Estimation of Aquifer Pontential Using Geoelectric and Hydraulic Parameters: A Case Study of Owerri And Some Selected Towns in Imo State

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Abstract

The aim of the study was to estimate the hydraulic characteristics of aquifers in Owerri and some selected towns in Imo State from surface geophysical techniques. Sixteen (16) Schlumberger vertical electrical soundings (VES) were carried out with maximum current electrode separation (AB) of 400 m. The data was acquired using R-plus resistivity meter and processed with Resixtm Interpex Software.

The results of the VES interpretation identified 3-5 geoelectric layers overlying the aquiferous layers: surface soil, lateritic earth, the fine-medium-coarse grained sands with intercalations of clay which constitute the water bearing zone. The curves identified in the study area include HK, KHK, KQQQ, KQHK, AAKH, HKHK, AKHK and HAAK. The results of the qualitative interpretation indicate that majority of the field curves terminated as K-shaped and Q-shaped type curves.

The general shapes suggest that the transverse resistance of the aquifers can be considered as the dominant parameter for the estimation of transmissivity in the study area. The main aquiferous zones occur between the 4^{th} and 6^{th} geoelectric layers with a resistivity range of 409.5 - 12704.7 ohm-m, depths range varying from 39.37 – 207.30m, and layer thickness range between 28.14 and 176.70m.

The hydraulic characteristics of the aquifer estimated from the geoelectric parameters revealed that the aquifer has protective capacities of between 0.008 and 0.085 mhos, transverse resistance ranges from 39573.3 – 1.911E + 06 ohm-m^2, transmissivity values from 1132.26 - 105211.12 m^2/day and hydraulic conductivity ranges from 11.72 – 2448.77 m/day.

The estimated aquifer transmissivity values suggest that aquifer materials are highly permeable to fluid movement within the aquifer. This study has demonstrated the efficacy of surface geophysics in estimating hydraulic characteristics of an aquifer where pumping test data are not available and also its vulnerability to surface contaminants.

Keywords: Groundwater Potential; Groundwater Vulnerability; Protective Capacity; Transmissivity And Hydraulic Conductivity

1. Introduction

Geophysical methods are increasingly being used for subsurface characterization as they offer the potential to derive basic characteristics and properties of geological formations (Vereeken *et al.*, 2005). The resistivity geophysical approach is used as the key to exploration because it can give detailed information about the subsurface layer by passing electrical current down the subsurface and also, its low cost of exploration (Bayewu 2018).

The vertical sounding (VES) technique has been effectively used by many researchers in diverse fields of application including groundwater investigations (Devi *et al*, 2002; Lenkey *et al.*, 2005; Gupta *et al.*,2012), groundwater contamination studies (Karlik and Kaya 2001; Park *et al.*, 2007; Frohlick *et al.*, 2008).

Water supply provision from public agency facilities in most part of Nigeria is well below demand and further aggravated by perennial problems associated with rapid population growth due to urbanization and industrialization. In the study area groundwater has always been preferred over surface water sources and is thus the primary source of water supply. The reason for this is probably the existence of rich aquifers, especially in Benin formation that are easily exploited in many areas with shallow boreholes. However, groundwater exploitation has not been accompanied by resource evaluation studies that are based on aquifer characteristics. Consequently, many groundwater-based schemes and associated boreholes that are designed and established without appropriate and relevant information performed well below capacity and are not sustainable.

Quantitative description of aquifers has become vital in order to address several hydrological and hydrogeological problems. Fluid transmissivity, transverse resistance, longitudinal conductance, hydraulic conductivity and aquifer depth are fundamental properties describing subsurface hydrology. As a result, many investigation techniques are commonly employed with the aim of spatial distribution of the above-mentioned hydraulic parameters.

Estimating these properties from pumping test can be very expensive and time consuming. Surface geoelectrical methods offer an alternative, rapid and cost-effective approach for aquifer evaluation and groundwater quality assessment using empirical relations between hydraulic and geoelectric parameters (Hubbard and Robin, 2002; Kelly, 1977).

The study area is underlain by the Benin formation (coastal plain sands) of Southeastern Nigeria. High productivity of many boreholes already drilled in the area supports the prolific nature of the Benin formation of Southeastern Nigeria. However, most of these boreholes penetrated the shallow unconfined aquifer with the attendant risk of possible contamination.

For a detailed and proper water resources management program, it is therefore necessary to use data input from aquifer potential, geoelectric and hydraulic parameters. The objective of the study is to evaluate the aquifer potential, geoelectric and hydraulic parameters for a detailed and proper water resources management program.

2. The Study Area

The study area is located on latitudes $5^0$40'N – $5^0$17'N and longitudes $6^0$55'E – $7^0$12'E. It is comprised of selected towns and villages around Owerri within a radius of 10 km.

The terrain of the study area is characterized by two types of land forms: high undulating and nearly flat topography. Borehole lithologic logs reveal that the undulating hills and ridges are under lain by a succession of thick unconsolidated sand stones and relatively thin clay units belonging to the Benin formation.

The sediments of the Benin formation are lenticular, unconsolidated, coarse to medium fine-grained sands with localized beds of fine sands and clayey sand. The sand units are mostly coarse grained, pebbly, poorly sorted and contains lenses of fine – grained sands (short and stauble, 1967; Onyeagocha, 1980).

