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LITHOLOGICAL DEDUCTIONS AND THE EVALUATION OF GROUNDWATER POTENTIALS FROM GEO-ELECTRICAL SOUNDINGS IN THE BENDE-AMEKI FORMATION OF EHIME-MBANO AREA, SOUTHERN NIGERIA

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ABSTRACT

Lithological deductions and evaluation of groundwater potentials from Geo-electrical soundings in the Bende-Ameki Formation of Ehime-Mbano Area, Southern Nigeria, was carried out by imploring the vertical electrical sounding (VES) technique. A total of nine VES points were obtained using the ABEM SAS 1000 Terrameter. The study reveals that the depth of the shallow wells in the area (upper aquifer) ranges from 12-22m and falls within the 3rd and 4th geo-electric layers with resistivity values ranging from 240Ωm - 2500Ωm; while the 2nd aquifer ranges from 34-45m and with range of resistivity values of 190Ωm - 300Ωm. The depth to the 3rd aquifer ranges from 70 – 120m, while that of the 4th aquifer is 130-300m. The data obtained after partial curve matching and computer iteration indicates a total of 8 - 10 geoelectric layers with inferred lithologies namely: silt, clay, fine-grained sand, medium-grained sand, coarse-grained sand and sandstone. Results show that most of the aquifers are hosted within the silts and fine-grained sands with the exception of a few locations with medium-grained and coarse-grained sands. By using the Dar-Zarrouk parameters, the overburden protective capacities of the aquifers in the study area were evaluated as poor, weak and moderate in some locations. It was concluded that in the area, sand mining (excavation) is a potential economic source except in the vicinity of VES 9.

Keywords: Dar-Zarrouk parameters, Overburden protective capacities, Groundwater potential, Sand mining

INTRODUCTION

Water existing under the surface of the Earth in the soil void / pore spaces of aquifers, or in the fractures of rock formations in form of underground streams is usually referred to as groundwater.

An aquifer is a porous and permeable substratum (sub-surface rock layer) that is able to store and release (yield) a good quantity of groundwater when penetrated by a borehole.

Groundwater as a natural resource has its inherent characteristics strongly being influenced and determined by the geologic properties / parameters of the host rock.

Therefore, the search for groundwater in an area should be dependent on a reliable empirical knowledge of the local geology of the area (Amos-Uhegbu and Ndubueze, 2022).

Increase in population, industrialization, urbanization, and modernized standards of living usually add pressure on natural resources. With the ever-increasing demand for groundwater supplies in Ehime-Mbano area, a guide to groundwater exploration in the area is necessary. For the evaluation of the groundwater potential of the area, the local geology need be studied; and modern scientific tools with well-outlined techniques are implored.

Amongst all the methods, geophysical surveying methods are most widely used because of their basic advantage of providing more reliable results than other methods.

While, the electrical resistivity method (Vertical Electrical Sounding 'VES' technique) has been the most widely used tool for groundwater investigation because of the portability of the equipment, affordability and reliability, efficiency in operation, and the involvement of fewer manpower in the field. It also has a good depth of penetration thus clarifying the subsurface structure together with the delineation of the aquifer systems.

The study area is situated in parts of the Central parts of Ehime Mbano Area of Imo State, Southern Nigeria. It is located within Latitude 5° 36' 54" and 5° 41' 18" N, and Longitude 7° 16' 07" and 7° 23' 07" E (Fig. 1), The climate is that of the sub-equatorial belt with average relative humidity values of about 70%; and the elevation ranges from about 142.9 to 203.9m above mean sea level.

The wet season spans for about 6 months from April to the end of October with an annual average rainfall of about 230mm and temperature of the area varies from 29°C to about 33°C.

