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Delineation of Potential Aquifer Zones from Geoelectric Soundings in KWA IBO River Watershed, Southeastern, Nigeria

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Abstract: Geoelectric soundings have been carried out around the KWA IBO River watershed in Ikwuano and Umuahia, southeastern Nigeria. The geology of the area (Benin Formation) mainly consists of fine-medium-coarse grained sands. The data of eleven Schlumberger Vertical Electrical Soundings (VES), with a maximum AB/2=500 m, were analyzed using the resist software. The layer parameters thus obtained were used to calculate the Longitudinal Conductance (S) and the Transverse Resistance (T) distribution. Assuming the sandy aquifer is homogeneous and using the existing lithologs and pumping test data, data analysis was done to arrive at the Hydraulic Conductivity (K) and Transmissivity (T_r) distribution within the study area. Aquifer characterization of the area also showed that the resistivity range is between 400-350WM and aquifer thickness ranged between 68 m near Usaka Elegu and 325 m near Government College Umuahia. From the results obtained, aquifer hydraulic conductivity and transmissivity values in most parts of the Watershed were observed to be high. Average aquifer transmissivity was 1722 m^2/day. In general sandy aquifer are known for their excellent groundwater potential due to the fact that the (K) values in such aquifer are high. The thick sandy aquifer exhibits high transmissivity values, which reflect the geological setting of typical sandy formation. Based on the above analysis potential aquifer zones have been identified for regional groundwater development.

Key words: KWA IBO river, aquifer, schlumberger, ves, transmissivity

INTRODUCTION

The increasing population in Umudike area in southeastern Nigeria and demand for po- water to cater for the needs of its growing institutions have prompted the present search for favourable groundwater potential zones in the area. Much of the wells drilled in different parts of the area, have become abortive or dried up, because of lack of prior systematic scientific investigation. Some of the existing shallow wells reflect high drawdown during the dry season (mainly, November through February) each year. The result of the drawdown or outright failure of wells as well as the inadequacy of water supply from improved schemes is the intake of poor drinking water by the people. It has become necessary therefore to study the groundwater resource potentials in the KWA IBO River watershed in order to meet the projected water demand of the communities within a time frame.

Thus the main objective of the present study is therefore to analyze the electrical resistivity data using a state-of-the-art software and delineate potential zones sui- for regional groundwater development in the KWA IBO River watershed. In order to achieve this objective, the geological formation within the area was first characterized. Later the hydrogeological data analysis for aquifer characteristics was then undertaken.

Location, geology and hydrogeology

Location: The KWA IBO River watershed was identified within the Ikwuano and Umuahia areas of souitheastern Nigeria for detailed aquifer characterization and other hydrogeological investigations. Figure 1 shows the location map of the study area. The watershed is located between latitude 5°19′ and 5°30′N and between longitude 7°30′ and 7°37′E. It covers a total area of about 180 square kilometers, represented by an oblong terrain, which has Government College Umuahia, Ariam, Usaka Elegu and Umuobia Olokoro at its borders.

Drainage pattern: The study area is drained by the KWA IBO River, which rises near Umuahia and flows in a southeasterly direction. Its main tributary, which is the

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Fig. 1: Map of KWA IBO River watershed showing VES points

Anya River, flows across the premises of the Michael Okpara University and the National Root Crops Research Institute both in Umudike. This river also called The Great KWA River in Cross River State also drains the eastern part of Calabar and finally empties into the Atlantic Ocean. It is popularly known for its waterfall (called KWA Falls) and well-exposed schist near Aningene and Abbiati in the Calabar Flank by Ekwueme *et al.*[1]. The eastern part of the study area is uplifted and is undisected upland. The western part of the study area is much influenced by the combination of various terrain elements such as slope, physiography, geology and geomorphology. It shows a dentritic drainage pattern. With this drainage pattern within the study area, the KWA IBO River is seen to flow in-between the undisected upland and the dentritic lowland. The general slope of the study area is NW-SE. The drainage is also observed to follow the topography, which has an average value of 120 m (amsl).

Geology: The Geology of the area is the deltaic marine sediment of Cretaceous to Recent age. There are two principal geological formations in the area namely: The Bende-Ameki and the coastal plain sands otherwise known as the Benin Formation. The Bende-Ameki Formation of Eocene to Oligocene age consists of medium to coarse-grained white sandstone, which may contain pebbles, gray-green sandstone, bluish calcareous silt, with mottled clays and thin limestone. Considerable lateral variation in lithology has also been observed. The lower part of the formation consists of fine-coarse-grained lenses of sandstones with abundant calcareous shales and thin shelly limestone. The Bende-Ameki Formation overlies the impervious Imo shale group of Paleocene age, which is characterized by lateral and vertical variations in lithology .

The coastal plain sands otherwise known as the Benin Formation overlies the Bende-Ameki Formation and dips southwestward. The Formation sediments were deposited during the late Tertiary-early Quaternary period by Mbonu *et al.*[2]. At Umudike, the formation is shallow. The expected thickness is about 200 m by Ebillah *et al.*[3]. The lithology consists of unconsolidated loosely medium to coarse-grained cross-bedded sands occasionally pebbly with localized clays and shales.

