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GEOELECTRIC INVESTIGATION FOR GROUNDWATER IN ANIOCHA SOUTH LOCAL GOVERNMENT AREA, DELTA STATE NIGERIA

O. E. FREEBORN

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ABSTRACT

The Vertical Electrical Sounding (VES) technique was employed in investigating for groundwater in Ogwashi-Uku and Ubuluku towns in Aniocha South Local Government Area, northern Delta State. In all, fourteen VES stations were occupied with a maximum current electrodes separation of 650m and station interval ranging from 225m to 450m. The acquired field data were interpreted quantitatively by partial curve matching and by computer iteration. The model curves are broadly classified into seven hybrid types viz: **AAA, KHA, AAK, KHKHA, HAKH, AKH** and **KHAK.** Five to seven geoelectric layers were delineated. The layer resistivity values range from 38Ω-m to 643Ω-m for the topmost layer to between 534000Ω-m and 1000000Ω-m for the bottommost layer. The inferred near surface geologic formations in the area are constituted by clay/clayey sand, silt/fine grained sand, medium-coarse grained sand and gravel as indicated in the computed model parameters and geoelectric sections. The topmost layer lithologic composition varies from clay, clayey sand, sandy clay and fine to medium grained lateritic sand. The intervening layers lithologic composition consist of fine-medium-coarse grained sand, gravely sand, sandy gravel, gravel and sometimes with clay lenses. The bottom layer lithologic composition consists of coarse sand, sandy gravel, gravely sand and gravel, spanning a depth range of 80m to 150m from the earth surface. The geoelectric sections also indicate that the lateral lithologic heterogeneity is due to gradational lithologic contacts arising from changes in sediment particle sizes, hence geologic formations do not persist over a broad area and the hydrological implication being an impaired lateral permeability. This invariably causes high rate of drawdown and low rate of recharge. A generalized depth to the water table from the earth's surface cannot be adduced for the entire study area because it varies from one locality to another. However, a "Static Water Level" at a depth range of between 110m to 140m in some parts of Ogwashi-Uku and 125m to 150m in parts of Ubuluku constituted of medium-coarse grained sand and gravely sand are adjudged generally suitable for relatively shallow groundwater (first aquifer) development. There is however, the need to carry out a geophysical investigation in any locality prior to sinking a borehole in order to forestall losses and to have productive wells

KEYWORDS: *Geoelectric layers *Lithologic heterogeneity *Static water level *Impaired permeability *Aquifer

INTRODUCTION

The study area consists of semi-urban towns situated in the northern part of Delta State. Development in the area hinges on small to medium scale industries, commercial activities, artesian works and farming. Few streams and rivers drain the area, while few boreholes (private and government owned) serve the water needs of the inhabitants. In addition, rain harvesters (concrete storage tanks) that are very often constructed in residential premises and purchase from tanker water vendors, all add to the source of water supply. Hand dug wells are virtually absent in the entire study area.

The lithologic sequence in most parts of the northern Delta State does not favour the occurrence of groundwater at shallow depths as a result of mainly sandy formations constituting the shallow sequence and a general lack of thick clayey interbeds. The encompassing communities have the highest number of packed up boreholes, poor water yielding or abandoned drilled holes including those of Delta State Urban Water Board. Due to improper understanding of the subsurface geology, huge financial losses have been suffered by government agencies, corporate organizations and individuals sinking boreholes in the area. These problems could be minimized or avoided with a good prior knowledge of the subsurface geology.

Geophysical methods are important in investigating near surface formations and modeling of aquifer units for groundwater development. Notable amongst them are the seismic refraction, magnetic, electromagnetic (VLF) and electrical resistivity methods. The choice of any one or a combination of two depends on the terrain and the level of resolution that is needed. Olorunniwo and Olorunfemi (1987), used a combination of magnetic, electromagnetic (VLF) and electrical resistivity methods to map buried bedrock relief in order to ascertain the groundwater potential in the Precambrian terrain of Ikare, Southwestern Nigeria. Afolayan et al., (2004) used a combination of electrical resistivity and electromagnetic (VLF) methods in investigating for groundwater in the Basement Complex within the premises of the Conference Center, Obafemi Awolowo University, Ile-Ife. This enabled them to make the deduction that the partly weathered/fractured Basement rocks constitute the aquifer units. Ako and Osundu (1985), employed the vertical electrical sounding technique to investigate variation in litholgy and structure of the Keri-Keri Formation in Darazo, Nigeria. They inferred that the major productive aquifer lies at a depth greater than 100m. Emenike (2000), used the vertical electrical sounding technique to investigate for groundwater in Nanka Formation, Anambra Basin. He inferred the thickness and depth to the sandstone that constitutes the aquifer unit to be in excess of 200m and 100m respectively. The electrical resistivity method has also been successfully employed in coastal areas of the Niger Delta Basin to investigate for groundwater, saltwater-freshwater interface and the lateral extent of salt water intrusion (Etu-Efeotor et al., 1989. Amadi and Amadi, 1990, Mbipon and Archibong, 1989)

The general preference of the electrical resistivity technique in groundwater exploration arises from the fact that the resistivity of a formation largely depends on the porosity, degree of fluid saturation and the chemical properties (ions concentration) of the filling fluid. Thus in a sedimentary sequence, a relatively high resistivity layer may broadly be associated with the presence of fresh groundwater in a porous medium (aquifer), while a low resistivity layer may be due to the presence of clay/shale or saline water

Attempting the delineation of depths to water tables in the study area is imperative because of rampant cases of boreholes with poor water yield, boreholes getting dried up soon after commissioning, and sometimes outright

O. E. Freeborn, Department of Geology, Delta State University, Abraka, Nigeria.

abandonment even amongst those owned by the state government. The present study is aimed at investigating the near surface geologic formations in the area in lieu of groundwater development. It entails the use of vertical electrical sounding (VES) technique using Schlumberger electrode configuration at fourteen VES locations in Ogwashi-Uku and Ubuluku in Aniocha South Local Government Area (LGA), northern Delta State, Nigeria. Borehole lithologic logs are being incorporated into the interpretation to minimize discrepancies in deduced geoelectric parameters and that obtained from boreholes. It is hoped that the results of this investigation will be of immense importance in future groundwater development programme in these areas, as it will provide information on probable depths to suitable aquifer units. This information will provide to some extent the causes of poor water yield by boreholes or boreholes getting dried outright sooner after commissioning.