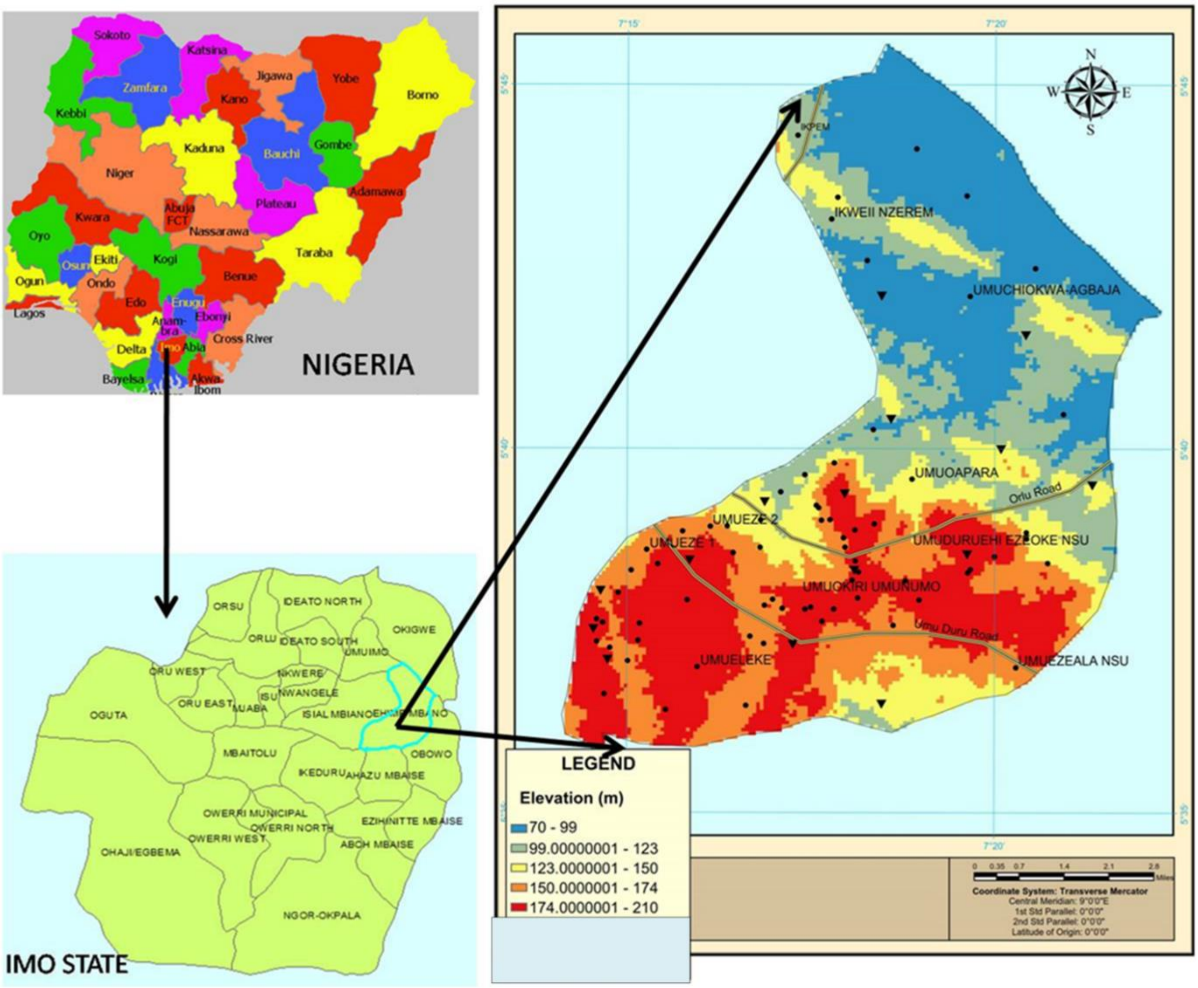


Figure 1: Map of Nigeria showing Imo State and the Physiography of the Study area (Ehime-Mbano)

Geologically, out of the five different geological sedimentary Formation in Imo State of Nigeria, the Bende-Ameki Formation of the Cenozoic Niger Delta is the study area which is underlain by the Imo shale (Paleocene) and overlain by the Late Tertiary-Early Quaternary Ogwashi-Asaba Formation (Fig. 2).

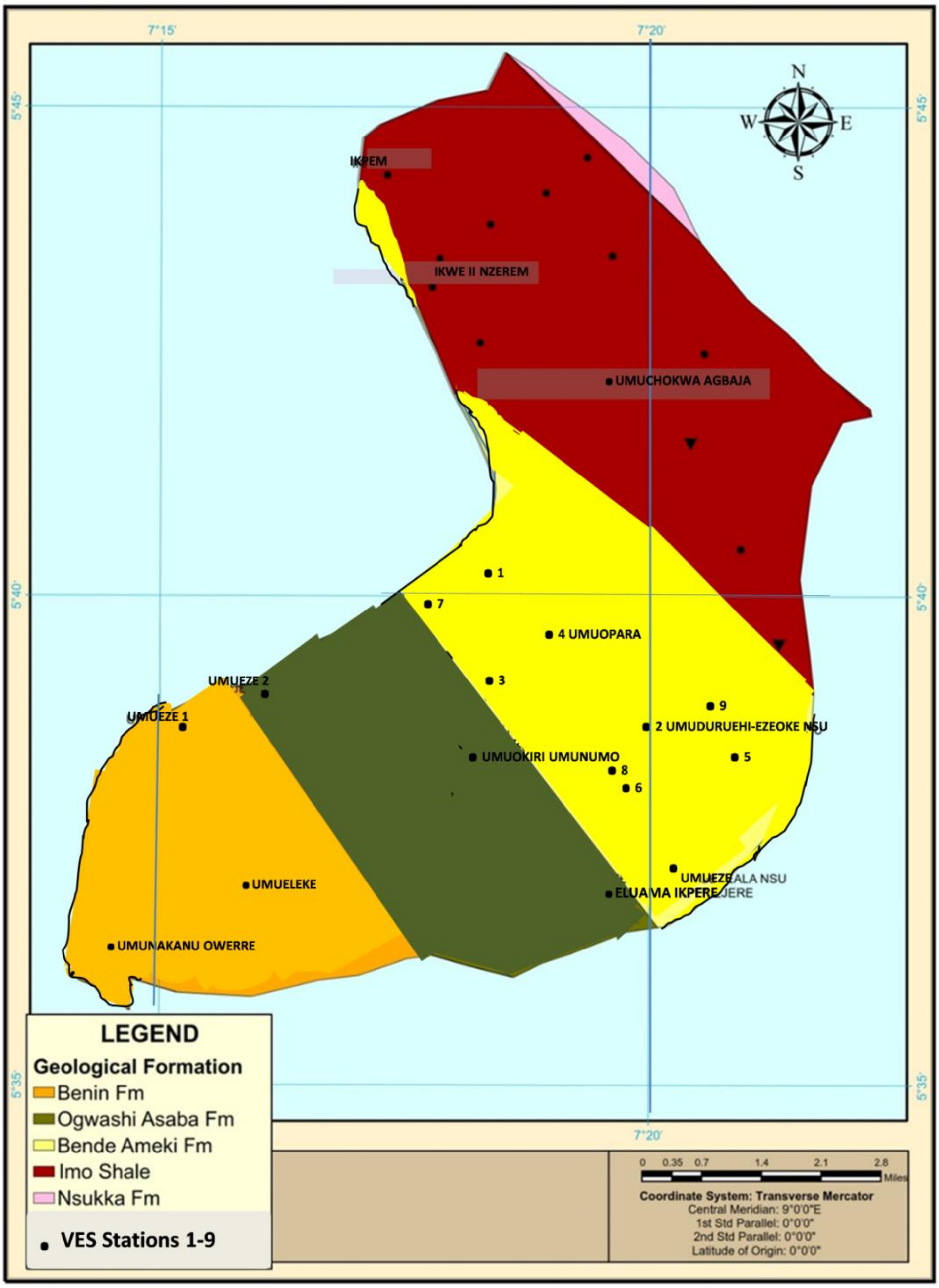


Figure 2: Geologic Map of Ehime Mbano Area showing the VES points in the study area

The Formation is about 200 meters thick and consists of a lower part which are of fine to coarse grained sandstones and intercalations of calcareous shales and thin shelly limestone bands (consisting of molluscs, foraminifera, and corals) and an upper part which comprises of medium to coarse, cross-bedded white sandstones with bands of fine, grey-green sandstones and sandy fossiliferous clays. The depositional environment has been interpreted as estuarine, lagoonal, and open marine based on the faunal content and comprises of medium to coarse-grained white sandstones (Simpson, 1954; Reyment, 1965, Adegoke, 1969, Nwajide, 1979, Arua 1986, Fayose and Ola1990; Obasi et.al; 2015).

Previous hydrogeological studies in the region focused on the lithological units, groundwater distribution, and borehole performance.