Hydrogeology: The two principal geological formations have comparative groundwater regime. They both have reliable groundwater that can sustain regional borehole production. The Bende-Ameki Formation has little groundwater when compared to the Benin Formation. The high permeability of the Benin Formation, the lateritic overburden earth and the weathered top of this formation as well as the underlying clay-shale member of the Bende-Ameki series provide the hydrologic conditions favouring aquifer formation in the area.

MATERIALS AND METHODS

Variation of electrical conductivity is investigated here with the help of electrical resistivity sounding. Eleven Schlumberger Vertical Electrical Soundings (VES) were collected using a maximum current electrode separation of AB/2 of 500 m. Digital averaging equipment, the ABEM SAS 300B Terrameter, was used for Direct Current (DC) resistivity work. The instrument displays directly the apparent resistivity of the subsurface under probe. It has an in-built dc power source. Four stainless metal stakes were used as electrodes.

Many of the sounding data were collected from government institutions such as the Abia State Water Board Umuahia, the Unicef Assisted Rural Water Supply Umuahia office and from Mbonu *et al.*[2]. The locations and the soundings data are contained in Fig. 1 and respectively. The Schlumberger electrode configuration was used in all the soundings. In the Schlumberger configuration, all the four electrodes are arranged collinearly and symmetrically placed with respect to the centre. In this array the potential electrode separation is very small compared to the current electrode separation (less than 1/5). The distance between the potential electrodes is increased only when the signal is too small to measure. Apparent resistivity ρ_a is given by

$$\rho a = \pi \left\{ \frac{\left\{ \left[\frac{AB}{2}\right]^2 - \left[\frac{MN}{2}\right]^2 \right\}}{MN} \right\} \frac{V}{1} \qquad (1)$$

where AB/2 is half current electrode separation and MN/2 is half potential electrode separation. The apparent resistivity is plotted against half current electrode spacing on a double logarithmic study. To get the layer parameters (resistivity and thickness) of the subsurface these sounding curves are first interpreted with the help of theoretically computed master curves by partial curve matching and drawing auxiliary point diagrams[4,8]. Based on this preliminary interpretation, initial estimation of the resistivities and thicknesses of the various geoelectric layers were obtained. These were later used as starting models for a fast computer-assisted interpretation. The computer programme of Jupp and Vazoff[9] and Resist (designed and used at the National Geophysical Research Institute (NGRI), Hyderabad India) were employed in the modeling of the VES data. The results of this computer modeled curves for the sounding stations are presented in Fig. 2-4 and in Table 1.

Most of the sounding curves in the KWA IBO River watershed reflected the presence of four geoelectric layers with resistivity decreasing with depth ($\rho_1 > \rho_2 > \rho_3 > \rho_4$)

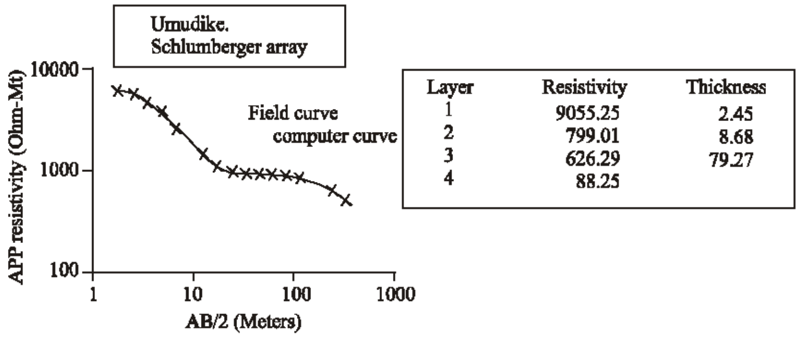

Fig. 2: Results of computer modelled curve for Umudil

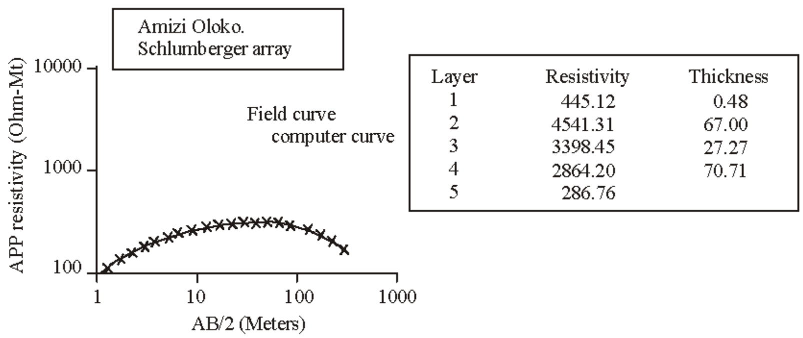

Fig. 3: Results of computer modelled curve for Amizi Oloko

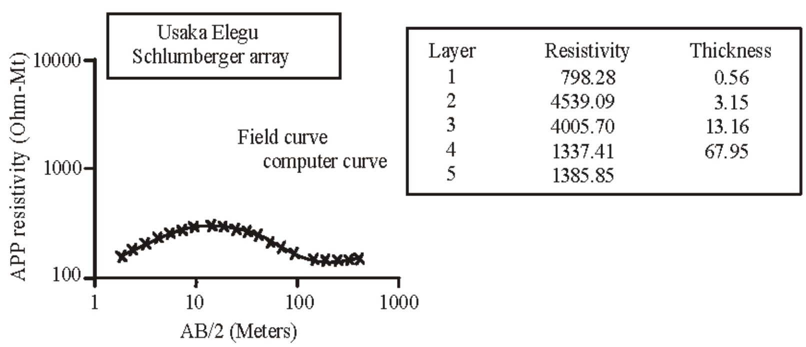

Fig. 4: Results of computer modelled curve for Usaka Elegu

i.e., a QQ-type curve. However, a few other sounding curves reflected the presence of three geoelectric layers ($\rho_1 > \rho_2 > \rho_3$) with results of the Q- type curve.