The very porous and permeable character of the Benin formation (coastal plain sands), the overlying lateritic earth and the weathered top of this formation as well as the underlying clay/shale member of the Bende Ameke Series provides the hydrologic conditions contributive to aquifer formation in the area.

Some of the towns and villages within the southern part of the study area include: Irete, Obinze, Mgbirichi, Umuokanne, Umuagwo, and located in the northern parts are Orogwe, Ohii, Akwakuma, Orji, Mbieri Nworieubi, Ihuo, Atta, Orodo and Amaraku. Network of motorable roads, both tarred and untarred, as well as footpaths made access to most parts of the area possible (fig 1.)

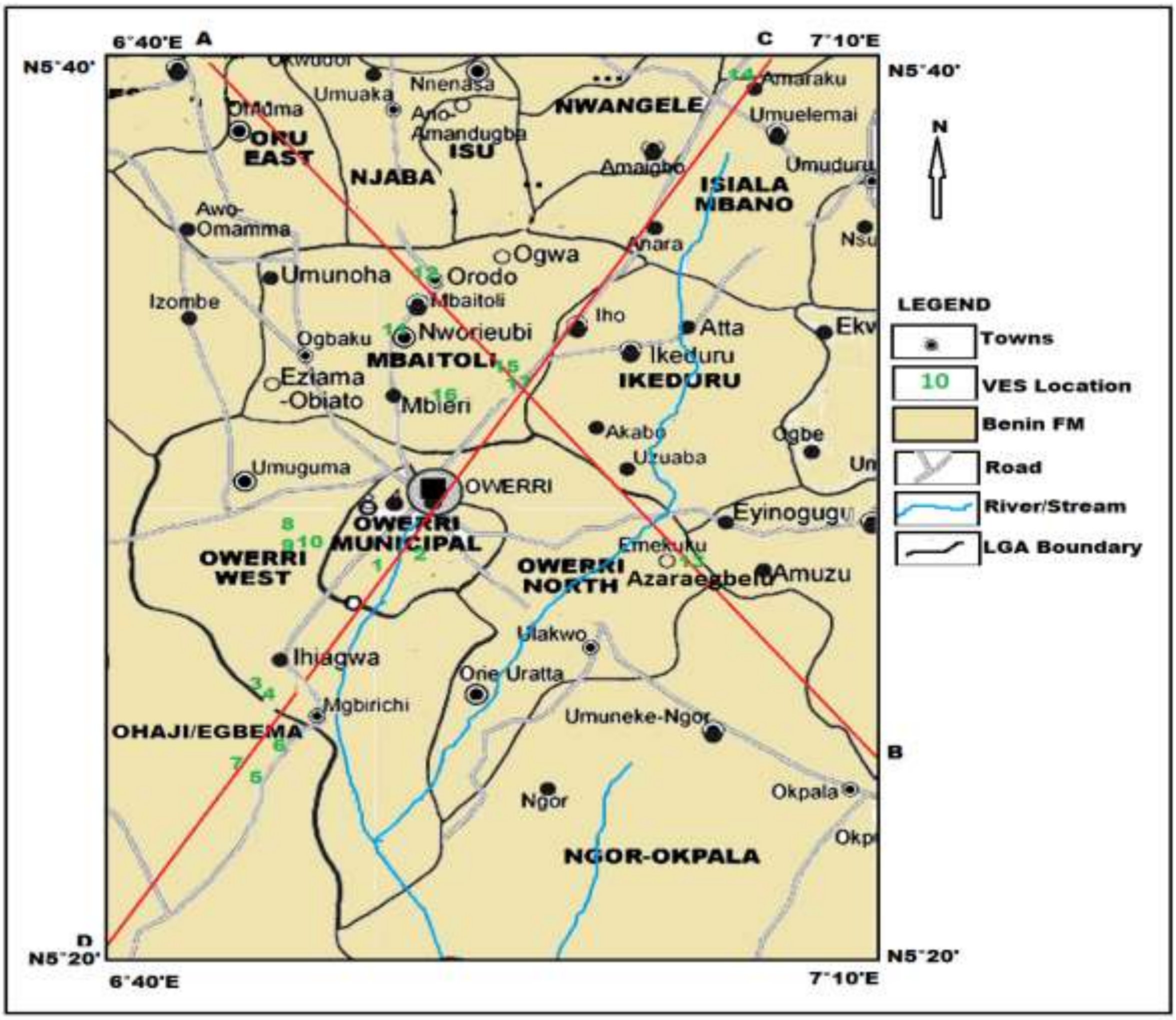


Fig.1. map of study area showing access roads and the location of sounding stations

Materials and Methods

3.1 Methodology

Schlumberger array was used to carry out seventeen (17) vertical electrical sounding (VES) with maximum current electrode spacing (AB) of 400m. The electrical resistivity measurements were performed with the aid of R-plus resistivity meter. The apparent resistivity (ρ_a) was determined using

$$\rho_a = \prod\left(\frac{\left(\frac{AB}{2}\right)^2\left(\frac{mN}{2}\right)^2}{mN}\right) \quad R_a \qquad (1)$$

where AB is the distance between the two current electrodes, MN is the distance between the potential electrodes, and R_a is the apparent electrical resistance measured from the equipment. The equation can be simplified to