Akpokodje et al. (2005) studied the lithological composition of southeastern Nigeria, revealing alternating layers of sand, clay, and shale typical of the Niger Delta. These findings are in line with the geology of the study area, indicating the presence of both aquiferous sandy layers and aquitard clayey units.

Onwuegbuche and Egboka (2013) evaluated the groundwater potential in parts of Imo State using resistivity methods and recommended VES surveys for better aquifer characterization. They found that groundwater availability varies significantly between sandy and clayey-dominated regions.

Njoku et al. (2018) investigated groundwater contamination risks in Imo State and emphasized the importance of evaluating protective layers. They suggested that Dar-Zarrouk parameters could be instrumental in identifying areas with effective natural protection from contamination.

However, Bende-Ameki Formation in the area hasn't been specifically studied and there may still be a gap for detailed studies focused specifically on the computation of geo-electrical parameters in the study area, which this research seeks to fill.

MATERIALS AND METHODS

Nine Vertical Electrical Soundings (VES) were acquired using the Schlumberger electrode configuration (Fig. 3). Along the survey line, the widely spaced current electrodes 'AB/2' were varied from 1.5m to a maximum of 350m; and in-between the current electrodes, are the potential electrodes 'MN/2' varied from 0.5m to a maximum of 55m.

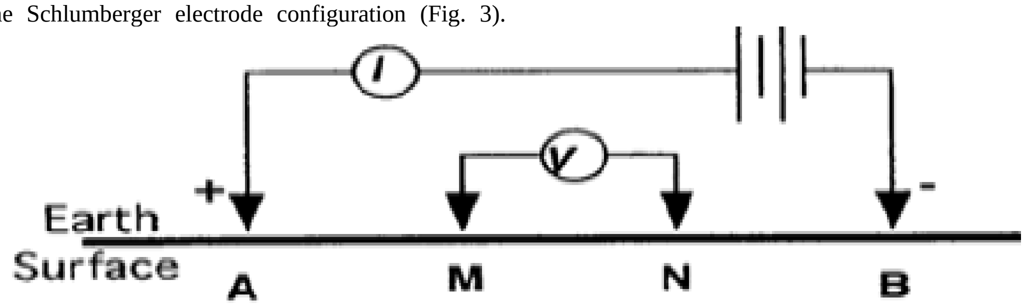


Figure 3: Schlumberger electrode configuration

The coordinates of each sounding point (longitude, latitude and elevation height above mean sea level); were determined using Garmin GPS 72 and the Resistivity meter used in the data acquisition was ABEM Terrameter SAS 4000.

The source of electrical power to the Terrameter was a 12V direct current (DC) battery. From the Terrameter, current was injected into the subsurface using the current electrodes 'AB/2' linked by insulated cables. For the determination of the resultant potential difference (voltage), the potential electrodes 'MN/2' were used and the observed field data subsequently displayed on the Terrameter. The observed field data as a ratio of the voltage to the current is the measured resistance of the subsurface (ground resistance) in ohms; and it is used to calculate the corresponding apparent resistivity in Ohm-meters by multiplying with the geometric factor.

The value of the geometric factor is a function of electrode spacing, thus giving the required apparent resistivity results as functions of depths of individual layers (eq. 1)

$$\rho a = KR = \pi R\left(\frac{L^2 - l^2}{2l}\right) \quad (1)$$

Where, ρa = Apparent resistivity. L = 'AB/2' = Half current electrode spacing (m).

l = MN/2 = Half potential electrode spacing (m). R = Resistance in ohms.

$\pi\left(\frac{L^2 - l^2}{2l}\right)$ = Geometric factor (K).

For each sounding point, the apparent resistivity differences were used in delineating the subsurface in layers. The apparent resistivity values were plotted against current electrode spacing 'AB/2' on a log-log graph paper to obtain sounding curves which were subjected to partial curve matching where initial estimates of the resistivity and thickness were derived and were further used for computer iteration using IPI2Win v. 2.1software package.

Igneous and metamorphic rocks usually have higher resistivity values than sedimentary rocks. The resistivity of igneous and metamorphic rocks depends greatly on the extent of fracturing, and the degree of saturation of the fractures with ground water. Sedimentary rocks are more porous than igneous and metamorphic rocks, therefore have higher water content, and lower resistivity values. Saturated soils have lower resistivity values; clayey soils because of their higher porosity have lower resistivity values than sandy soils. However, an overlap exists in the resistivity values of the different classes of rocks, soils and minerals (Fig. 4). This overlap is because of the dependent of resistivity on a number of factors (percentage porosity / extent of fracturing, the degree of water saturation and the concentration of dissolved salts).

Previous studies within the region of study and adjacent sedimentary Formation has deduced that sediments with resistivity of 100 Ωm or < 100 Ωm are clays, >100 Ωm – 500 Ωm are silts, >500 Ωm – 1500 Ωm are fine-grained sands, >1500 Ωm – 3000 Ωm are medium-grained sands, >3000 Ωm – 5500 Ωm are coarse-grained sands, and >5500 Ωm as sandstone (Amos-Uhegbu, 2014). This deduction shall be used in the lithological characterization of the various geoelectric layers.

Furthermore, the Dar Zarrouk parameters were used in the evaluation of the groundwater potentials (Niwas and Singhal, 1981).

Longitudinal conductance $S = \sum \frac{h}{\rho}$ (2)

Transverse resistance $R = \sum h\rho$ (3)

Where, h = layer thickness measured in metres (m); ρ = aquifer resistivity in measured in ohm metres (Ωm)

The longitudinal conductance 'S' is a measure of the impermeability of a rock layer (Billing, 1972); and it was used in the evaluation of the protective capacity of the study area (Table 1).