Geoelectric sections: Interpreted values of eleven (11) electrical resistivity soundings carried out around the watershed are presented in Table 1. From the-the following litho-units are easily discernible: the clay/conducting layer has resistivity, ρ less than 400Ω m, while the fine-medium-coarse grained sands (Aquifer) has resistivity between 401 and 1350 Ω m. The resistivity of the undifferentiated laterite is seen to lie between 1351 and 2650Ω m while that of the top soil is less than 2650 Ω m.

Three geoelectric sections have been prepared from the interpreted results of the vertical electrical soundings within the watershed. The interpreted parameters are true esistivities and thicknesses of the layers.

Table 1: Interpreted layer parameters from geoelectric resistivity soundings around KWA IBO river watershed

VES	Location	Latitude	Longitude	No. of layers	ρ^1 H_1	ρ^2 h_2	ρ^3 h_3	ρ^4 h_4	ρ^5 h_5	ρ^6 h_6	ρ^7	Total thick--ness (m)	Fitting error %	References
1	Amawom	5° 26.95'	7°	32.62'	3	5130.2	1334.3	172.2				142.9	1.9	Mbonu *et al.*[2]
					4.49	138.4	-							
2	Government college umuahia	5° 29.86'	7° 32.39'	4	5104.2	2568.2	85.1	277.1				355.62	4.4	Mbonu *et al.*[2]
					3.06	27.06	325.5	-						
3	Usaka Elegu	5° 19.23'	7° 31.24'	*4	798.3	4539.1	4005.7	1337.4	1385.9			84.90	2.4	Present Study
					0.6	3.1	13.2	68.0	-					
4	Isiala Oboro	5° 25.19	7° 33.55'	4	3874.0	1509.3	667.2	194.8				232.23	2.2	Mbonu *et al*[2]
					1.80	14.03	216.40	-						
5	Amizi Oloko	5° 22.22	7° 34.97'	*4	422.5	5909.5	4364.0	4061.6	4525.2	544.7	686.1	322.20	2.4	Present Study
					0.5	3.9	10.3	30.6	75.8	201.1	-			
6	Umudike	5° 28.34'	7° 32.97'	4	9055.3	799.0	626.3	88.2				90.4	2.8	Present Study
					2.4	8.7	79.3							
7	Agbama Ahiaukwu	5° 29.41'	7° 30.30'	4	5158.4	2338.4	930.6	332.3				323.30	6.3	Mbonu *et al.*[2]
					4.08	23.33	295.9	-						
8	Umuobia Olokoro	5° 29.57'	7° 30.26'	4	3994.1	1891.6	826.6	192.3				316.30	3.6	Mbonu *et al.*[2]
					1.94	18.15	296.2	-						
9	Itaja	5° 28.62'	7° 30.54'	4	3413.1	1810.5	702.4	130.2				305.00	7.5	Mbonu *et al.*[2]
					2.18	14.01	288.8	-						
10	Nnono	5° 25.92'	7° 32.91'	3	3011.9	1021.6	147.2					100.74	5.4	Mbonu *et al.*[2]
					3.25	97.49	-							
11	Ndoro	5° 26.32'		4	4932.5	2601.0	1141.3	246.8				213.36	2.4	Mbonu *et al.*[2]
		7° 33.97'			1.62	11.74	200.0							

* More than four initial layer parameters were used in the computer modeling

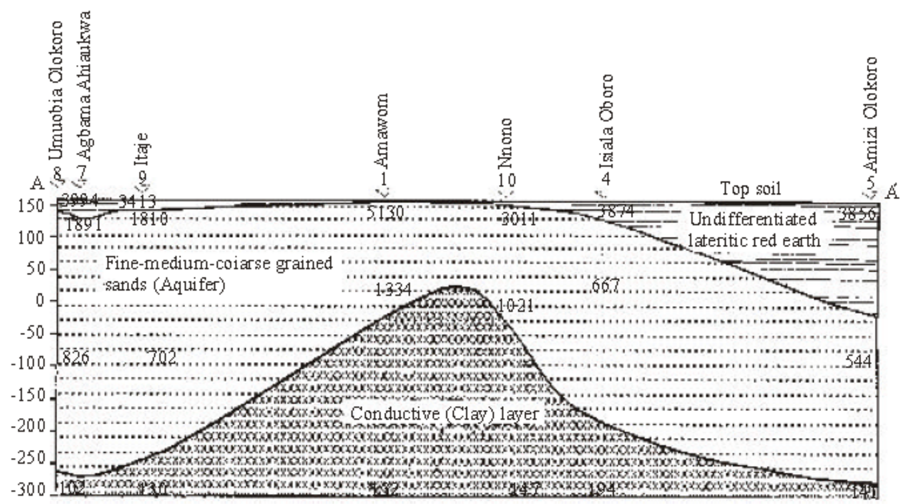

Fig. 5: Geoelectrical section along section AÁ (incliding depths obtained by Mbonu *et al.*[2])

Various geoelectric layers delineated from the electric resistivity soundings along particular profiles are hereunder presented in the three geoelectric sections namely: AA$^{/}$ and BB$^{/}$ and CC$^{/}$.