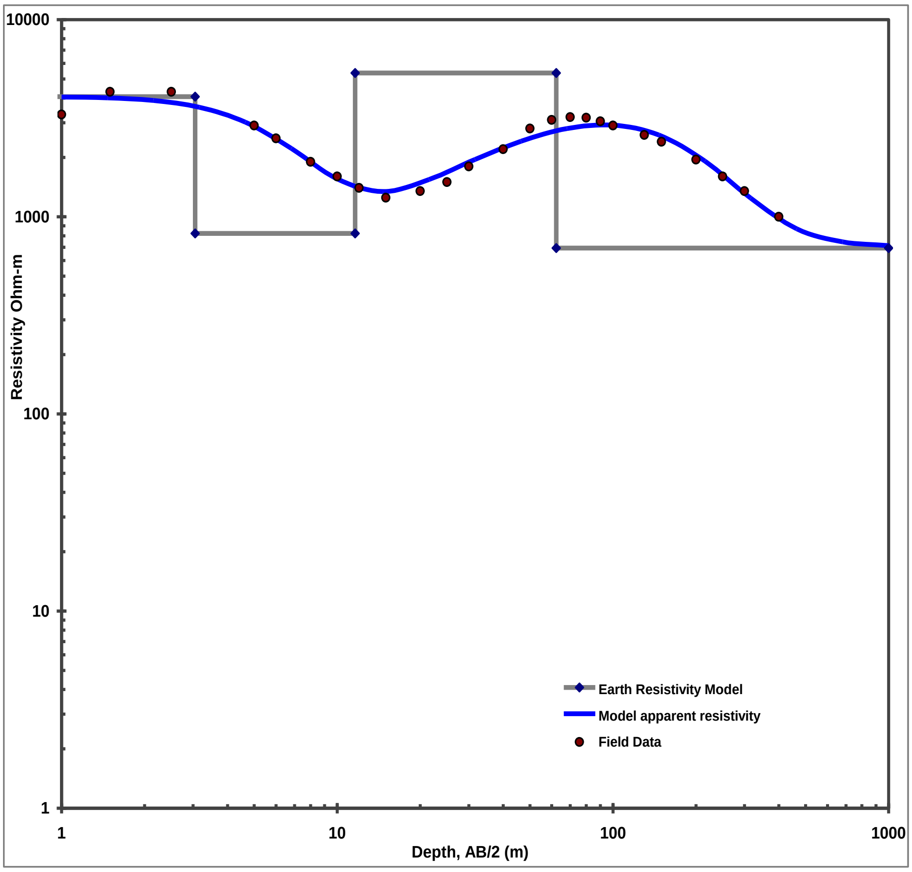
$$\rho_a = KR_a \qquad (2)$$

where K is the geometric factor given by

$$\Pi\left(\frac{\left(\frac{AB}{2}\right)^2\left(\frac{mN}{2}\right)^2}{mN}\right) \qquad \text{(Zohdy } et\ al., \text{1974)} \qquad (3)$$

The apparent resistivity (ρ_a) values were then plotted against their corresponding half current electrode spacing ($AB/2$) on a bi-logarithmic paper. The plotted field curves were interpreted by partial curve matching and computer assisted 1-D forward modelling with RESIXTM interpex software to determine the true resistivity and depths of the subsurface formations. Figure 2 shows a typical geoelectric type curve obtained in the study area.

Number of Layers	4		
Layer NO	Thickness (m)	Depth (m)	ρ (Ω-m)
1	3.05	3.05	4069.60
2	8.55	11.60	822.60
3	50.68	62.28	5363.90
4	-		693.50
-	-		
-	-		
-	-		
-	-		



FIELD DATA	
AB/2 (m)	ρa (Ω–m)
1.0	3300.00
1.5	4300.00
2.5	4300.00
5.0	2900.00
6.0	2500.00
8.0	1900.00
10.0	1600.00
12.0	1400.00
15.0	1250.00
20.0	1350.00
25.0	1500.00
30.0	1800.00
40.0	2200.00
50.0	2800.00
60.0	3100.00
70.0	3200.00
80.0	3180.00
90.0	3050.00
100.0	2900.00
130.0	2600.00
150.0	2400.00
200.0	1950.00
250.0	1600.00
300.0	1350.0
400.0	1000.0

VES NUMBER:	**1**	DIRECTION LAYOUT:	**N - S**	DATE:	**March 24, 1991**
LOCATION:		**OWERRI MUNICIPAL, IMO STATE**			
COORDINATES:	**5°28'15.3"N**		**7°01'58.3"E**	ELEVATION :	**61m**
PROJECT		**RESEARCH WORK**			

Fig. 2 Typical iterated sounding curve of the study area at VES 1

The resulting model curves exhibit curve type with four to six interpretable geoelectric layers. The model results were quantitatively interpreted in terms of the true resistivity of the formations with the aid of the lithologic log of nearby borehole penetrated to depth greater than 120m (fig. 3).