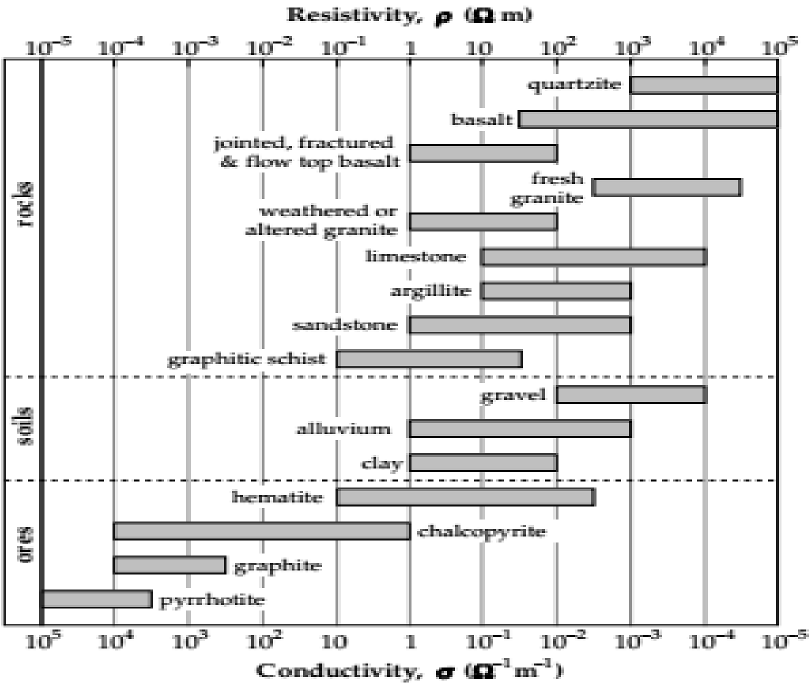


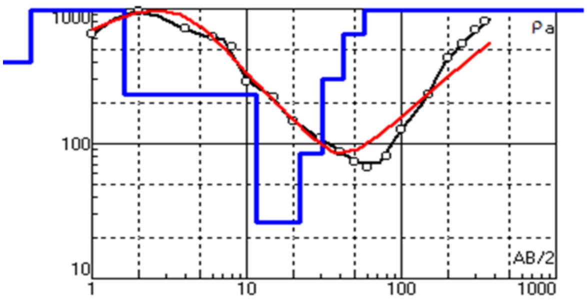
Figure 4: Electrical resistivity values for some common rocks, soils and ores (After Lowrie, 2007)

Table 1: Aquifer protective capacity rating (After Egbai and Iserhien-Emekeme (2015)

Longitudinal conductance (mhos, Siemens)	**Protective capacity**
> 10	Excellent
5 - 10	Very good
0.7 - 4.9	Good
0.2 - 0.69	Moderate
0.1 - 0.19	Weak
< 0.1	Poor

RESULTS AND DISCUSSION

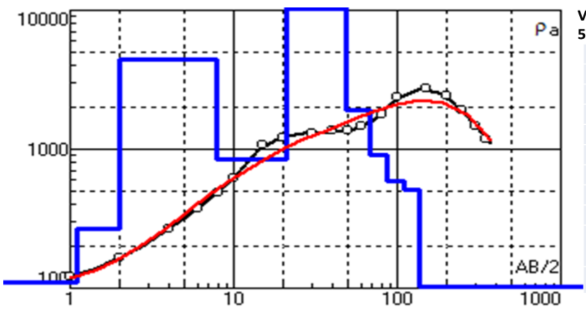
The final result of the computer iteration (sounding curve) is usually a quantitative display of the layer parameters with the minimum root mean square error (Fig. 5, 6, 7 and 8). A summary of the interpreted VES data and their locations is as shown (Table 2)



VES 01 :Umumanu Umuezeala
5°39.01'N, 7°16.49'E, H164.3m

N	ρ(m)	h(m)	d(m)
1	398	0.5	0.5
2	2100	1.1	1.6
3	240	10.4	12.0
4	27	13.1	25.1
5	85	6.5	31.6
6	300	10.0	41.6
7	660	20.0	61.6
8	3350		

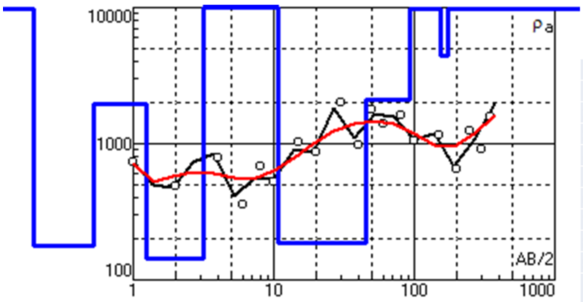
Figure 5: Typical vertical electrical sounding curve of VES 1



VES 02: Umuduruehi Ezeoke-Nsu
5°38.31'N, 7°19.59'E, H203.9m

N	ρ(m)	h(m)	d(m)
1	115	1.15	1.15
2	275	0.85	2.0
3	4450	6.0	8.0
4	850	14.0	22.0
5	10500	28.0	50.0
6	1950	20.0	70.0
7	900	15.0	85.0
8	590	35.0	120.0
9	520	25.0	145.0
10	105		

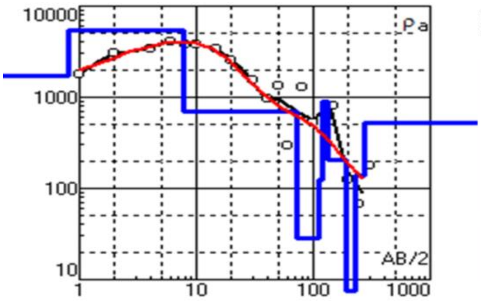
Figure 6: Typical vertical electrical sounding curve of VES 2



VES 04: Umuoparaije Ogboama Umuopara
5°41.01'N, 7°16.07'E, H142.9m

N	ρ(m)	h(m)	d(m)
1	25100	0.2	0.2
2	100	0.4	0.6
3	1900	0.4	1.0
4	145	1.8	2.8
5	22050	7.5	10.3
6	190	34.5	44.8
7	2100	45.0	89.8
8	19800	65.0	154.8
9	4450	16.5	171.3
10	20950		

Figure 7: Typical vertical electrical sounding curve of VES 4



VES 07: Umuduru Ikpeafor Ikperejere
5°36.54N, 7°23.07'E, H175.9m

N	ρ(m)	h(m)	d(m)
1	1750	0.8	0.8
2	5400	7.2	8.0
3	710	67.0	73.0
4	28	45.0	118.0
5	123	30.0	148.0
6	900	15.0	163.0
7	204	34.0	197.0
8	7.5	33.0	230.0
9	136	50.0	280.0
10	522		

Figure 8: Typical vertical electrical sounding curve of VES 7

Sounding curve acquired over a horizontally stratified substratum is a function of the resistivity and thickness of the layer as well as the electrode configuration. As the calculated apparent resistivity is plotted against the corresponding half current electrode spacing (AB/2), VES curves are derived, and the letters Q, A, K and H are used singly for 3-layered curves or in combination for more layers to display the qualitative variation of resistivity with depth (Fig. 9).