Location and Geology of Study Area

The study area (Ogwashi-Uku and Ubuluku) lies within the northern flank of the Niger Delta basin between Latitudes 6^0 00'N and 6^0 20'N and Longitudes 6^0 20'E and 6^0 40'E (Fig. 1). It falls within the localities where the lithofacies of the Niger Delta grade gradually into the lithofacies of the Anambra Basin. The area is thus underlain from the earth's surface by the Benin Formation, Ogwashi-Asaba Formation and Ameki Formation, with the Ogwashi-Asaba Formation as a lateral equivalent of Upper Agbada Formation of the Niger Delta (Fig. 2). The geology of the Niger Delta has been described by Allen (1965), Burke et al., (1972), Short and Stauble (1972), and Murat (1972). It consists basically of three diachroneous stratigraphic units viz:

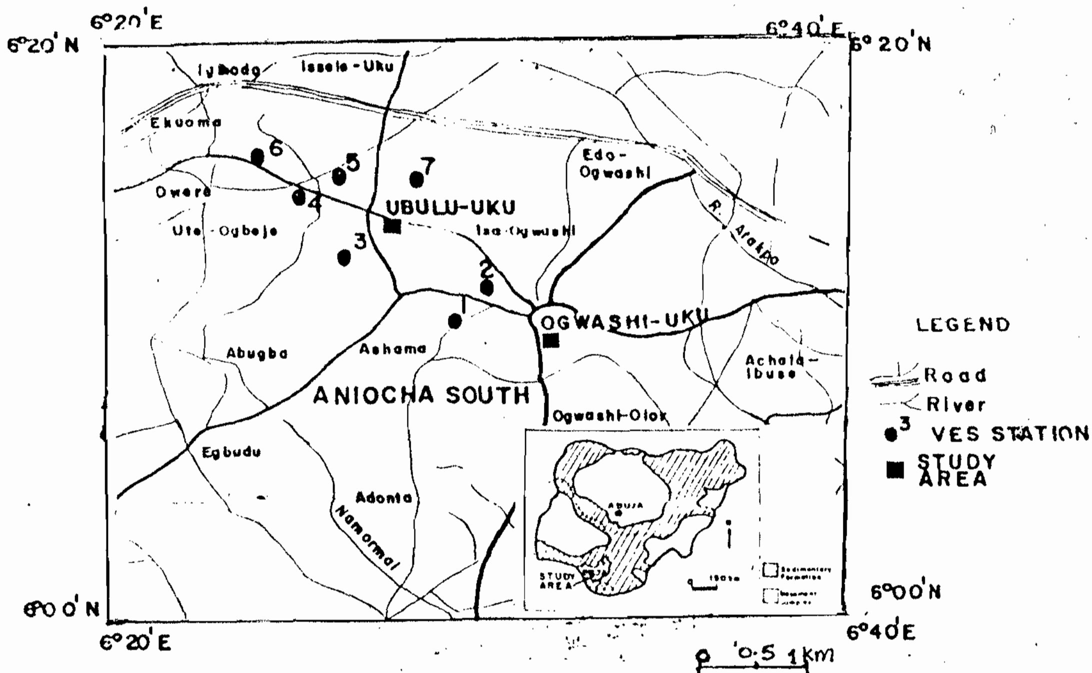

Fig. 1: Location map of the study area with VES locations, inset is a simplified geological map of Nigeria.

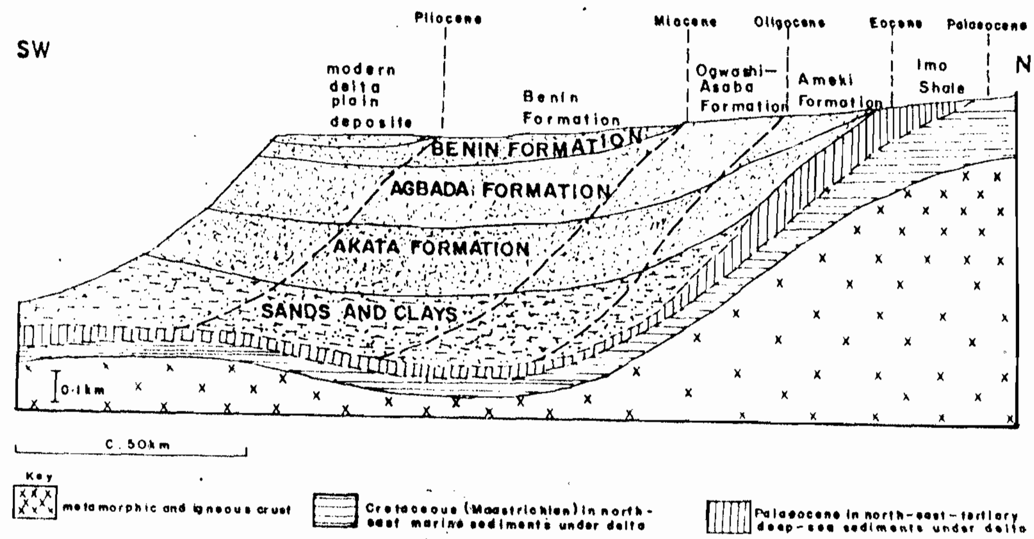

Fig. 2: Stratigraphy of the Niger Delta.

(i) Benin Formation (Oligocene to Recent): This formation is dominantly a fluvial facies unit made up of 90% sand/sandstone and clay intercalations.

(ii) Agbada Formation (Eocene to Recent): This is a deltaic facies {clinoform} unit made up of an alternating sequence of sandstone and shale. This paralic sequence {sandstone-shale} is in response to eustatic changes in sea-level during sedimentation.

(iii) Akata Formation (Palaeocene to Recent): This is an open marine facies {pro-delta} unit dominated by under pressured shale of 2000m to 4000m in thickness.

The overall lithostratigraphic sequence is up to 12,000m thick, and covering an area of about 75,000km^2. Superficial deposits include sandy clay, loose sand, fine-medium grained lateritic sand with characteristic colours of reddish brown, brownish red and light brown. Figure 2 is a schematic diagram of lithostratigraphic units of the Tertiary Niger Delta, while Table 1 shows the characteristics of lithostratigraphic units of Niger Delta modified after Reyment, (1965)

Table 1: Outcropping Lithostratigraphic Units of Tertiary Niger Delta (modified after Reyment, 1965)

Age span	Lithostratigraphic unit	Characteristics
Oligocene to Recent	Benin Formation	Known also as Coastal Plain Sand, it consists of cross bedded, coarse pebbly continental sand with clay lenses and lignite , has marine shales with foraminifera, ostracods and mollusks
Oligocene to Miocene	Ogwashi-Asaba Formation [Lignite series]	Clay, silts and sands with lignite seams up to 2m thick
Eocene to Early Oligocene	Ameki Formation	Calcareous clays and silts with thin shelly limestone, rich in foraminifera.
Eocene	Nanka Formation	Mainly sand, minor silts and clay.
Paleocene to Early Eocene	Imo Formation	Blue grey shale's with sand lenses, marls and limestone, shale formation with ostracords.