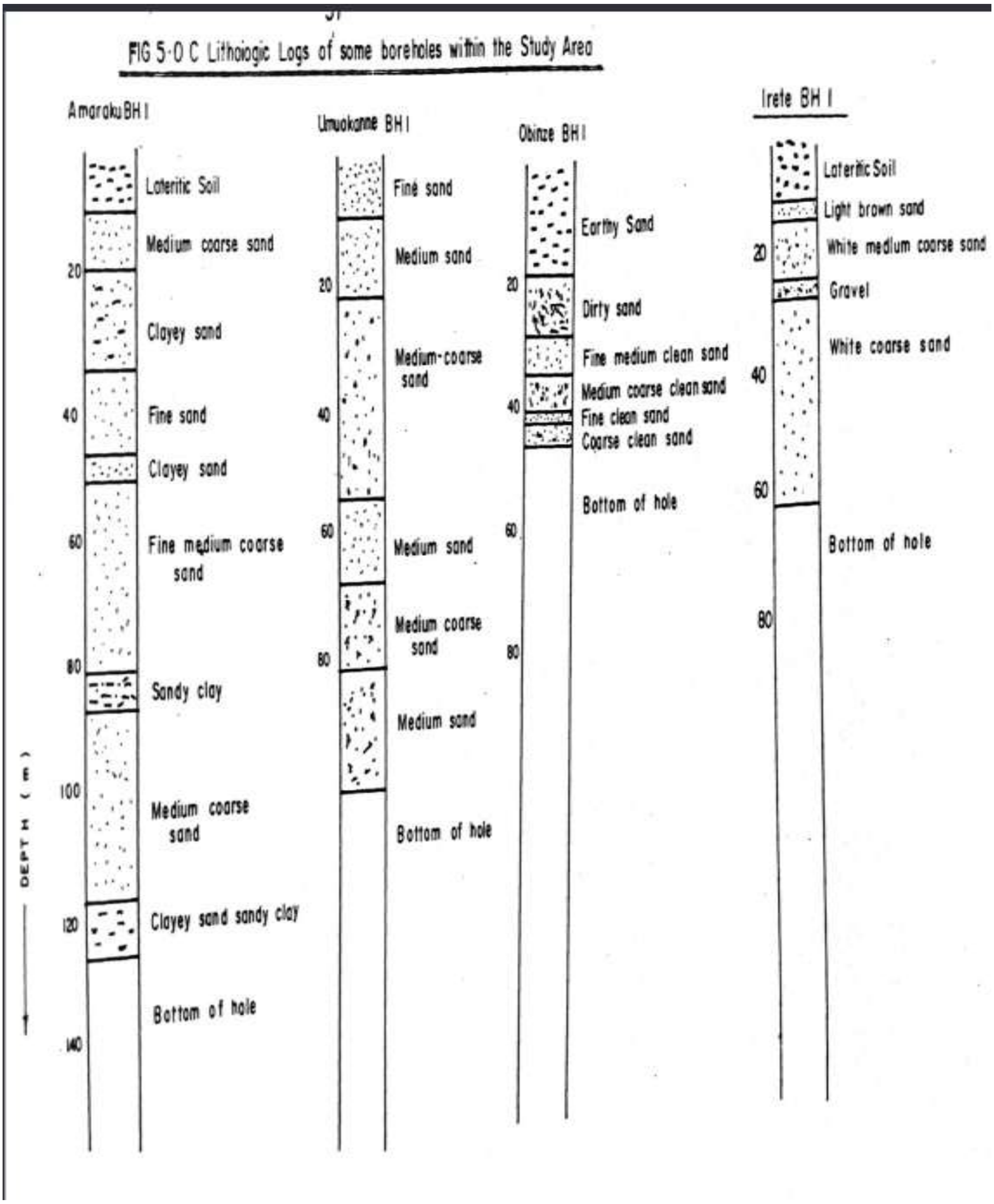


Fig. 3. Lithologic logs of some boreholes within the study area.

3.2 Dar Zarrouk

The secondary parameters (longitudinal conductance (Lc), transverse resistance (RT), longitudinal resistivity (ρl), transverse resistivity (ρt) and coefficient anisotropy (⋋) were determine from the layers resistivities and thicknesses using the mathematical relations (Zohdy *et al.*, 1974):

$$L_C = \sum_{i=1}^{n} h_i/\rho_i \quad (4)$$

$$R_T = \sum_{i=1}^{n} h_i\rho_i \quad (5)$$

$$\rho_l = \sum_{i=1}^{n} h_i/L_c \quad (6)$$

$\rho_t = \sum_{i=1}^{n} R_T / h_i$ (7)

$\lambda = \sqrt{\rho_t / \rho_l}$ (8)

3.3 Hydraulic Conductivity

The hydraulic conductivity K is directly proportional to the layer resistivity ρ (Kosinki and Kelly, 1981). Hilmi S. Salem (1999) says that hydraulic conductivity is proportional to permeability. In a porous aquifer media according to Johasem (1977), the relation between hydraulic conductivity and layer resistivity is given by the equation:

$K(m/s) = 10^{-5} \times 97.5^{-1} \times \rho^{1.195}$ (9)

$K(m/day) = 60 \times 60 \times 24 \times K(m/s)$ (10)

3.4. Transmissivity of the aquifer

Transmissivity is a major property of an aquifer which helps in the characterization of rocks as water conducting media.