The A – type curve represents a subsurface condition depicting an increase in resistivity values from the topsoil to the 3rd layer (ρ1< ρ2< ρ3). While, the H – type curve indicates a subsurface condition where the resistivity of the first layer is greater than the second layer and the resistivity of the second layer is less than the third layer (ρ1> ρ2< ρ3).

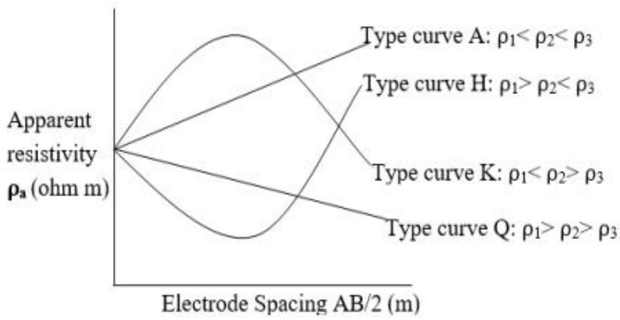


Figure 9: Illustrative diagram of resistivity type curves for 3-layered structures

The AA – type curve represents a four-layered substratum whereby there is an increase in resistivity from the first layer to the 4th layer (ρ1< ρ2< ρ3< ρ4). The HA – type curve depicts a four-layered subsurface whereby the resistivity of the first layer is greater than that of the second layer while that of the second layer is less than the third layer and the resistivity of the third layer is less than the fourth layer (ρ1> ρ2< ρ3< ρ4).
The sounding curves of the study area reveal the existence of 8 to 10 geoelectric layers and the 9 VES stations showed curve types KQHAAA in VES 1 and KQHAAAAA in VES 9, AKHKQQQQ in VES 2 and KHKOQQH in VES 5 (Table 2). The resistivity of the topsoil varies from 47.1Ωm in VES 6 to 25050 Ωm in VES 4, while the thickness varies from 0.19m in VES 4 to 1.1m in VES 2.
The resistivity values of all the sub-surface layers range from 7.5 Ωm in VES 7 to 39400 Ωm in VES 3 while the thicknesses varies from 0.85 m in VES 2 to 149 m in VES 8 (Table 2).