Hydrogeology of the Study Area

Two main rivers drain Aniocha South Local Government Area., with River Ubu being the notable river in Ogwashi-Uku and flows through the Forest Reserve, while River Iyiagbo flows through the oil palm plantation in Ubuluku. The drainage is dendritic and these rivers are at relatively long distances away from places of habitation. Their courses generally follow the valley systems as the area is dotted with small hills and valleys, however, some of these valleys serve only as channels for surface runoff after rainfall. Rainwater collected over roofs tops and channeled through pipes into concrete or metallic tanks in residential premises is one of the major sources of surface water. These areas have potentials for groundwater development. Multi-layered aquifer systems exist in the sandy units of Ameki, Ogwashi-Asaba and Benin Formations respectively. The aquifer units are however, occurring at relatively deep depths in comparison to some parts of central and southern Delta State. Hydrogeological data obtained from Delta State Urban Water Board indicates that the "Static Water Levels" [SWL] of the first and second aquifers lie averagely between 335ft and 470ft (102m – 145m), and 600ft and 750ft (180m – 225m) respectively in Ogwashi-Uku and at about 362ft and 552ft (110m – 168m) and 730ft and 800ft (222m - 240m) in Ubuluku. There is a high degree of variability of Static Water Level from one locality to another. Generally, most government owned water boreholes penetrate beyond the first aquifer.

Research Data Base and Data Interpretation

The Vertical Electrical Sounding [VES] technique adopting the Schlumberger electrode configuration was used in the data acquisition that was carried out around Ubuluku and Ogwashi-Uku, in Aniocha South Local Government Area, Delta State. The choice of locating VES stations was guided by observed relief in the area and the need to have a good geographic spread. Seven VES stations were occupied each in Ogwashi-Uku and Ubuluku. The maximum current electrodes separation ranged from 450m to 650m depending on accessibility. The intervals between stations varied from 225m to 450m. A digital SAS 300 Model Terrameter was used for the data recording. The apparent resistivity values obtained from the field measurement were plotted against half current electrodes spacing [AB/2] on a bi-logarithm graph paper to produce corresponding field curves. The field curves were interpreted quantitatively by partial curve matching using two layer model curves and by computer iteration using Resist Version 1.0 interpretation software (Figures 3-6). The geoelectric parameters deduced and inference made therein were compared with lithologic logs obtained from drilled boreholes in the study area (Fig 7).

DISCUSSION OF RESULT

The fourteen field curves can be classified into seven categories of **AAA**, **KHA**, **AAK, KHKHA, HAKH**, **AKH** and **KHAK** as shown in Table 2. The **AAA** curve type depicts increasing layer resistivity values with depth. The geologic implication being a lithologic sequence in which the sand content/grains sizes increase with depth. The coarsest sediment tends to have the highest resistivity value because of less surface area for electrical conductivity. The **KHA** hybrid curve type indicates a relatively low resistivty top layer between a high resistivity layer and a low resistivity underlying layer and subsequently the layer resistivity increasing with depth. This is typical of localities where the superficial sediment is mainly clayey sand to sandy clay, overlying a lateritic medium-coarse grained sand and an underlying layer of silty sand or fine grained sand. Subsequent underlying layers becoming coarser with depth. The **AAK** hybrid curve type depicts localities in which layer resistivity increases with depth, but truncated by a relatively higher resistivity layer and a subsequent underlying low resistivity layer. This is interpreted to correspond to a sequence in which the first three layers are constituted of clayey sand, lateritic fine – medium grained sand and light brown to brownish medium to coarse grained sand and followed by coarse grained sand and a subsequent underlying layer of medium grained sand. The **AKH** curve type is indicative of a lithostratigraphic section in which layer resistivity increases with depth in the first three layers and a subsequent underlying layer of a relatively higher resistivity underlain by a lower resistivity layer. It is typical of localities in which the top layer is constituted of fine grained lateritic sand and subsequent increasing sedime

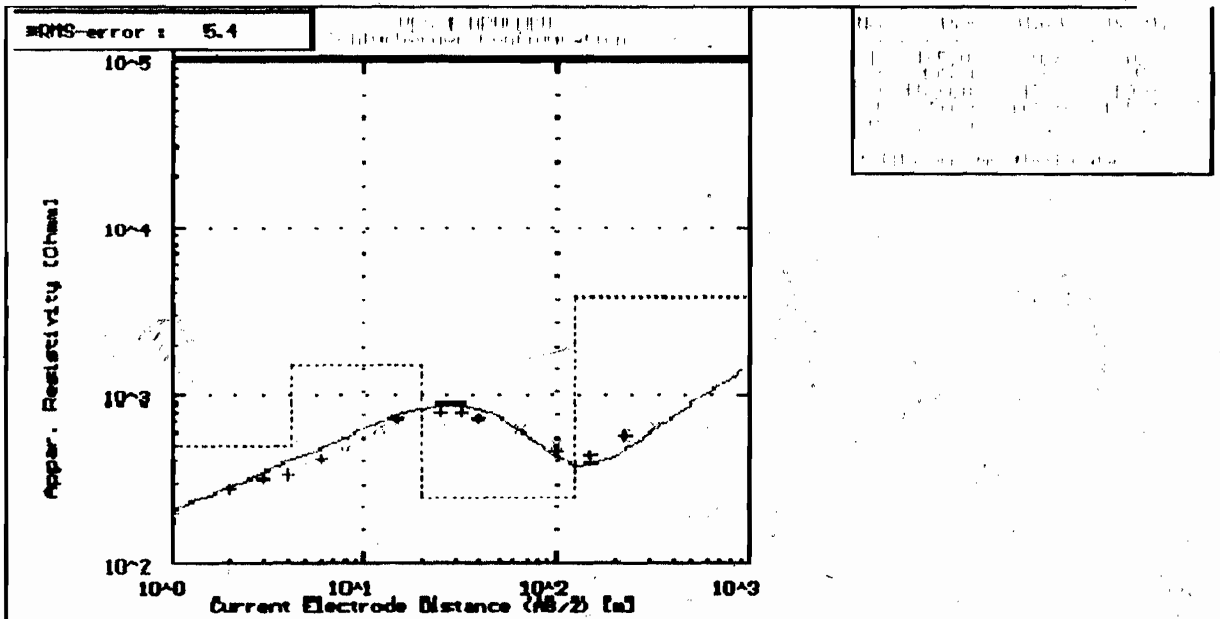

Fig 3: VES 1 Ubuluku Computer Model Curve and geoelectric parameters [AKH type]