T = Kh (11)

Where T is the aquifer transmissivity, K is aquifer hydraulic conductivity and h is the aquifer thickness.

3.5. Protective capacity

The values of the total longitudinal conductance of the overburden layers of an aquifer were used in evaluation of the protective capacity of the aquifer.

$\boldsymbol{P_C = \sum L_C = \sum h_i / \rho_i}$ (12)

where P_C is protective capacity, L_C is longitudinal conductance, h_i is thickness of ith layer and ρ_i is resistivity of ith layer. The rating of protective capacity of an aquifer was described by Oladapo and Akintorinwa (2007) as expressed in table 1.

Table 1: Classification of Protective Capacity

Protective Capacity (mhos)	**Rating**
> 10	Excellent
5-10	Very good
0.7 - 4.9	Good
0.2 - 0.69	Moderate
- 0.19	Weak
< 0.1	Poor

4.0 Results and Discussion

The geoelectric and hydraulic parameter for estimation of aquifer potential are presented in table 2 and the lateral distribution of the parameters are shown in figures 3 – 5.

Table 2: Geoelectric and hydraulic parameters for thee estimation of aquifer potential

VES	LOCATION	CURVE TYPE	RESISTIVITY (ohm-m)	THICKNESS (m)	HYDRAULIC CONDUCTIVITY m/day	DEPTH (m)	TRANSMI-SSIVITY m^2/day	P_C	λ
01	Owerri	HK	5363.9	50.68	253.65	62.28	12854.98	0.011	1
02	Owerri	HK	6854.8	72.17	339.98	85.60	24536.35	0.008	1.41
03	Obinze	KQHK	2744.5	136.10	113.88	211.50	15499.06	0.037	1
04	Ohaji	AAKH	409.5	96.61	11.72	143.90	1132.26	0.022	1
05	Ohaji	HKHK	2049.3646	75.58	80.32	88.79	6070.58	0.027	1
06	Ohaji	AKHK	3531.1	116.70	153.90	207.30	17960.13	0.043	1
07	Irete	KHK	3295.3	153.20	141.70	202.30	21708.44	0.036	1
08	Orogwe	HK	7955.0	28.14	406.23	39.37	11431.31	0.004	1
09	Orogwe	HK	10712.7	69.18	579.94	85.71	40106.41	0.009	1
10	Nwaorieubi	HK	9491.1	176.70	501.65	185.40	88641.55	0.013	1
11	Orodo	HK	11732.0	162.80	646.26	177.10	105211.12	0.020	1.41
12	Azaraegbelu	HAAK	12704.7	35.65	710.79	68.08	25339.66	0.011	1
13	Amaraku	HK	6903.4	138.20	342.91	154.70	47390.16	0.024	1
14	Mbieri	AK	5924.0	106.80	285.61	118.00	30503.14	0.008	1
15	Mbieri	KHK	7396.1	65.43	372.36	75.97	24363.51	0.014	1
16	Mbieri	KHK	35768.9	40.19	2448.77	53.07	98416.06	0.017	3

The vertical electrical sounding curve types identified in the study area include HK, KHK, KQQQ, KQHK, AAKH, HKHK, AKHK, HAAK and AK (Table 2). Approximately, 41.1% of all the sounding curves are HK-Type whereas the remaining 58.9% belongs to the eight curve types. Therefore, HK-type is the most dominant sounding curve type in the study area. The results revealed four - six geoelectric layers with five to nine lithologic units identified. The aquiferous layers are composed mainly of fine - medium - coarse grain sands with intercalations of clay.

To further discuss the curve types above;

The terminal K-shaped segments of the resistivity curves (HK, KHK, KQHK,,HKHK, AKHK, HAAK) has a definite maximum indicating a layer of anomalously high resistivity value overlying the aquiferious layers. This may be due to the increase in the grain size of the granuler sand formations from fine-medium grained sand to coerce grained sand units, Further down to depth below the dry sand formation is the aquifer unit saturated with water which manifested in a much lower resistivity value.

The terminal Q-shaped segment of the resistivity curve (KQQQ) indicates the presence of geoelectric layers of decreasing resistivity values overlying the aquifer units. This variation in resistivity may be due to increase in the degree of water saturation of the granuler sand formations of the aquiferious layers. The terminal H-shaped segment of the resistivity curves (AAKH) has a definite minimum indicating a layer of anomalously low resistivity value overlying the aquifer units. This may be due to increase in the amount of clay content in the granuler sand formations further down to a depth below the anomalously low resisting layer is the relatively high resistive aquifer material. This variation could be traced to deficiency of clay content and increased degree of water saturation of the underlying aquifer units.

The resistivity values of the aquifers ranged from 409.5 to 12704.7 ohm-m, depths range varying from 39.37 to 207.30m and layer thickness ranged between 28.14 and 176.70m. Fluid transmissivity and electric transverse resistance are important parameters in groundwater exploration. Determination of these parameter provides a good knowledge of the potential of porous media as they relate fluid flow to electric current conduction in terms of layer thickness, permeability and resistivity.

Figures 4, 5 and 6 are the contour maps showing the lateral distributions of the resistivity, hydraulic conductivity and transmissivity values estimated from the electrical sounding data for the sixteen (16) stations in the study area. Hydraulic conductivity values for the potential aquifers determined from the geoelectrical technique range between 11.72 m/day to 2448.77 m/day. It shows low hydraulic conductivity values at Western part of the study area and high values of hydraulic conductivity across the Eastern part of the map.