Table 2: A summary of the interpreted VES data and their locations

VES Location and coordinates	Resistivity of layers (Ωm)	Inferred lithology	Type Curves	Thickness of layers (m)	Depth of Layers (m)	Layer conductivity (σ)	Transverse resistance (T)	Longitudinal Conductance (S)	Groundwater evaluation remarks	Protective Capacity
1	ρ_1 =398	Silt		h_1 =0.5	d_1 =0.5	σ_1 =0.002513	T_1 = 199.0	S_1 =0.001256	L_1=Protective layer	L_1 = Poor
Umumanu	ρ_2 =2100	Medium-grained sand	KQHAAA	h_2 = 1.1	d_2 = 1.6	σ_2 =0.000476	T_2 = 2310.0	S_2= 0.000524	L_2=Protective layer	L_2 = Poor
Umuezeala	ρ_3 =240	Silt		h_3 = 10.4	d_3 = 12.0	σ_3 =0.004167	T_3 = 2496.0	S_3= 0.043333	L_3 Water table	L_3 = NA
7°.16 49 E	ρ_4 =27	Clay(Saturated layer)?		h_4 = 13.1	d_4 = 25.1	σ_4 =0.037037	T_4 = 353.7	S_4= 0.485185	L_4=Protective layer	L_4= Moderate
5°.39 01 N	ρ_5 =85	Clay		h_5 = 6.5	d_5 = 31.6	σ_5 =0.011764	T_5 = 559.0	S_5= 0.076471	L_5=Protective layer	L_5 = Poor
164.3m	ρ_6 =300	Silt		h_6 = 10.0	d_6 = 41.6	σ_6 =0.003333	T_6 = 3000.0	S_6= 0.033333	L_6 = Aquifer	L_6 = NA
	ρ_7 =660	Fine-grained sand		h_7 = 20.0	d_7 = 61.6	σ_7 =0.001515	T_7 = 13200.0	S_7= 0.030303	L_7 = NA	L_7 = NA
	ρ_8 =3350	Coarse-grained sand		h_8 = ?	d_8 = ?	σ_8 =0.000299			L_8 = NA	L_8 = NA
2	ρ_1 =115	Silt		h_1 =1.15	d_1 = 1.15	σ_1 =0.008696	T_1 = 132.3	S_1 =0.01	L_1=Protective layer	L_1 = Poor
Umuduruehi	ρ_2 =275	Silt	AKHKQQQQ	h_2 =0.85	d_2 = 2.0	σ_2 =0.003636	T_2 = 233.8	S_2= 0.003090	L_2=Protective layer	L_2 = Poor
Ezeoke-Nsu	ρ_3 =4450	Coarse-grained sand		h_3 =6.0	d_3 = 8.0	σ_3 =0.000225	T_3 = 26700.0	S_3= 0.001348	L_3 Protective layer	L_3 = Poor
7°.19 59 E	ρ_4 =850	Fine-grained sand		h_4 = 14.0	d_4 = 22.0	σ_4 =0.001176	T_4 = 11900.0	S_4= 0.016471	L_4= Aquifer	L_4= Aquifer
5°.38 31 N	ρ_5 =10500	Sandstone		h_5 = 28.0	d_5 = 50.0	σ_5 =0.000095	T_5 =294000.0	S_5= 0.002667	L_5 = NA	L_5 = NA
203.9 m	ρ_6 =1950	Medium-grained sand		h_6 = 20.0	d_6 = 70.0	σ_6 =0.000512	T_6 = 39000.0	S_6= 0.010256	L_6 = NA	L_6 = NA
	ρ_7 =900	Fine-grained sand		h_7 = 15.0	d_7 = 85.0	σ_7 =0.001111	T_7 = 13500.0	S_7= 0.016667	L_7 = NA	L_7 = NA
	ρ_8 =590	Fine-grained sand		h_8 = 35.0	d_8 = 120.0	σ_8 =0.001695	T_8 = 20650.0	S_8= 0.059322	L_8 = NA	L_8 = NA
	ρ_9 =520	Fine-grained sand		h_9 = 25.0	d_9 = 145.0	σ_9 =0.001923	T_9 = 13000.0	S_9= 0.048077	L_9 = NA	L_9 = NA
	ρ_{10}= 105	Silt		h_{10} =?	d_{10} = ?	σ_{10}=0.009524			L_{10} = NA	L_{10} = NA
3	ρ_1 =490	Silt		h_1 =1.0	d_1 = 1.0	σ_1 =0.002041	T_1 = 490.0	S_1 =0.002041	L_1=Protective layer	L_1 = Poor
Umuokiri	ρ_2 =28	Clay	HAAKQQHK	h_2 = 1.5	d_2 = 2.5	σ_2 =0.035714	T_2 = 42.0	S_2= 0.053571	L_2=Protective layer	L_2 = Poor
Umunumo	ρ_3 =820	Fine-grained sand		h_3 = 1.5	d_3 = 4.0	σ_3 =0.001220	T_3 = 1230.0	S_3= 0.001829	L_3 Protective layer	L_3 = Poor
7° 18.08 E	ρ_4 =8810	Sandstone		h_4 = 5.5	d_4 = 9.5	σ_4 =0.000114	T_4 = 48455.0	S_4= 0.000624	L_4=Protective layer	L_4 = Poor
5°.38 18 N	ρ_5 =39400	Sandstone		h_5 = 60.5	d_5 = 69.5	σ_5 =0.000025	T_5=2383700.0	S_5= 0.001536	L_5=Protective layer	L_5 = Poor
195.1 m	ρ_6 =4500	Coarse-grained sand		h_6 = 53.3	d_6 = 122.8	σ_6 =0.000222	T_6= 239850.0	S_6= 0.011844	L_6=Protective layer	L_6 = Poor
	ρ_7 =3520	Coarse-grained sand		h_7 = 45.0	d_7 = 167.8	σ_7 =0.000284	T_7= 158400.0	S_7= 0.012784	L_7=Protective layer	L_7 = Poor
	ρ_8 =2800	Medium-grained sand		h_8 = 45.0	d_8 = 212.8	σ_8 =0.000357	T_8=1260000.0	S_8= 0.016071	L_8 = Aquifer	L_8 = NA
	ρ_9 =3950	Coarse-grained sand		h_9 = 40.5	d_9 = 253.3	σ_9 =0.000253	T_9= 159975.0	S_9= 0.010253	L_9 = NA	L_9 = NA
	ρ_{10}= 3100	Coarse-grained sand		h_{10} =?	d_{10} = ?	σ_{10}=0.000323			L_{10} = NA	L_{10} = NA
4	ρ_1 =25100	Sandstone	HKHKHAKH	h_1 = 0.2	d_1 = 0.2	σ_1 =0.000040	T_1 = 5020.0	S_1 =0.000008	L_1=Protective layer	L_1 = Poor
Umuoparaije	ρ_2 =100	Clay		h_2 = 0.4	d_2 = 0.6	σ_2 =0.01	T_2 = 40.0	S_2= 0.004	L_2=Protective layer	L_2 = Poor
Ogboama	ρ_3 =1900	Medium-grained sand		h_3 = 0.4	d_3 = 1.0	σ_3 =0.000526	T_3 = 760.0	S_3= 0.000211	L_3 Protective layer	L_3 = Poor
7°.16 07 E	ρ_4 =145	Silt		h_4 = 1.8	d_4 = 2.8	σ_4 =0.006897	T_4 = 261.0	S_4= 0.012414	L_4=Water table ?	L_4 = NA
5°.41 01 N	ρ_5 =22050	Sandstone		h_5 = 7.5	d_5 = 10.3	σ_5 =0.000045	T_5 = 165375.0	S_5= 0.000340	L_5=Protective layer	L_5 = Poor
142.9 m	ρ_6 =190	Silt		h_6 = 34.5	d_6 = 44.8	σ_6 =0.005263	T_6 = 6555.0	S_6= 0.181579	L_6 = Aquifer	L_6 = NA
	ρ_7 =2100	Medium-grained sand		h_7 = 45.0	d_7 = 89.8	σ_7 =0.000476	T_7 = 94500.0	S_7= 0.021429	L_7=Protective layer	L_7 = Poor
	ρ_8 =19800	Sandstone		h_8 = 65.0	d_8 = 154.8	σ_8 =0.000051	T_8 =1287000.0	S_8= 0.003283	L_8=Protective layer	L_8 = Poor
	ρ_9 = 4450	Coarse-grained sand		h_9 =16.5	d_9 = 171.3	σ_9 =0.000225	T_9 = 73425.0	S_9= 0.003708	L_9 = Aquifer	L_9 = NA
	ρ_{10}= 20950	Sandstone		h_{10} =?	d_{10} = ?	σ_{10}=0.000048			L_{10} = NA	L_{10} = NA

