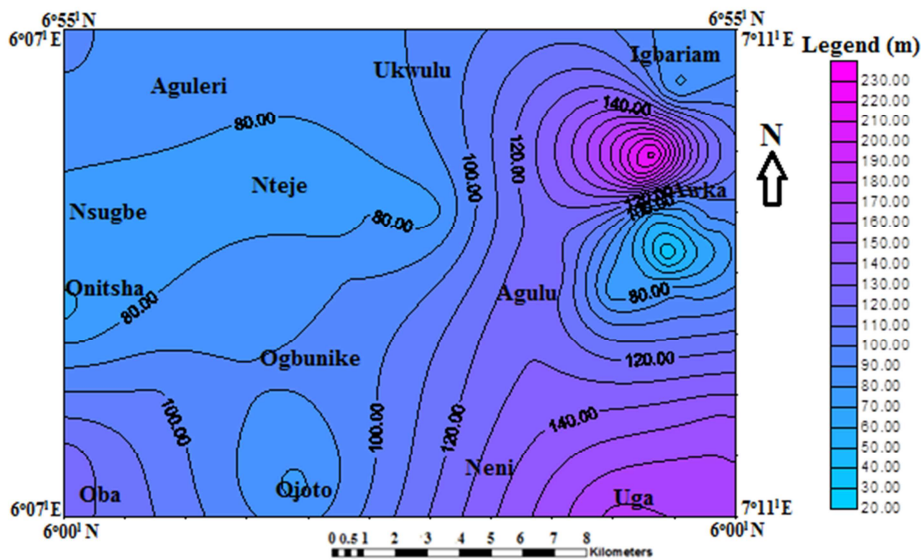


Fig. 5. Aquifer Depth map in the study area (Contour Interval~10m).

4.3. Aquifer Thickness Map

The aquifer thickness map was produced using various aquifer thickness obtained within the study area (Fig. 6 and Table 1). The thickness map reveals high aquifer thickness in the northeastern part than the other parts. The distribution of aquifer thickness values at contour interval of 1m indicates

that two distinct zones can be identified within the area. The whitish colour which occurs at the northeastern parts of the map reveals the existence of relatively high thickness of the aquiferous unit (36 to 44m), while the brownish colour at other parts corresponds to relatively moderate thickness of the saturated unit (20 to 36m). The area is generally characterized by a thick and prolific aquiferous unit.

4.4. Aquifer Characteristics

The result of aquifer characteristics revealed that the hydraulic conductivity obtained ranges from 2.84×10^{-3} to 3.37×10^{-1} m/day while the transmissivity ranges from 0.091

to $1.039\text{m}^2/\text{day}$ within the study area (Table 1). The transmissivity distribution map (Fig. 7) shows high transmissivity values in the northeastern part than in the other parts of the study area.

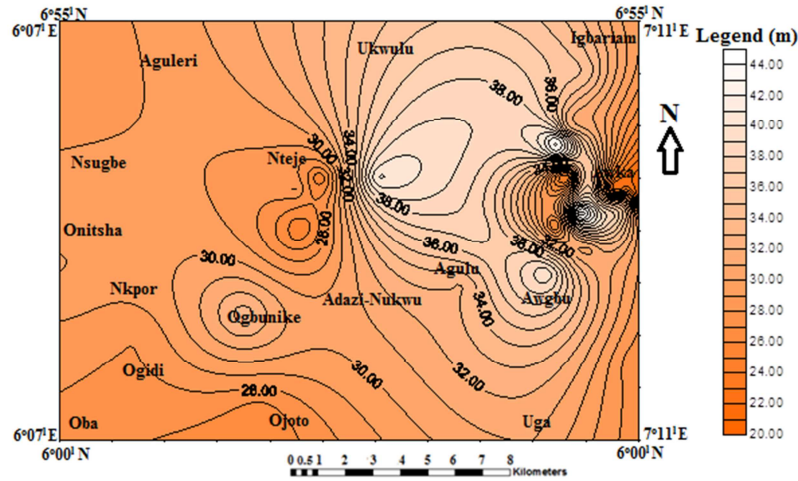


Fig. 6. Aquifer thickness map in the study area (Contour Interval-1m).