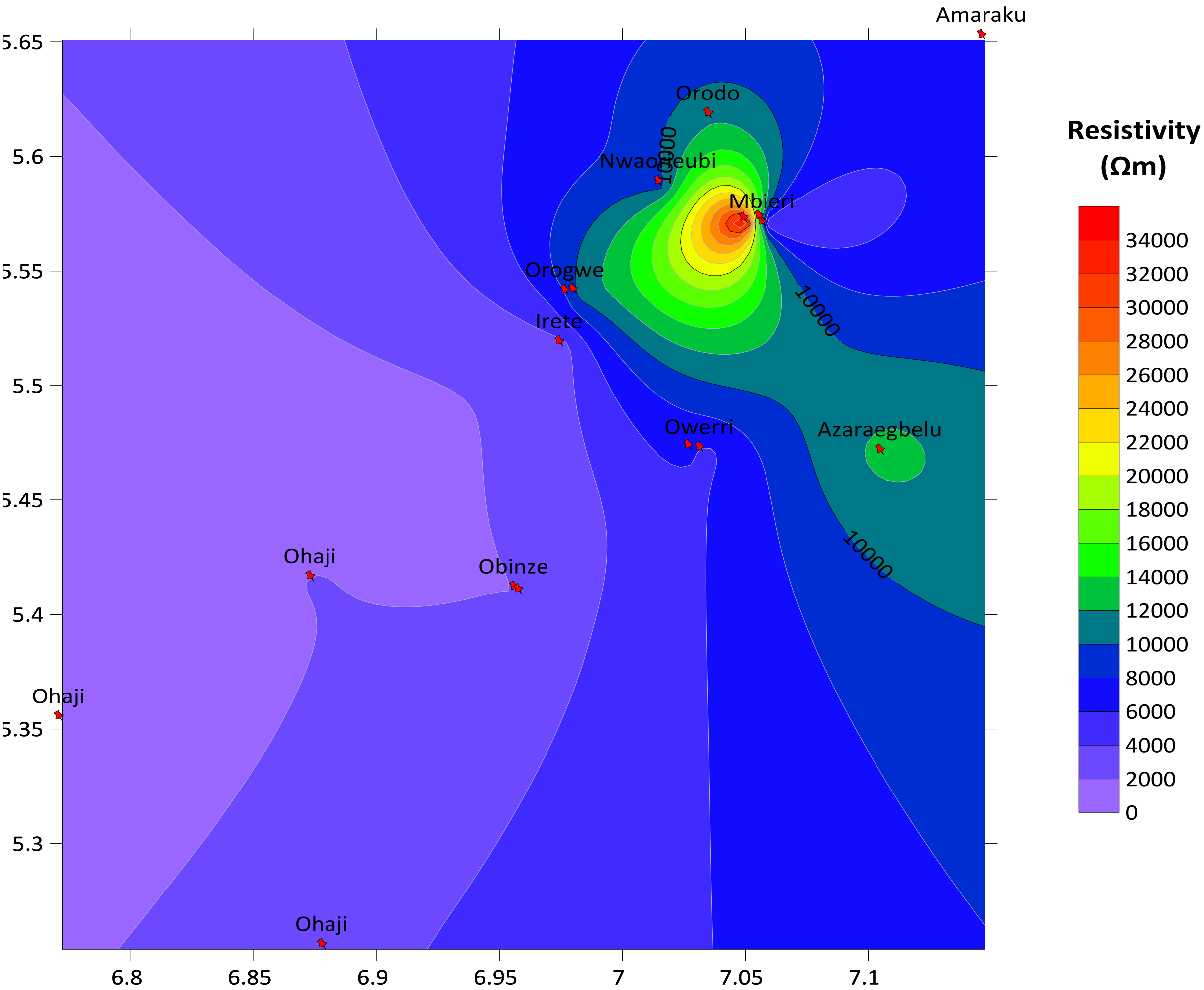


Fig.4 Resistivity map

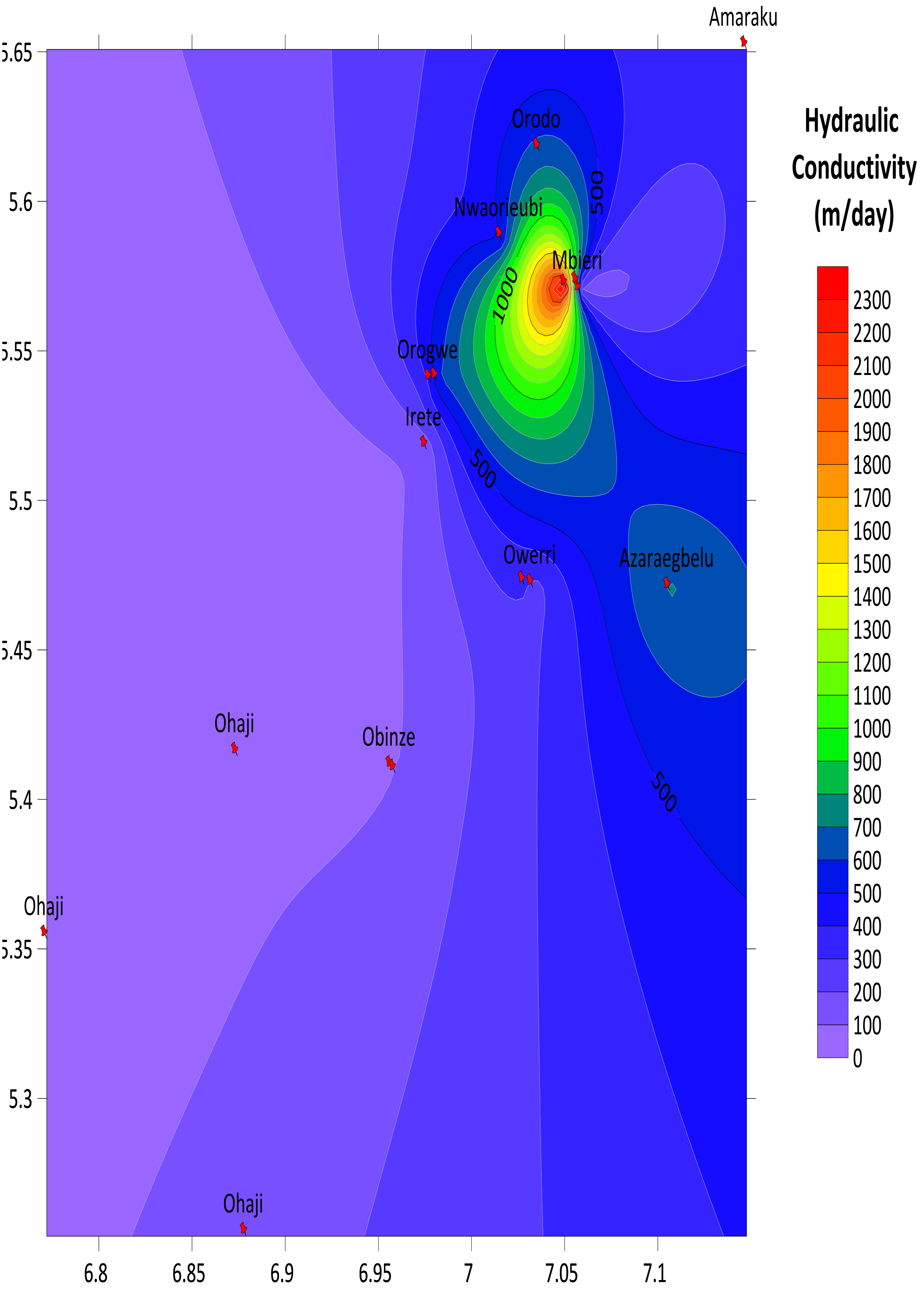


Fig. 5. Hydraulic Conductivity

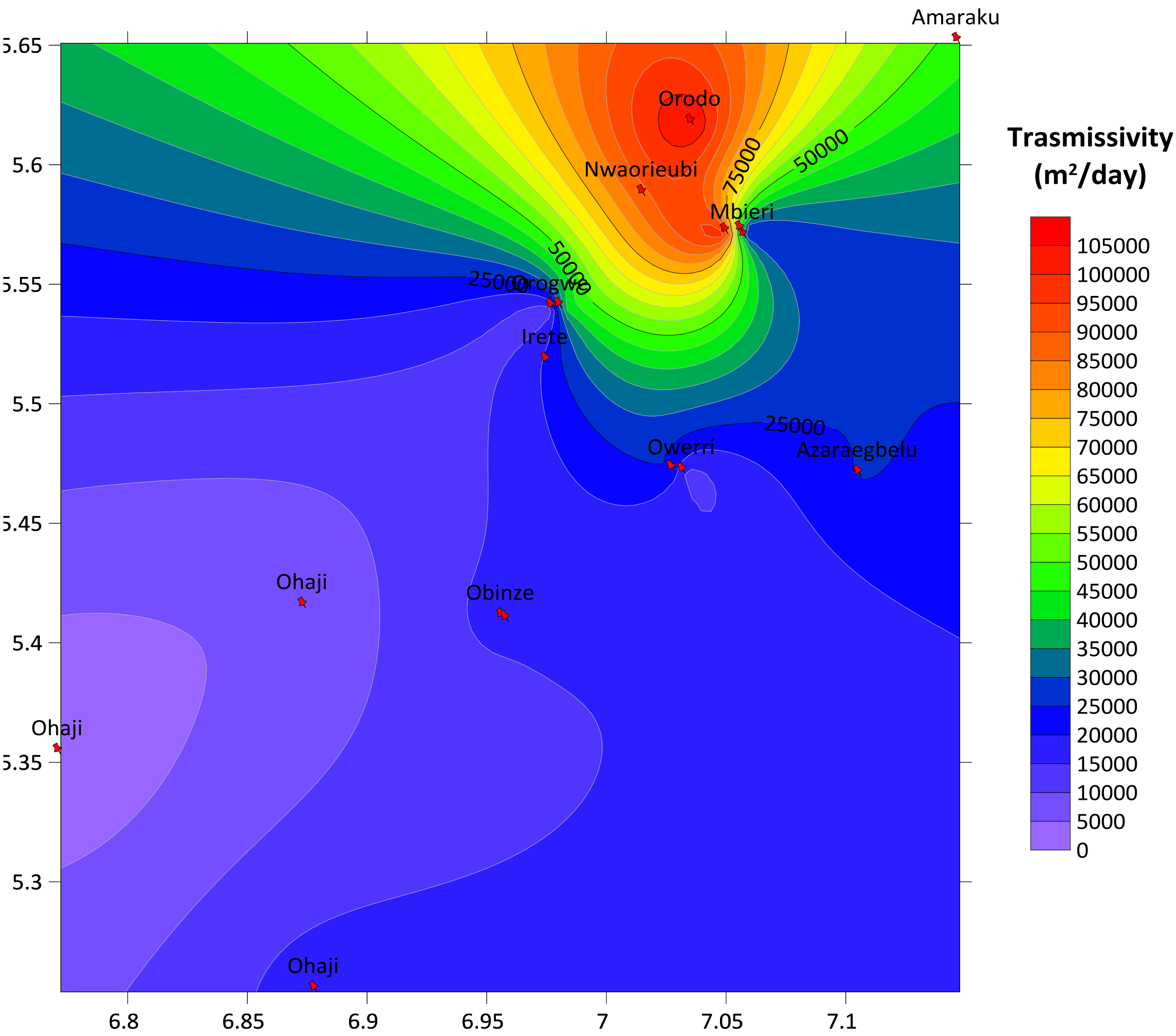


Fig. 6. Transmissivity Map

From the fundamental relation between hydraulic conductivity and electrical resistivity through their common dependence on tortuosity and porosity (Kelly, 1977), we can estimate transmissivities of the aquiferous zone and its variation from place to place including those areas where borehole data are not available. Fig. 6. shows that transmissivity values are high over the entire area with values ranging from 1132.26 m^2/day in the vicinity of VES 5 to 105211.12 m^2/day at VES 12. This result is in general agreement with the geology of the Benin formation (coastal Plain sands). Comparison of resistivity map and transmissivity map shows that areas underlain by relatively resistive aquifer material have higher transmissivity values than areas underlain by aquifer materials with low resistivity values. This is expected because transmissivity is a function of aquifer transverse resistance, where the distribution of the product of Kσ is assumed to be constant.

Anisotropy cannot be detected in subsurface layers during vertical electrical sounding and normally results in too large a thickness being assigned to the layers. The abnormally high resistivity value at VES 17 and overestimation of layer thickness at VES 3 may be due to the effect of anisotropy on the interpretation of vertical