Section AA$^{/}$: The section (Fig. 5) is based on the results of seven soundings namely: VES No. 8,7,9,1,10,4,5. It traverses Umuobia Olokoro (point A) through Amizi Oloko (point A') across Nnono, which lies more or less at the center of the section. This is a NW-SE cross-section of the study area. This study shows the presence of four (sometimes interrupted) geo-electric layers namely the top soil, underlain by brown-reddish laterite. Other layers lying immediately below the laterite are the fine-medium-coarse-grained sands (the aquiferous zone) and lastly the conductive (clay) layer-see the litholog of a borehole at Oboro, Fig. 6 as culled from Mbonu *et al.*[2].

The aquiferous zone is thickest at the northwest ranging from 288.8 m at Itaja to 296.2 m at Umuobia Olokoro. The reisistivity of this zone ranges form 702.4Ω m at Itaja to 826.6Ω m at Umuobia Olokoro. The shallowest

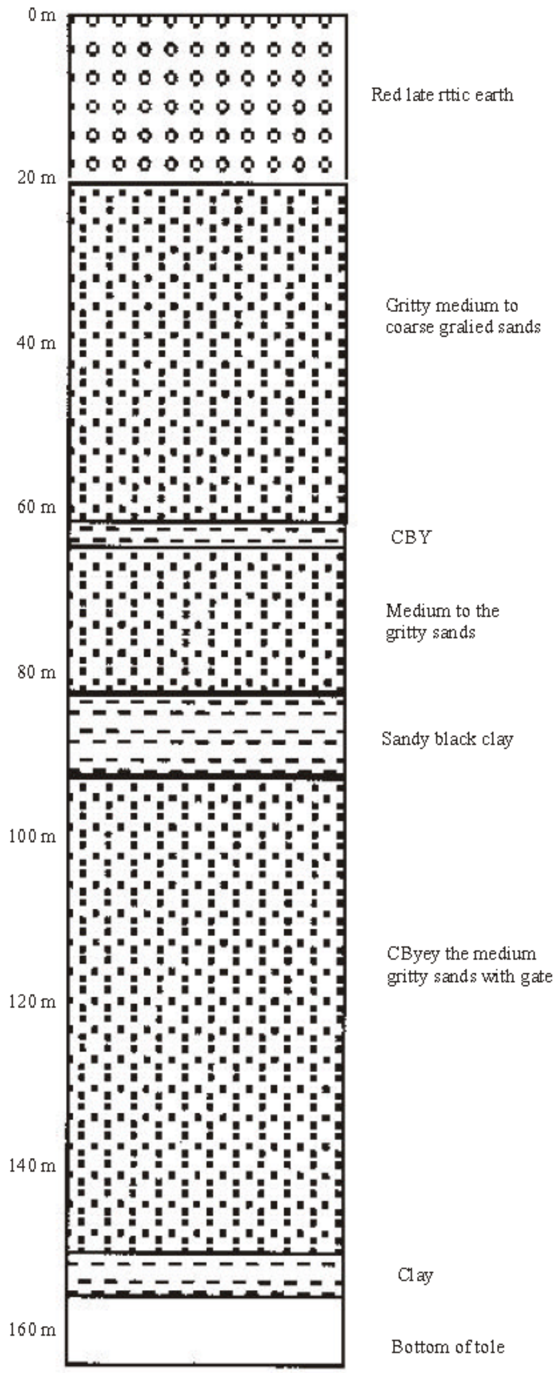

Fig. 6: Litholog of a borehole at Oboro by Mbonu *et al.*[2]

aquifer in this section is located at Nnono with a value of 97.49 m thick and resistivity, 102.6Ω m.

Section BB$^/$: The cross-section BB$^/$ (Fig. 7) lies in the N-S of the study area. The VES numbers are 2, 6, 11 and 5. The section starts from Government College Umuahia (point B) through Umudike to Amizi Oloko (point B$^/$). It shows the same structure as AA$^/$ namely: a shallow thin top soil followed by an undifferentiated laterite, then the aquiferous sandy zone and finally a conductive zone which is most probably clay. The clay layer is not however defined. This is because of lack of drilling information from such depth since the total depth of probe was not enough to delineate the layer.

The aquifer is thickest at Government College Umuahia, with a value of 325.5m and shallowest at Umudike, which is only 88 m thick. Aquifer resistivities vary from 544.7 at Amizi Oloko to 1141.3Ω m at Ndoro.

It should be noted agrees perfectly well with the lithologs of BH No.3 situated at Michael Okpara University of Agriculture, Umudike (Fig. 8) which is near Government College, Umuahia.