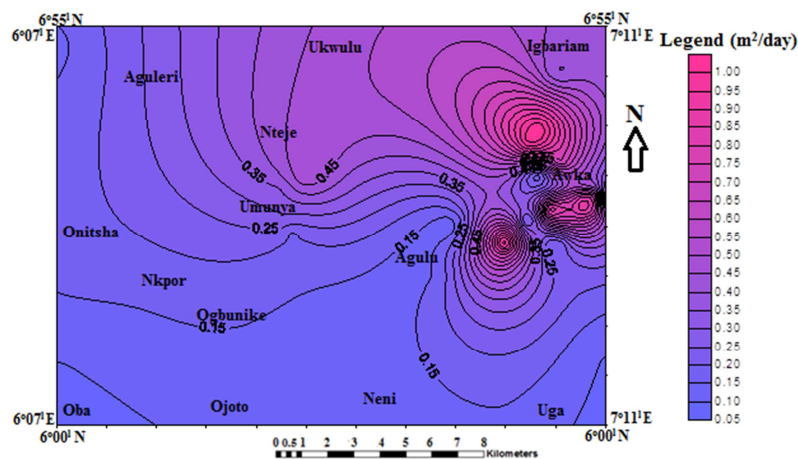


Fig. 7. Transmissivity map of the study area (Contour Interval-0.05m²/day).

4.5. Geotechnical Results and Analysis

4.5.1. Grain Size Analysis

The grain size distribution analysis was carried out (using mechanical shaker) on six soil samples. The result of sieve analysis reveals medium to coarse grained sand of 85% (by weight) of the soils, while the remaining 14% and 1% are fine grained sand and coarse silt. The sorting indicates that

the samples range from very poorly sorted at Awka to moderately sorted at Uga (Table 2 and Fig. 8). Based on the grain size analysis results, removal and transportation of the soil grains by runoff water is easier [18]. Smaller particles are easily carried away by water since the transporting medium requires relatively small amount of energy. This is why erodibility potential of the soil units is high.

Table 2. Index properties of collected soil samples.

Property	Sample Description						Average (%)
	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	
Specific Gravity	2.67	2.64	2.69	2.61	2.71	2.68	2.67
% gravel (> 2mm)	0	0	0	0	0	0	0
% Coarse grained sand (<2mm to 0.15mm)	86.43	78.02	85.88	87.43	86.89	87.06	85.29
% fine Sand (<0.15mm to 0.018mm)	12.55	21.53	12.81	11.7	12.13	12.856	13.93
% silt (<0.018mm)	1.02	0.45	1.31	0.87	0.98	0.084	0.79
Liquid limit (%)	64.62	60.74	67.71	64.21	63.42	60.00	63.45
Plastic limit (%)	21.04	21.02	17.04	18.05	19.10	18.50	19.13
Plasticity Index (%)	43.58	39.72	50.67	46.16	44.32	41.50	44.33

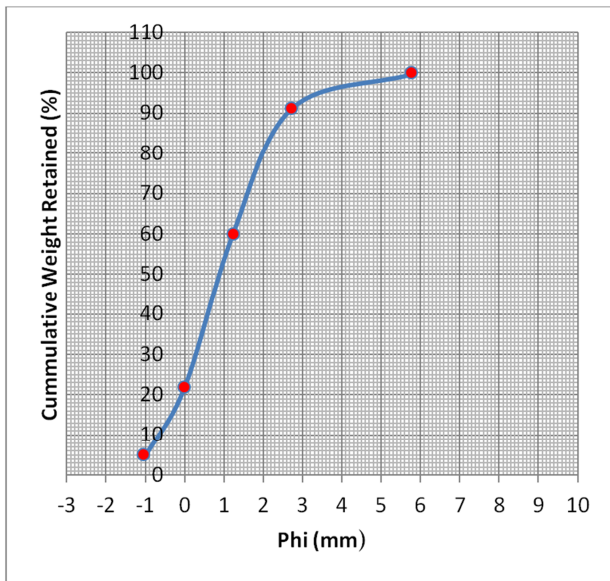


Fig. 8. A Cumulative frequency graph of sample 1 from the study area.