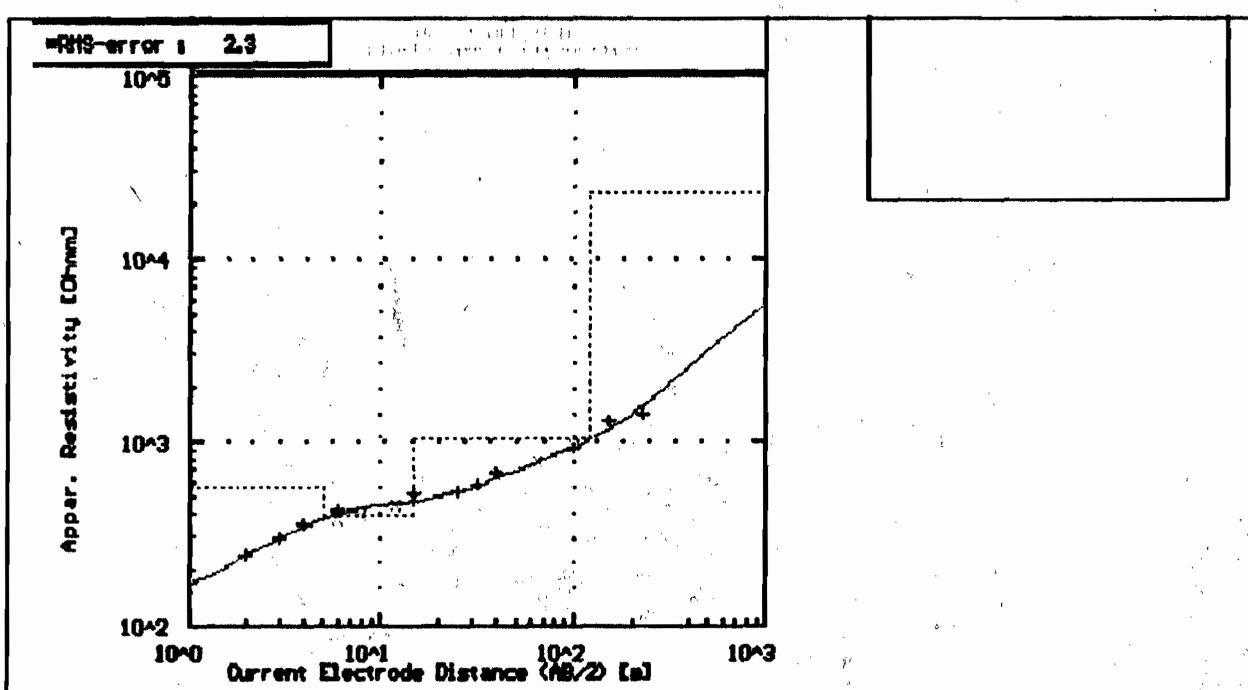

Fig 4: VES 4 Ubuluku Computer model and geoelectric parameters [KHA Type]

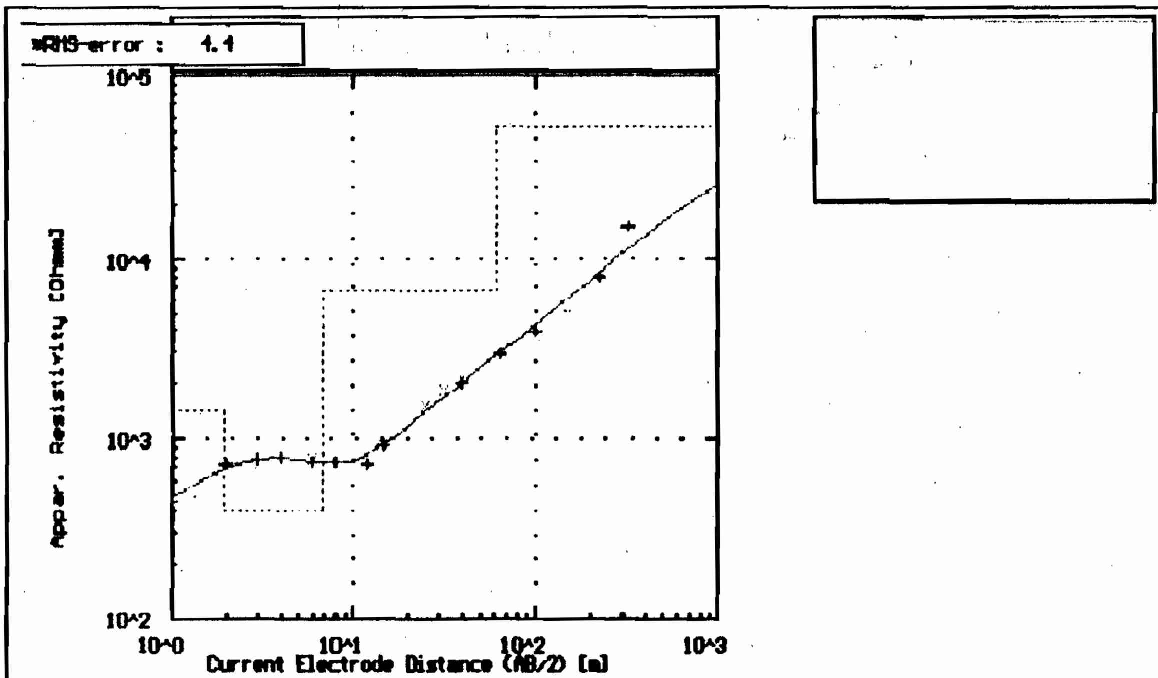

Fig 5: VES 1 Ogwashi-Uku Computer Model curve and geoelectric parameters [KHA Type]