VES Location and coordinates	Resistivity of layers (Ωm)	Inferred lithology	Type Curves	Thickness of layers (m)	Depth of Layers (m)	Layer conductivity (σ)	Transverse resistance (T)	Longitudinal Conductance (S)	Groundwater evaluation remarks	Protective Capacity
5	ρ_1 =1950	Medium-grained sand	KHKOQQH	h_1 = 0.6	d_1 = 0.5	σ_1 =0.000512	T_1 = 1170.0	S_1 =0.000307	L_1=Protective layer	L_1 = Poor
Umuchiaku Lowa	ρ_2 =5400	Coarse-grained sand		h_2 = 2.2	d_2 = 2.8	σ_2 =0.000185	T_2 = 11880.0	S_2= 0.000407	L_2 Protective layer	L_2 = Poor
7°.20 52 E	ρ_3 =1850	Medium-grained sand		h_3 = 11.3	d_3 = 14.1	σ_3 =0.000541	T_3 = 20905.0	S_3= 0.006108	L_3 Water table	L_3 = NA
5°.38 22 N	ρ_4 = 5450	Coarse-grained sand		h_4 = 26.0	d_4 = 40.1	σ_4 =0.000183	T_4 = 141700.0	S_4= 0.004771	L_4=Protective layer	L_4 = Poor
167.0 m	ρ_5 = 2800	Medium-grained sand		h_5 = 14.0	d_5 = 54.1	σ_5 =0.000357	T_5 = 39200.0	S_5= 0.005	L_5=Protective layer	L_5 = Poor
	ρ_6 = 1950	Medium-grained sand		h_6 = 14.5	d_6 = 68.6	σ_6 =0.000513	T_6 = 28275.0	S_6= 0.007436	L_6=Protective layer	L_6 = Poor
	ρ_7 = 320	Silt		h_7 = 61.5	d_7 = 130.1	σ_7 =0.003125	T_7 = 19680.0	S_7= 0.192188	L_7= Aquifer	L_7 = NA
	ρ_8 = 90	Clay		h_8 = 70.0	d_8 = 200.1	σ_8 =0.011111	T_8 = 6300.0	S_8= 0.777778	L_8 = NA	L_8 = NA
	ρ_9 = 345	Silt		h_9 = ?	d_9 = ?	σ_9 =0.002898			L_9 = NA	L_9 = NA
6	ρ_1 = 50	Clay	KQHKQQQQ	h_1 = 0.6	d_1 = 0.6	σ_1 =0.02	T_1 = 30.0	S_1 =0.012	L_1=Protective layer	L_1 = Poor
Ekwereocha	ρ_2 =2450	Medium-grained sand		h_2 = 1.8	d_2 = 2.4	σ_2 =0.000408	T_2 = 4410.0	S_2= 0.000735	L_2 Protective layer	L_2 = Poor
Amakohia	ρ_3 =1100	Fine-grained sand		h_3 = 7.1	d_3 = 9.5	σ_3 =0.000909	T_3 = 7810.0	S_3= 0.006455	L_3 Protective layer	L_3 = Poor
7°.20 51 E	ρ_4 = 750	Fine-grained sand		h_4 = 9.9	d_4 = 19.4	σ_4 =0.001333	T_4 = 7425.0	S_4= 0.0132	L_4=Aquifer	L_4 = NA
5°.37 16 N	ρ_5 =17200	Sandstone		h_5 = 80.6	d_5 = 100.0	σ_5 =0.000058	T_5= 1386320.0	S_5= 0.004686	L_5=NA	L_5 = NA
195.7m	ρ_6 =7350	Sandstone		h_6 = 50.0	d_6 = 150.0	σ_6 =0.000136	T_6= 367500.0	S_6= 0.006803	L_6=NA	L_6 = NA
	ρ_7 = 5300	Sandstone		h_7 = 48..0	d_7 = 198.0	σ_7 =0.000189	T_7= 254400.0	S_7= 0.009057	L_7=NA	L_7 = NA
	ρ_8= 4100	Coarse-grained sand		h_8 = 50.2	d_8 = 248.2	σ_8 =0.000244	T_8= 250820.0	S_8= 0.012244	L_8=NA	L_8 = NA
	ρ_9= 2600	Medium-grained sand		h_9 = ?	d_9 = ?	σ_9 =0.000385			L_9 =NA	L_9 = NA
7	ρ_1 = 1750	Medium-grained sand	KQHAKQHA	h_1 = 0.8	d_1 = 0.8	σ_1 =0.000571	T_1 = 1400.0	S_1 =0.000457	L_1=Protective layer	L_1 = Poor
Umuduru Ikpeafor	ρ_2 =5400	Coarse-grained sand		h_2 = 7.2	d_2 = 8.0	σ_2 =0.000185	T_2 = 38880.0	S_2= 0.001333	L_2 Protective layer	L_2 = Poor
7°.23 07 E	ρ_3 =710	Fine-grained sand		h_3 = 67.0	d_3 = 73.0	σ_3 =0.001408	T_3 = 47570.0	S_3= 0.094366	L_3 Aquifer	L_3 = NA
5°.36 54 N	ρ_4 = 28	Clay		h_4 = 45.0	d_4 = 118.0	σ_4 =0.003571	T_4 = 1260.0	S_4= 1.607143	L_4=Protective layer	L_4 = Good
175.9 m	ρ_5 =130	Silt		h_5 = 30.0	d_5 = 148.0	σ_5 =0.007692	T_5 = 3900.0	S_5= 0.230769	L_5= Aquifer	L_5 = NA
	ρ_6 =900	Fine-grained sand		h_6 =15.0	d_6 = 163.0	σ_6 =0.001111	T_6= 13500.0	S_6= 0.166667	L_6=Protective layer	L_6 = Weak
	ρ_7 = 250	Silt		h_7 =34.0	d_7 = 197.0	σ_7 =0.004	T_7= 8500.0	S_7= 0.136	L_7=Protective layer	L_7 = Weak
	ρ_8 =7.5	Clay		h_8=33.0	d_8 = 230.0	σ_8 =0.133333	T_7= 247.5	S_8= 4.4	L_8=Protective layer	L_8 = Good
	ρ_9 = 140	Silt		h_9 = 50.0	d_9 = 280.0	σ_9 =0.007143	T_8= 7000.0	S_9 =0.357143	L_9= Aquifer	L_9 = NA
	ρ_{10}= 540	Fine-grained sand		h_{10} =?	d_{10} = ?	σ_{10}=0.001852			L_{10} =NA	L_{10} = NA
8	ρ_1 = 650	Fine-grained sand	KQHAAKQQ	h_1 = 0.4	d_1 = 0.4	σ_1 =0.001538	T_1 = 260.0	S_1 =0.000615	L_1=Protective layer	L_1 = Poor
Umudimezeji	ρ_2 =7350	Sandstone		h_2 = 3.6	d_2 = 4.0	σ_2 =0.000136	T_2 = 26460.0	S_2= 0.000490	L_2 Protective layer	L_2 = Poor
7°.20 00 E	ρ_3 =2500	Medium-grained sand		h_3 = 9.0	d_3 = 13.0	σ_3 =0.0004	T_3 = 22500.0	S_3= 0.0036	L_3 Water table	L_3 = NA
5°.41 18 N	ρ_4 = 48	Clay		h_4 = 16.0	d_4 = 29.0	σ_4 =0.020833	T_4 = 768.0	S_4= 0.333333	L_4=Protective layer	L_4= Moderate
164.0 m	ρ_5 =250	Silt		h_5 = 10.0	d_5 = 39.0	σ_5 =0.004	T_5 = 2500.0	S_5= 0.04	L_5= Aquifer	L_5 = NA
	ρ_6 =1000	Fine-grained sand		h_6 =16.0	d_6 = 55.0	σ_6 =0.001	T_6= 16000.0	S_6= 0.016	L_6= Aquifer	L_6 = NA
	ρ_7 =9900	Sandstone		h_7 =149.0	d_7 = 204.0	σ_7 =0.000101	T_7=1475100.0	S_7= 0.015051	L_7=Protective layer	L_7 = Poor
	ρ_8 =1500	Fine-grained sand		h_8 = 50.0	d_8 = 254.0	σ_8 =0.000667	T_8= 75000.0	S_8= 0.033333	L_8=Protective layer	L_8 = Poor
	ρ_9 = 850	Fine-grained sand		h_9 =40.0	d_9 = 294.0	σ_9 =0.001176	T_9= 34000.0	S_9 =0.047058	L_9= Aquifer	L_9 = NA
	ρ_{10}= 225	Silt		h_{10} =?	d_{10} = ?	σ_{10}=0.004444			L_{10} =NA	L_{10} = NA