4.5.2. Result of Atterberg Limit Tests

The Atterberg Limit Tests of the samples collected (Table 2) shows 63.45% liquid limit (LL), 19.13% plastic limit (PL), and 44.33% plasticity index (PI) indicates that the soil samples have good intergranular cohesive force (Fig. 9 and Table 2) and the result also correlate with that obtained by researchers [5]. The result also indicates that there is existence of both plastic and non-plastic soil units. The areas that have plastic materials include Unizik Awka, Ifite Awka, Igbariam, Ngozika Housing Estate Awka, Enugwu-Agidi and Amawbia. The moderate clay content of the soil units observed in parts of the study area minimises devastation caused by gullies. Where non-plastic soils prevail and are highly affected by the gullies, indicates low intergranular cohesive force. They include Agulu, Nkpor, Ogidi, Oba, Umunya, Enugwu-Ukwu, Uga, Ekwulobia, Awgbu, Abagana, Ogbunike, Umunachi and Umudioka.

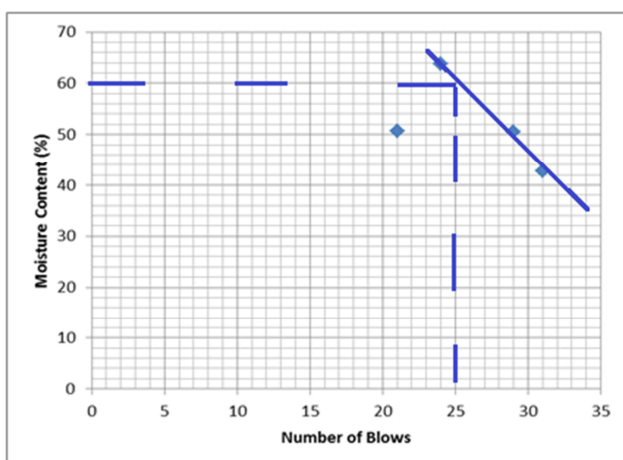


Fig. 9. A plot of moisture content against number of blows.

5. Conclusion

Hydrogeophysical and Geotechnical Assessment in Central Part of Anambra State, Nigeria has been carried out and the conclusions are as follows:

1. The geo-electric results revealed eight different curve types namely; K, H, QH, HK, KH, QK, KQ and KHK-curve types. 54% of all the sounding curves belong to HK and H-types whereas the remaining 46% belongs to other six curve types within the study area.
2. The results also revealed that depths to the water saturated sandstones (aquifer) within the study area range from 67.83m at Toll-Gate Onitsha to 225.03m at UNIZIK Science Village Awka with an average resistivity of 1205.12 Ohm-m.
3. The water table map indicates multi flow direction and correlates favourably with the topography of the area.
4. The result of the aquifer parameters revealed that the hydraulic conductivity ranges from 2.84×10^{-3} to 3.37×10^{-1} m/day while the transmissivity ranges from 0.091 to 1.039m²/day within the study area.
5. The result of sieve analysis reveals medium to coarse grained sand of 85% (by weight) of the soils, while the remaining 14% and 1% are fine grained sand and coarse silt.
6. The Atterberg Limit Tests of the samples collected shows 63.45% liquid limit (LL), 19.13% plastic limit (PL), and 44.33% plasticity index (PI) indicates that the soil samples have good intergranular cohesive force.
7. Based on the hydrogeophysical and geotechnical results, the aquifers are capable of yielding enough water that would serve the immediate environs as well as the soil nature encouraging soil erodibility.

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