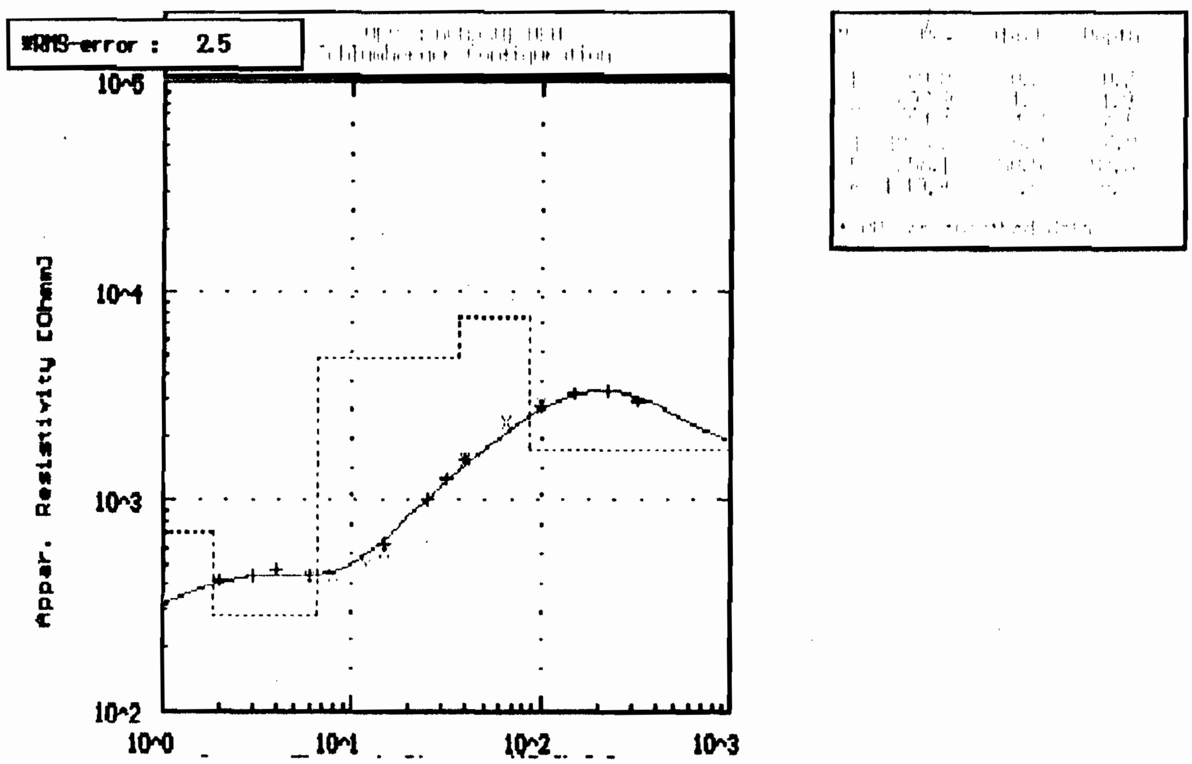

Fig 6: VES 3 Ogwahi-Uku Computer model curve and its Geoelectric parameters [KHAKK Type].

particle/grain sizes with depth in the first 3 layers and an interbedding of a relatively higher resistivity layer underlain by a low resistivity layer. The **KHKHA, HAKH** and **KHAK** model hybrid curve types are indicative of a more complex stacking pattern of lithologic sequence involving mainly changes in grain sizes and intercalations of silty sand and clay lenses.

Table 2: Classification of field curve types of the study area.

Model curve type	No of layers	VES Station	Frequency
AAA $\rho_1<\rho_2<\rho_3<\rho_4<\rho_5$	5	Ogwashi-Uku VES 4 and 7	2
KHA $\rho_1<\rho_2>\rho_3<\rho_4<\rho_5$	5	Ogwashi-Uku VES 1 Ubuluku VES 4 and 7	3
AAK $\rho_1<\rho_2<\rho_3<\rho_4>\rho_5$	5	Ogwashi-Uku VES 2 and 5 Ubuluku VES 2	4
KHKHA $\rho_1<\rho_2>\rho_3<\rho_4>\rho_5<\rho_6<\rho_7$	7	Ubuluku VES 3	1
HAKH $\rho_1>\rho_2<\rho_3<\rho_4>\rho_5<\rho_6$	6	Ubuluku VES 5	1
AKH $\rho_1<\rho_2<\rho_3>\rho_4<\rho_5$	5	Ubuluku VES 1	1
KHAK $\rho_1<\rho_2>\rho_3<\rho_4<\rho_5>\rho_6$	6	Ogwashi-Uku VES 3 and VES 6	2

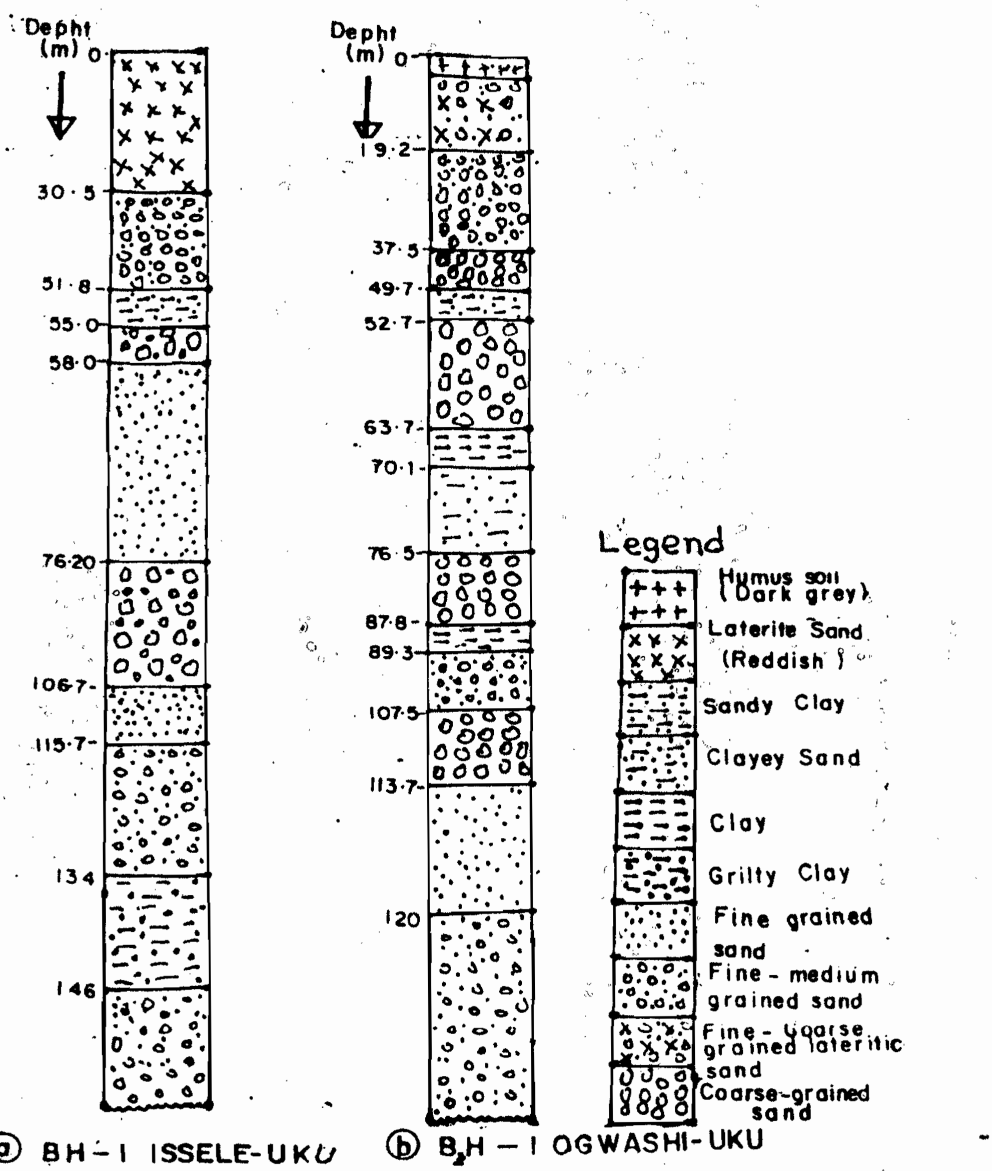

Fig. 7: Borehole lithologic log ⓐ BH-1 ISSELE-UKU Omodo primary school.
ⓑ BH-1 OGWASHI-UKU near Post office.