VES Location and coordinates	**Resistivity of layers (Ωm)**	**Inferred lithology**	**Type Curves**	**Thickness of layers (m)**	**Depth of Layers (m)**	**Layer conductivity (σ)**	**Transverse resistance (T)**	**Longitudinal Conductance (S)**	**Groundwater evaluation remarks**	**Protective Capacity**
9	ρ_{1} = 565	Fine-grained sand	KQHAAAAA	h_1 = 0.7	d_1 = 0.7	σ_1 =0.001770	T_1 = 395.5	S_1 =0.001239	L_1=Protective layer	L_1 = Poor
Okpu Uzinomi /	ρ_2 =1333	Fine-grained sand		h_2 = 2.9	d_2 = 3.6	σ_2 =0.000750	T_2 = 3865.7	S_2= 0.002176	L_2 Protective layer	L_2 = Poor
Uboma	ρ_3 = 33	Clay		h_3 = 3.4	d_3 = 7.0	σ_3 =0.030303	T_3 = 112.2	S_3= 0.103030	L_3= Protective layer	L_3 = Weak
7° 22.27 E	ρ_4 = 8.0	Clay		h_4 = 12.0	d_4 = 19.0	σ_4 =0.125	T_4 = 96.0	S_4= 1.5	L_4= Water table	L_4 = NA
5° 38 01 N	ρ_5 =30	Clay		h_5 = 121.0	d_5 = 140.0	σ_5 =0.033333	T_5 = 3630.0	S_5= 4.033333	L_5= Aquifer ?	L_5 = NA
175.3 m	ρ_6 =33	Clay		h_6 =40.0	d_6 = 180.0	σ_6 =0.030303	T_6= 1320.0	S_6= 1.212121	L_6= NA	L_6 = NA
	ρ_7 =35	Clay		h_7 = 45.0	d_7 = 225.0	σ_7 =0.028571	T_7= 1575.0	S_7= 1.285714	L_7= NA	L_7 = NA
	ρ_8= 48	Clay		h_8 =50.0	d_8 = 275.0	σ_8 =0.020833	T_8= 2400.0	S_8= 1.041667	L_8= NA	L_8 = NA
	ρ_9 = 73	Clay		h_9 = ?	d_9 = ?	σ_9 =0.013699			L_9= NA	L_9 = NA
									L_{10} =NA	L_{10} = NA

Based on the extent (depth) of probe of the survey in the study area together with the parameters determined, the groundwater potential of the area is mostly indicative of single aquiferous units (VES Stations 1, 2, 3, 5 and 6). Other VES stations with the exception of VES 9 are either double (VES 4 or 8) or multi-aquiferous in nature (VES 7). The first aquifers in the study area likely fall within the 3rd and the 4th layers at a depth range of about 10 to 14m, except in the vicinity of VES stations 3 and 7.

The parameters of VES Station 4 indicate favourable groundwater potential from the depth of about 10.3 to 44.8m (first aquifer), and at about 154.8 to 171.3m (second aquifer).

The parameters of VES Station 9 are doubtful of huge aquiferous potentials based on the resistivity values being very low after the 2nd layer from the depth of about 3.6m, thus leading to the lithology being referred to as clay. Clays are porous but not permeable; and an aquifer should be porous and permeable. But it should be noted that resistivity is dependent on many factors such as porosity, degree of water saturation, lithology, dissolved minerals and salts, etc; based on this, the possibility of the 4th layer in VES 9 being a saturated unit is not in doubt, but is it permeable (able to transmit water upon penetration by a borehole)?

These findings have shown that the area is undoubtedly a productive aquiferous Formation but may exhibit difficulty in groundwater exploitation in some zones, this corroborates the findings of IWADA, (2002); and Nwosu et.al, 2014).

Deep wells could be drilled to depths of about 200m at VES Stations 3 and 5, and to the depth of about 280m in VES 7

Most of the aquifers in the study area are hosted in silts and fine-grained sands, except in the deep aquifers of VES 3 ((medium-grained sands) and VES 4 (coarse-grained sands).

The area possesses huge sand deposits with thicknesses varying from 0.2 -149.0m, with the exception of VES Station 9 were clay deposits are predominant.

CONCLUSION

The study which is aimed at delineating the groundwater potentials and the lithological deductions of the Bende-Ameki Formation in Ehime-Mbano area of Imo State, using electrical resistivity method revealed that boreholes for sustainable water supply could be derived from varying lithologies such silt, clay and sands. Shallow boreholes are likely to be encountered with the 3rd and 4th layers at a depth of about 12 - 20 m with the vicinity of VES 4 having the best prospects.

Based on the extent of probe (depth) of the survey in the study area, and the resultant resistivity type curves, areas of groundwater potential are indicative of single aquiferous units in the vicinity of VES Stations 1, 2, 3, 6 and 8 with a fairly average aquifer depth of about 12.5m. While the VES Stations 4, 7 and 8 are indicative of multi-aquiferous units. The vicinity of VES Station 9 do not exhibit high prospects of groundwater potential but if an attempt within the first 12m couldn't yield any groundwater, the search should be truncated.

The area possess huge sand deposits except in the vicinity of VES 9, therefore sand mining (excavation) is a potential economic source, however the shallow boreholes in the area are prone to contamination.

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