Section CC$^/$: The section CC$^/$ (Fig. 9) lies between Umuobia Olokoro and Government College Umuahia along the E-W direction of the study area. The VES numbers are 2 and 8. Prolific aquifers are thickest at this zone of the entire study area. The thicknesses range from 296.2 m at Umuobia Olokoro (point C) to 325.5 m at Government College Umuahia (point C$^/$). The corresponding resistivities are 826.6Ω m at Umuobia Olokoro and 845.1Ω m at Government College Umuahia.

Aquifer characterization: The various aquifer units within the watershed are shown in - 2. With the hydraulic conductivity values obtained from pumping tests at the locations 4,6 and 8, it was possible to estimate the other values at the locations shown, using a grid map (Fig. 10). Locations 1-11 corresponded with VES 1-11 while locations 12-23 were simulated to cover the areas with no sounding stations. Aquifer geoelectric sections DD^1 and EE^1 were created to take care of locations 3,22 and 5 and locations 3,21, 20, 19,18, 17,16 and 13, respectively. For such sections, a horizontal, homogenous and isotropic medium was assumed. The constant layer conductivity was first calculated by applying the mathematical method of variation into the Dar Zarrouk parameters denoted by Niwas and Singhal,[10]; Mbonu *et al.*,[2] for any two known VES points thus:

$$\rho = \frac{T_1 - T_2}{h_1 - h_2} \qquad (2)$$

where T is the transverse resistance and h is the thickness of the aquiferous layer. The thicknesses of individual

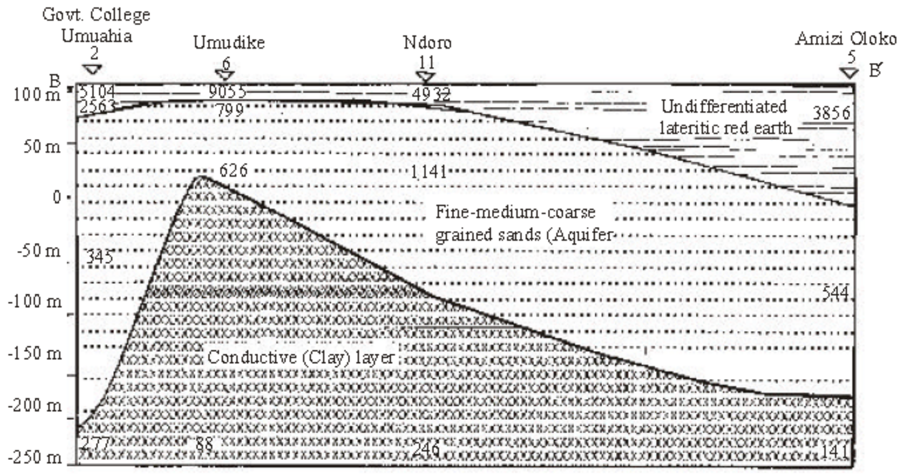

Fig. 7: Geoelectrical section along section BB'(Including depths obtained by Mbonu *et al.*[2])

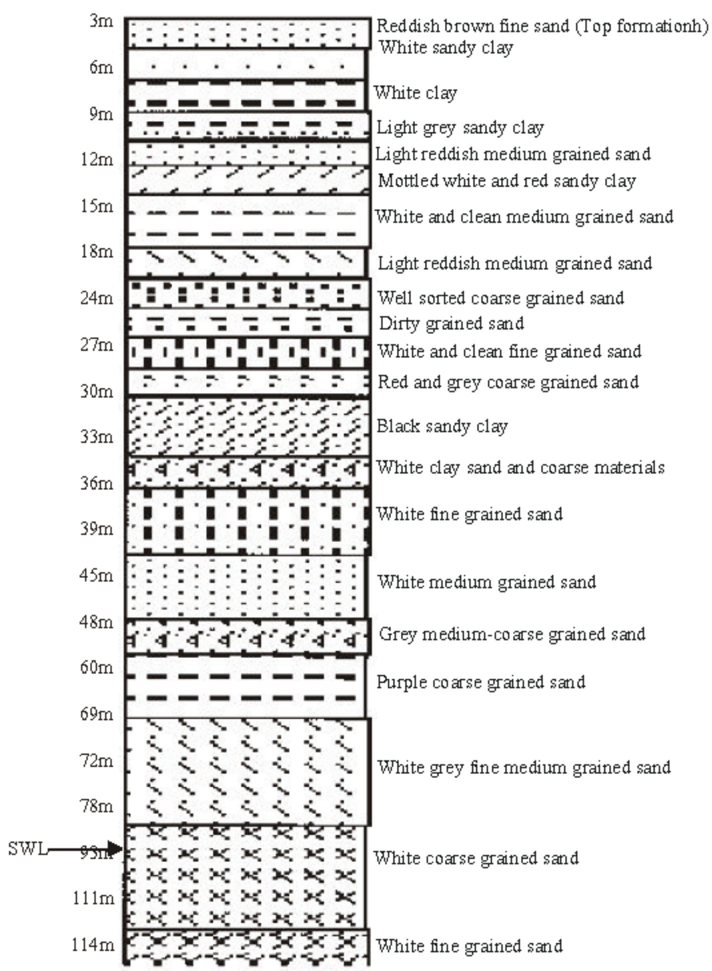

Fig. 8: Litholog of BH No. 3 at Moua, Umudike by Ebilah *et al.*[3]