A quantitative evaluation of the fourteen VES model curve types and the computed geoelectric layers parameters indicate five to six geologic layers in Ogwashi-Uku and five to seven in Ubuluku respectively as shown in Table 3 and Figures 8 and 9. Thus in Ubuluku, the first layer has resistivity values ranging from 138 Ω-m (VES 4) to 539 Ω-m (VES 5) (see Figure 8). These resistivity values are inferred to be sandy clay, clayey sand and fine grained lateritic sand that commonly constitute the superficial deposits in this area of study. Its thickness varies from 0.6m to 1.3m. The second layer has resistivity values that range from 167 Ω-m (VES 6) to 844 Ω-m (VES 3) and spanning a depth range of between 2.4m and 9.2m with a thickness ranging from 1.6m to 7.9m. The deduced lithologies include sandy clay, medium – coarse grained sand and coarse grained sand. The third layer resistivity values range from 254 Ω-m (VES 5) to 395 Ω-m (VES 4) within a depth range of 7.3m to 18.6m and thickness of between 7.3m and 15.6m and does not extend to the sites of VES 1 and 7. The inferred lithologic types include silty sand, fine-medium grained sand and coarse grained sand. The fourth layer has resistivity values ranging from 138 Ω-m (VES 5) to 5150 Ω-m (VES 3). The inferred lithologies include sandy clay, medium – coarse grained sand and gravelly sand, spanning a depth range of 24.1m to 126m with a thickness ranging from 8.1m (VES 3) to 106.1m (VES 4). This is inferred a potential shallow aquifer unit at VES 2 and VES 4 locations respectively. These VES stations (VES 2 and 4) are located in areas with a relatively higher relief and simple lithostratigraphic section and sediment sagging/syn and post-depositional processes could have resulted in a more complex intervening lithostratigraphic section (Figure 9). Boreholes drilled to depths of 110m to 125m is inferred will have good water yield. The transverse unit resistance of this unit ranges from 1.092 x10^5 Ω-m^2 to 5.192 x10^5 Ω-m^2. The fifth layer has resistivity values ranging from1528 Ω-m (VES 2) to 3870 Ω-m (VES 1). The inferred litholgies include medium grained sand to coarse – gravely sand with a minimum depth of 41.9m (VES 6) and maximum of 121.1m. This is another potential aquifer unit that is more persistent laterally and hence better boreholes water yields. Layer six is common to VES 3 and VES 5 only. Its resistivity values range from 360 Ω-m (VES 3) to 372 Ω-m [VES 5] and extends through to VES 7 as lateral equivalent . It is inferred to be a fine grained sand. Its thickness ranges from 21.9m (VES 3) and 22.7m (VES 5). Layer seven is also common to both VES 3 and VES 5. Its

Table 3: Geoelectric Layers' Parameters Deduced from Computer Iteration and Modeling of the VES Field Curves in Parts of Aniocha South LGA, Delta State.

VES Station	Layer number	Resistivity ρ_a [Ω-m]	Thickness [m]	Depth [m]	Transverse unit Resistance [Ω-m^2]	Longitudinal Unit Resistance [Siemens]	Inferred lithology
VES 1 Ubuluku	1	165.0	0.6	0.6	99.0	0.0036	Gritty clay
	2	495.0	3.6	4.2	1782.00	0.0073	Silty fine sand
	3	1520.0	15.6	18.8	23712.0	0.0103	Medium-coarse sand
	4	250.0	105.8	125.8	26450.0	0.4232	Clayey sand
	5	3780.0	-	-	-	-	Coarse-gravely sand
VES 2 Ubuluku	1	310.1	0.8	0.8	248.08	0.026	Clayey sand
	2	392.5	1.6	2.4	628.00	0.0041	Silty sand
	3	412.5	4.9	7.3	2021.25	0.0119	Fine grained sand
	4	5150.7	100.8	108.1	519190.56	0.0200	Coarse-gravely sand
	5	1528.3	-	-	-	-	Medium grained sand
VES 3 Ubuluku	1	174.5	2.6	2.6	453.7	0.0150	Sandy clay
	2	843.6	6.4	9.0	5399.04	0.0076	Medium grained sand
	3	362.6	7.0	16.0	2094.4	0.0234	Clayey sand
	4	165.3	8.1	24.1	1338.93	0.0490	Sandy Clay
	5	890.2	28.8	52.9	25637.76	0.0324	Medium grained sand
	6	359.6	21.9	74.8	7875.24	0.0610	Silty sand
	7	6741.3	-	-	-	-	Coarse-gravely sand
VES 4 Ubuluku	1	138.3	0.9	0.9	124.47	0.0065	Sandy Clay
	2	564.8	4.2	5.1	2372.16	0.0074	Fine grained sand
	3	394.8	9.8	14.9	3869.04	0.0248	Clayey sand
	4	1029.0	106.2	121.1	109176.9	0.1031	Medium grained sand
	5	23350.4	-	-	-	-	Sandy gravel
VES 5 Ubuluku	1	538.8	1.3	1.3	700.44	0.0024	Silty fine grained sand
	2	146.7	7.9	9.2	1158.93	0.0540	Sandy clay
	3	258.3	8.6	17.8	1365.68	0.0542	Clayey sand
	4	138.0	9.4	27.2	1297.2	0.0681	Sandy clay
	5	3169.0	69.7	96.9	220879.3	0.0220	Coarse-gravely sand
	6	372.5	22.7	119.5	8455.75	0.0610	Silty sand
	7	6253.6	-	-	-	-	Coarse-gravely sand
VES 6 Ubuluku	1	147.2	0.9	0.9	132.48	0.0061	Sandy clay
	2	167.2	1.9	2.8	317.68	0.0114	Clayey sand
	3	337.4	9.1	11.9	3070.34	0.0270	Silty sand

	4	202.3	32.0	41.9	6473.6	0.1582	Clayey sand
VES Station	Layer number	Resistivity ρ_a [Ω-m]	Thickness [m]	Depth [m]	Transverse unit Resistance [Ω-m^2]	Longitudinal Unit Resistance [Siemens]	Inferred lithology
	5	30803.8	-	-	-	-	Sandy gravel
VES 1 Ogwashi-Uku	1	329.0	0.5	0.5	164.5	0.0015	Silty sand
	2	1401.1	1.5	2.0	2101.65	0.0011	Medium grained sand
	3	401.7	4.9	6.9	1968.33	0.0122	Silty fine grained sand
	4	6588.0	55.9	62.7	368269.2	0.0085	Coarse-gravely sand
	5	53400.7	-	-	-	-	Sandy gravel
VES 2 Ogwashi-Uku	1	233.7	0.6	0.6	140.22	0.0026	Clayey sand
	2	1144.9	5.2	5.8	5953.48	0.0045	Medium grained sand
	3	1616.4	10.0	15.8	16164	0.0062	Medium-coarse sand
	4	15989.2	66.9	82.8	1069677.48	0.0042	Sandy gravel
	5	2147.8	-	-	-	-	Coarse grained sand
VES 3 Ogwashi-Uku	1	269.8	0.7	0.7	188.86	0.0026	Clayey sand
	2	697.9	1.2	1.9	837.48	0.0017	Fine grained sand
	3	284.6	4.7	6.6	1337.62	0.0165	Clayey sand
	4	4865.7	30.3	36.8	147430.71	0.0062	Coarse grained sand
	5	7556.1	50.5	87.3	381583.05	0.0067	Coarse-gravely sand
	6	1719.9	-	-	-	-	Medium-coarse sand
VES 4 Ogwashi-Uku	1	112.8	0.7	0.7	78.96	0.0062	Gritty clay
	2	481.1	4.9	5.6	2357.39	0.0102	Silty sand
	3	1484.0	8.2	13.8	12168.8	0.0056	Medium grained sand
	4	27607.2	15	28.9	414108.00	0.0005	Sandy gravel
	5	100000.0	-	-	-	-	Gravel/lignite?
VES 5 Ogwashi-Uku	1	38.1	0.7	0.7	26.67	0.0184	Clay
	2	140.4	7.5	8.2	1053.0	0.0534	Gritty clay
	3	835.1	7.5	15.7	6263.25	0.0090	Medium grained sand
	4	3806.1	43.9	59.6	167087.79	0.0115	Coarse grained sand
	5	614.1	-	-	-	-	Fine grained sand
VES 6 Ogwashi-Uku	1	643.7	0.8	0.8	514.96	0.0013	Fine grained sand
	2	1745.8	1.2	2.0	2094.96	0.0007	Medium grained sand
	3	745.8	5.0	7.0	3729.0	0.0067	Fine grained sand
	4	3452.8	23.6	30.6	81486.08	0.0068	Coarse grained sand
	5	4716.5	68.5	99.1	323080.25	0.0145	Gravely sand
	6	3831.9	-	-	-	-	Coarse grained sand

resistivity values range from 6253 Ω-m to 6741 Ω-m. Its lithology is mainly gravely sand. It is inferred that boreholes drilled to a depth range of 125m to 150m will have good water yield at these VES locations.

Ogwashi-Uku geoelectric layers parameters are very similar to that of Ubuluku, however, a highly resistive layer (ρ_a > 1.6 x10^4 Ω-m) is encountered at the fourth or fifth layer of some VES stations (Table 3). Lithologic logs of some boreholes drilled in the area indicate the occurrence of a layer of lignite that is often less than 5m in thickness and at a variable depth ranging from 34.5m to 62.3m. The first three layers are characterized by resistivity values that range from 38 Ω-m to 1745 Ω-m. This is inferred to be lthologies that vary from clay, sandy clay, clayey sand, silty sand and fine – medium grained sand within a depth range of 0.5m to 15.8m. Borehole lithologic logs indicate that this interval is composed of lithologies that are rich in iron [ii] oxide (lateritic). The fourth layer has resistivity values that range from 3806 Ω-m (VES 5) to 27,607 Ω-m. The lithology varies from a coarse grained sand to coarse-gravely sand. Its thickness ranges from 23.6m (VES 6) to 55.9m (VES 4) within a depth range of 28.9m to 82.8m. The fifth layer has resistivity values that range from 2147 Ω-m (VES 2) to 100,000 Ω-m (VES 4) corresponding to an inferred lithology varying in composition from coarse grained sand, coarse gravely sand, sandy gravel and lignite and lies within a depth range of 99.1m (VES 6) to an undetermined depth (infinity) at VES 1, 2, 4 and 5 respectively. Other VES stations (VES 3 and 6) have an underlying layer of coarse grained sand. The fifth layer is inferred a potential aquifer unit especially at VES 2, VES 3 and VES 6 with an

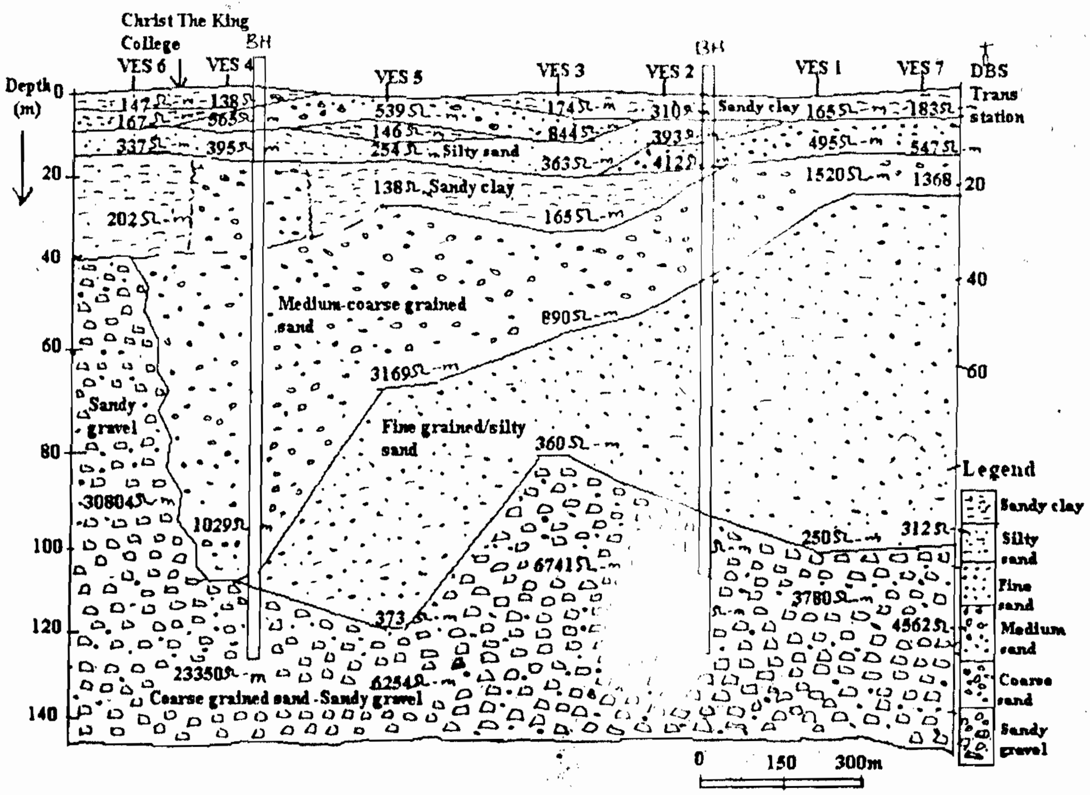

Fig 8: Geoelectric section of Ubuluku showing near surface lithologic distribution and recommended borehole (BH) sites.