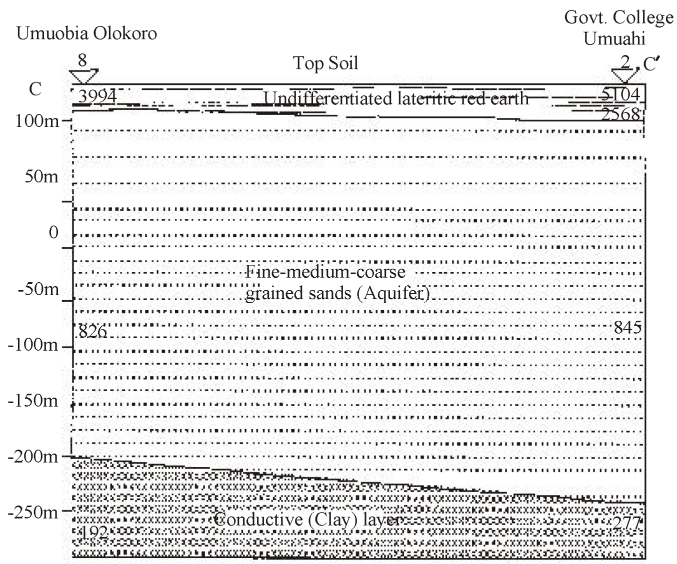

Fig. 9: Geoelectrical section along section CC' Including depths obtained by Mbonu[2]