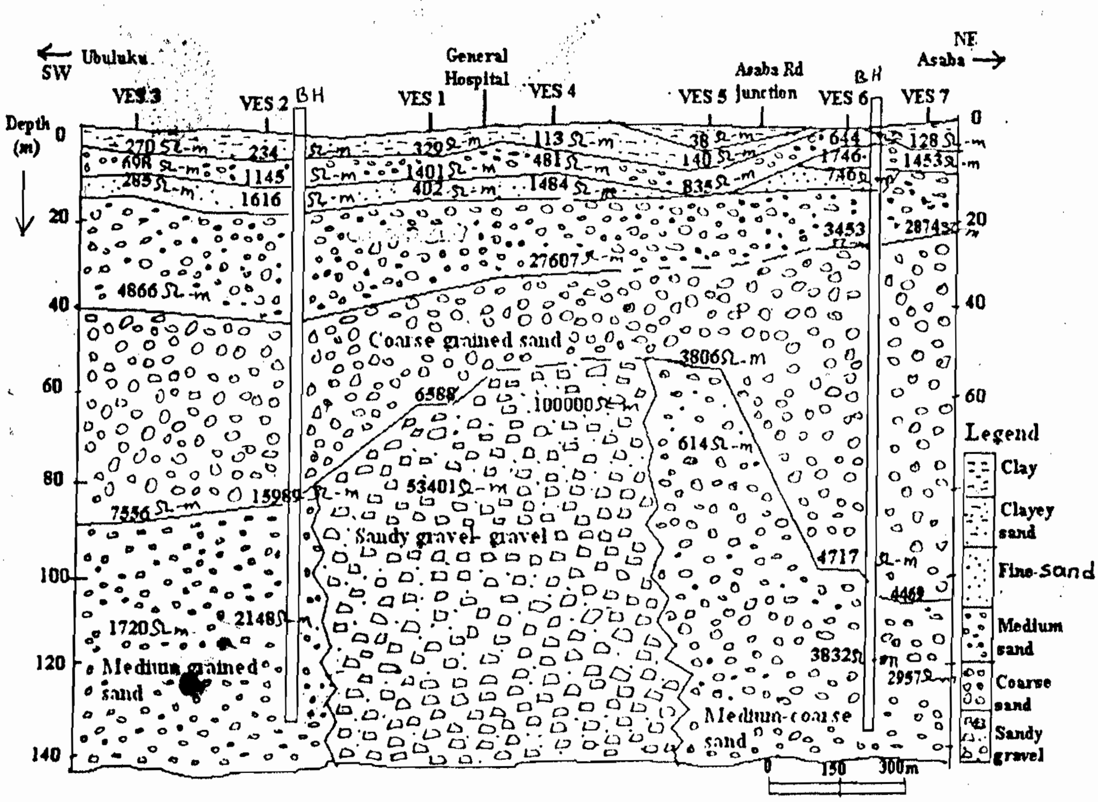

Fig 9: Geoelectric section of Ogwashi-Uku showing near surface lithologic distribution and recommended borehole (BH) sites

average static water level of 74m (first aquifer) and lithology of medium – grained sand. This layer also has transverse unit resistance that range from 1.67 $x10^5$ Ω-m^2 to 4.14 $x10^6$ Ω-m^2. According to Ako and Osundu (1985), high values of transverse unit resistance are directly related to high aquifer transmisivity. Thus boreholes drilled to a depth range of 85m to130m at these VES locations will have good water yield. The sixth layer is encountered at VES 3 and 6 locations only. Its resistivity values range from 1719 Ω-m (VES 3) to 2831 Ω-m (VES 6), and an inferred lithology of medium to coarse grained sand. This is a probable aquifer unit that can be effectively tapped at a depth range of 95m to 125m at VES 3 and 6 locations.

The geoelectric sections (see Figures 8 and 9) indicate that the study areas lateral lithologic heterogeneity is as a result of gradational lithologic contacts. Lithologic units are quite impersistent over a broad area and lithofacies variation is quite common. This makes unit correlation between VES stations somehow difficult over a wide area. This is anticipated because at the proximal part of a coastal sedimentary basin, depositional conditions are rarely persistent over a wide surface area and a long duration of time. There is a close association of several sub-environments such as estuary, lagoon, lake, delta/delta lobes, tidal flats/inlets, creeks, channel fill, overbank, flood plain and alluvial plain, most of which are directly influenced by marine processes including changes in relative sea-level. Each of these sub-environments has its characteristic lithofacies. Consequently, there is a complex lithofacies association in response to changing depositional conditions. This is inferred to be the cause of gradational lithologic units contacts and lithologic association of clay, sandy clay, clayey sand, silty sand, fine –medium – coarse grained sand, lignite and gravel in the study area. The hydrogeologic implications are: low water yielding boreholes due to reservoir heterogeneity (porosity, grain size distribution and permeability), low rate of recharge and a high rate of drawdown.

CONCLUSION

The field curve types and the geoelectric parameters derived from computer iterative modeling reveal that the shallow subsurface geologic formations heterogeneity, both laterally and vertically in the study area are directly related to gradational lithologic contacts. The field curves are classified into seven categories viz: **AAA**, **KHA**, **AAK**, **KHKHA**, **HAKH**, **AKH** and **KHAK** types. The **AAA** type curve simply indicates a graded lithologic sequence in which the sediment layering is becoming coarser with increasing depth. The others: **KHA**, **AAK**, **KHKHA**, **HAKH**, **AKH** and **KHAK** represent more complex lithologic sequence of alternating high and low resistivity layers with a fluctuating clay content and grain sizes as major determining factors. The area is characterized with high lateral lithologic heterogeneity arising from gradational changes in sediment grains sizes. This is ascribed to rapidly changing depositional conditions that range from fluvial, deltaic, lacustrine and nearshore environments that often characterize the proximal part of a sedimentary basin. According to Agumamu (1976), these depositional settings often result in complex lithofacies stacking patterns. The overall hydrological implications being an impaired lateral permeability, and consequently high rates of drawdown and low rates of aquifers' recharge.

The lithologies constituting the aquifer units range from medium to coarse grained sand, gravely sand and sandy gravel in both areas and occurring at relatively deep and variable depths from the earth's surface. In Ubuluku, VES 2 and 4 locations (see Figure 8) have been identified as suitable sites for sinking boreholes with the first aquifer static water level lying averagely at 12m and a lithologic composition of mainly coarse grained sand to sandy gravel. Thus boreholes drilled to depths range of 125m to 150m are inferred will have good water yields. In Ogwashi-Uku, the aquifer materials are medium to coarse grained sand, sandy gravel and gravel with the static water level lying averagely at 105m and corresponding depths range of 110m to 140m. This unit also has a relatively high transverse unit resistance ranging from 1.60 $x10^5$ Ω-m^2 to 1.07 $x10^6$ Ω-m^2, thus implying a likelihood of a relatively high aquifer transmisivity. VES 2, VES 3 and VES 6 locations (see Figure 9) are adjudged suitable sites for sinking boreholes within a depth range of 90m to 135m. Generally, the aquifer units have varying thicknesses and depths from one locality to another, hence a generalized depth to water table cannot be deduced for the entire study area.

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