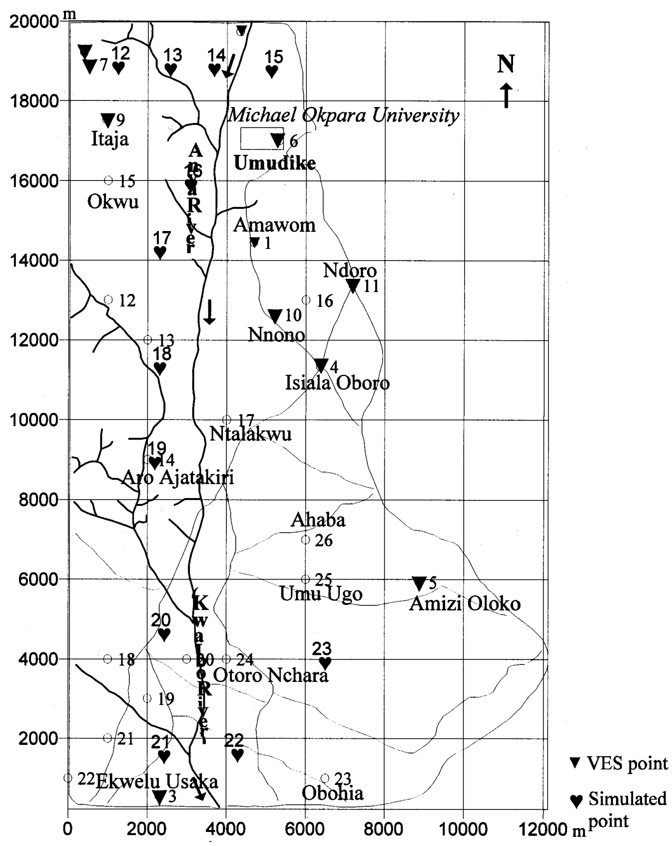

Fig. 10: Grid map of KWA IBO rivers watershed showing location 1-23

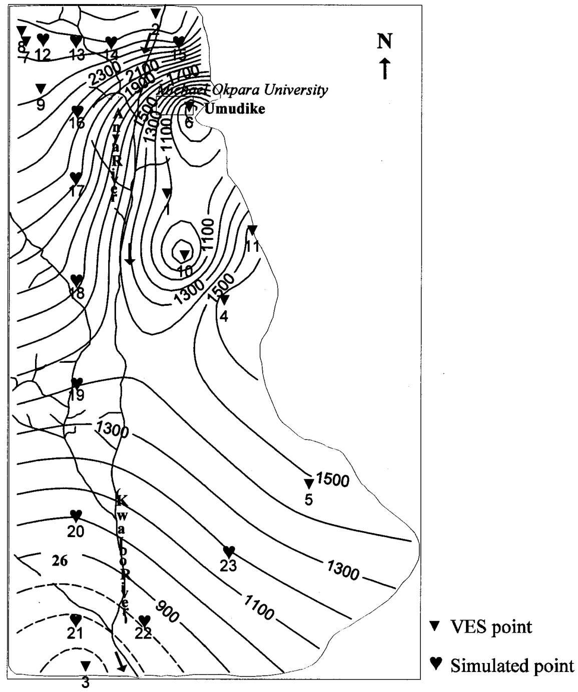

Fig. 11: Contour map of Transmissivity (Tr) for the aquiferous zone

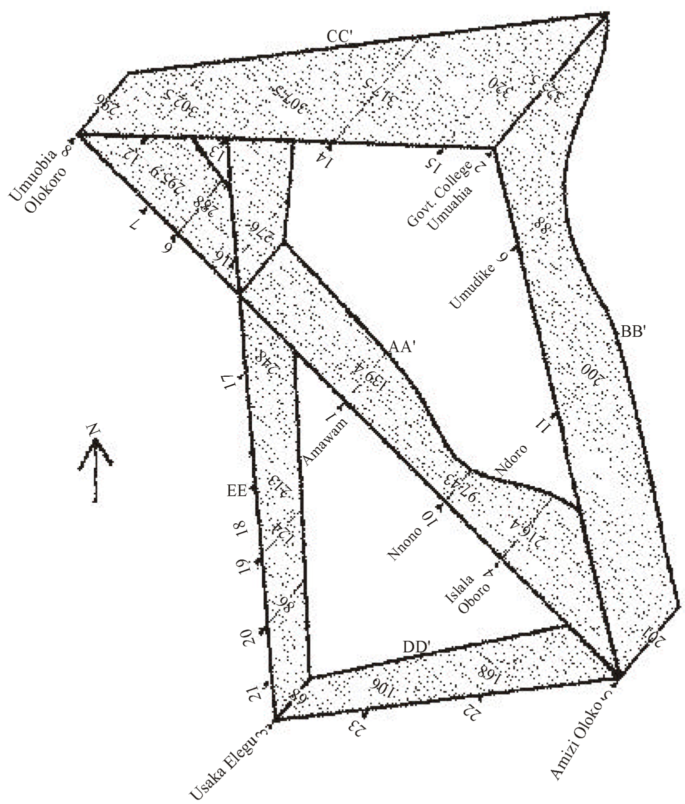

Fig. 12: Fence diagram of the aquiferous zone showing thickness

Table 2: Calculated values of Transmissivity from geoelectric sections

Section	Locations	Transmissivty (m^2/day)	
AA^1	8, 7, 9, 1, 10, 4, 5	1798.00	Average = 1722 m^2/day
BB^1	2, 6, 11, 5	1605.31	
CC^1	8, 12, 13, 14, 15, 2	2602.14	
DD^1	3, 22, 23, 5	1016.00	
EE^1	3, 21, 20, 19, 18, 17, 16, 13	1531.43	

locations were then determined by scale diagram. With these data the transverse resistance, the longitudinal conductance and the transmissivity values were calculated.

Aquifer transmissivity: Aquifer transmissivity has been found to be a very powerful means of confirming zones of prolific aquifers. Aquifer transmissivity is defined as the product of hydraulic conductivity (or permeability) and thickness.

$$\text{i.e. } T_r = kh \qquad (3)$$

It is measured in m^2/day. With hydraulic conductivity values obtained from the pumping tests in the boreholes within the study area, it was possible to estimate the transmissivity of the aquiferous zone and its variation from place to place, including those areas where borehole data are not available. Transmissivity values are high over the entire area under study. The minimum transmissivity is about 600 m^2/day near Usaka Elegu while the maximum is about 2700 m^2/day near Government College cum Umuobia Olokoro axis. The average aquifer transmissivity for the entire watershed was also calculated and found to be 1722 m^2/day. The average transmissivity values for the geoelectric sections were determined as shown in Table 2 below:

Aquifer transmissivity for all the locations was later contoured, Fig. 11. Results obtained are consistent with the aquifer being unconsolidated fine-medium-coarse grained sands. The results further show that areas underlain with relatively thick aquifer have higher transmissivity values than areas underlain by relatively thin aquifer. The Fence diagram of the aquiferous zones in the study area further confirms this, Fig. 12. This means that transmissivity is indeed a function of aquifer thickness.

It should be noted from Fig. 11 that the spatial variability of the transmissivity contour lines increases more rapidly towards the north, attaining a maximum between Umudike and Government College Umuahia. This is a reflection of the magnitude and direction of the velocity of groundwater flow which is seen to be increasing due northeast in this zone by Igboekwe,[8]. Detailed statistics of the aquifer is shown in Table 3.

The fence diagram: Fence diagrams are the most useful means of displaying the sub-surface lithology. In this

Table 3: Aquifer statistics of KWA IBO river watershed

Location No.	Coordinate X (m)	Coordinate Y (m)	Thickness h (m)	Resistivity ρ(Ωm)	Hydraulic conductivity k (m/day)	Transissivity Tr (m^2/day)
1.	4675	14459	138.40	1334.30	8.10	1121.04
2.	4329	19740	325.50	845.10	8.20	2669.10
3.	2294	563	68.00	1337.40	8.00	544.00
4.	6364	11342	216.40	667.20	7.76	1679.26
5.	8874	5931	201.10	544.70	7.40	1488.14
6.	5325	17013	88.00	712.70	8.00	704.00
7.	520	18918	295.90	930.60	8.50	2515.15
8.	390	19220	296.20	826.60	8.65	2562.13
9.	952	17532	288.80	702.40	8.45	2440.36
10.	5195	12640	97.49	1021.60	8.00	779.92
11.	7186	13377	200.00	1141.30	7.80	1560.00
12.	1000	19000	302.50	1032.12	8.50	2571.25
13.	2000	19000	307.50	1032.12	8.40	2583.00
14.	3000	19000	317.50	1032.12	8.30	2635.35
15.	5000	19000	320.00	1032.12	8.10	2592.00
16.	2000	17000	275.00	945.46	8.00	2200.00
17.	2000	15000	248.00	945.46	8.30	2058.40
18.	2000	12000	213.00	945.46	8.25	1757.25
19.	2000	9000	174.00	945.46	8.14	1416.36
20.	2000	5000	124.00	945.46	8.10	1004.40
21.	2000	2000	86.00	945.46	8.00	688.00
22.	4000	2000	106.00	139.71	7.84	831.04
23.	6500	4000	158.00	139.71	7.60	1200.80

study, the fence diagram displays in a more succinct manner the various thicknesses of the aquifer in the study area. It exhibits north to south view. The litho-units have already been displayed in the geoelectrical sections AA/, BB/ and CC/ discussed above. They were inferred from the interpretation of the sounding data.

In Fig. 12, the fence diagram shows the aquifer thicknesses resulting from the sounding data. As can be seen, the northern part of the area between Umuobia Olokoro (Ves No.8) and Government College Umuahia (Ves No.2) has the thickest fence with values between 288 m and 325 m. Along the Eastern part, we see a thick aquifer beginning with Government College Umuahia (Ves No.2) and ending with Amizi Oloko (Ves No.5). The aquifer is no doubt very thick (325 m) in the beginning but suddenly tapers down to 88m around Umudike (Ves No.6).

From Amizi Oloko there is a drastic thinning down towards the southwest zone, culminating at Usaka Elegu (Ves No.3) with a thickness of 68 m. This point appears to be the thinnest aquifer in the entire study area. The trend changes from this point towards the northwest area where it again reaches a maximum thickness at Umuobia Olokoro (Ves No. 8). The thickness of the aquifer at the other points of the study area such as those at Isiala Oboro, Nnono and Amawon (Ves Nos 4, 10 and 1) respectively fall within this range of 68-325 m.

Following an earlier deduction that the aquiferous zone in the study area is essentially fine-medium-coarse-grained sands, we conclude that the fence diagram here shows the thickness of the sands in the area under study. For a complete picture of the sub-surface lithology of the study area, the geoelectrical sections AA/, BB/, CC/, DD/ and EE/ are placed at the positions labelled.

RESULTS AND DISCUSSION

In the study area, it is observed that fresh aquifers with good quality water consists of white fine-medium-coarse grained sands and the resistivity range is between 400-1350Ω m. Aquifer thickness also ranges from 68 m at Usaka Elegu to 325.5 m at Government College Umuahia. Although there are not many VES sounding stations along the geoelectric Section CC/, the sounding stations at Umuobia (point C) and Government College (point C/) show that the aquifer is not only thick and prolific but also extensive. The regional extent is roughly 3.4 km. The KWA IBO River also presents here a basin which has a favourable topographic slope of 15m (ie., 137-122 m) tilted in the direction of this section from Umudike-Itaja axis. The aquifer is thickest at this place because of sedimentation and natural groundwater recharge arising from the drainage, which is in the direction of the slope. Runoff is low here and groundwater recharge is of the order of 1800 mm±30%. Hence abstraction from the terrain could reach 1.3 million cubic metres per square kilometre of land every year. This is far in excess of potential needs. With an aquifer transmissivity of about 2700 m^2/day, the sub-basin (Fig. 11) is therefore a promising zone for regional groundwater development for the catchment area. The catchment area in this axis includes Olokoro, Umuohu (Ahiaeke) and Umudike. The entire watershed is also generally good for groundwater development judging from its high average transmissivity of 1722 m^2/day and relatively high conductivity values except for some locations near Usaka Elegu, Umudike and Nnono that have low transmissivity and high resistivity. It appears from the subsurface lithology, as inferred from BH No.3 at Umudike, that due to sedimentation process, there are intercalations of clay lenses within the aquifer. In general, the boreholes in this area are of collapsible nature. Hence the casing is laid for the entire length of the borehole with necessary screens at the required depth where white fine-medium-coarse grained sands are encountered.

Water analysis has not been carried out for the entire watershed in this research. However, the water analysis carried out at Michael Okpara University of Agriculture Umudike by Ebilah *et al.*[3] indicates good quality water, which complies with the WHO standards except that the pH is low (5.64) and free CO_2 (1.21mmol/l) is high. The low pH value and the high CO_2, are insitu conditions in the Tertiary formations where lignite seams are in contact. The two features are not detrimental to health but create aggressive water, which causes corrosion and encrustation and attack steel riser pipes in a borehole. The problem can, however, be solved by the use of class D (black) API casings for the borehole construction and flanged API risers for the submersible pumps.

CONCLUSION

From the foregoing, we conclude that the geological formation in the study area is essentially that of Benin Formation. This Formation consists of fine-medium-coarse-grained sands, which is consistent with the geology of the marine sediments of southeastern Nigeria. The soundings also identified thick aquifer zones especially the Umuobia Olokoro cum Government College Umuahia sub-basin as a favourable zone for regional groundwater development for the catchment area: Olokoro, Umudike and Umuohu (Ahiaeke). The results demonstrate the reliability of geoelectric soundings in the delineation of aquifers. With an average aquifer transmissivity of 1722 m^2/day, the watershed can generally be scored excellent for any ground-water development programme in the country.

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