electrical soundings. The total longitudinal conductance values can be utilized in evaluating overburden protective capacity in an area, because the earth medium acts as a natural filter to percolating fluids. According to Oladapo and Akintorinwa (2007) an aquifer protection capacity rating can be classified on the basis of the total longitudinal unit conductance (ΣL_c) as Excellent ($L_c > 10$), Very Good ($5 < L_c \leq 10$), Good ($0.7 < L_c \leq 5$), moderate ($0.2 < L_c \leq 0.7$), Weak ($0.1 < L_c \leq 0.2$) and poor (($L_c < 0.1$) proctective capacity. Evaluation of the overburden protective capacity rating for the seventeen (17) potential aquifer zones showed poor protective capacity values ranging from 0.008 – 0.085 which indicates that the entire study area is vulnerable to infiltration of leachate and other surface contaminants.

5. Conclusion and Recommendation

Electrical resistivity method involving VES has proven useful in the evaluation of groundwater potential and overburden protective capacity of the study area. The VES data were quantitatively interpreted using partial curve matching and the results were refined using RESIXTM software. The first order geoelectric parameter obtained from the interpretation of VES data and the second order Dar-Zarrouk parameters were used to generate maps which were analyzed with respect to groundwater potential and overburden protective capacity of the study area. Fluid transmissivity, transverse resistance, protective capacity, hydraulic conductivity, aquifer resistivity and depth which are fundamental properties describing subsurface hydrology have been determined for the study area.

2-D surface maps of the aquifer characteristics were produced. It was observed that the aquifer properties range from 11.72 to 2448.77 m/day, 1132.26 to 105211.12 m^2/day, 409.5 to 12704.7 ohm-m, 39573.3 to 1.911E+06 ohm-m^2, 0.008 to 0.085 mhos. For hydraulic conductivities, transmissivities, resistivities, transverse resistance, and protective capacities respectively within the study area.

Drilling of wells to determine aquifer hydraulic parameters is often prohibitively expensive. Thus, Dar Zarrauk transmissivity technique outlined in this study in determining the aquifer transmissivity from VES is a cost-effective alternative. The advantage of using Dar-zarouk parameters to estimate transmissivity is that the non-uniqueness of interpreting resistivity data is minimized. The results give a useful first approximation of the transmissivity variation and could be used to site exploratory boreholes. The results signify that the aquifers are characterized by high groundwater potential and low protective capacities of overburden layers indicating that they are highly vulnerable to surface contamination.

The high transmissivity values recorded over most parts of the area also agree with the geology of the Benin formation (coasted plain sands) consisting of the fine-medium-coarse grained sands. The study has demonstrated the efficacy of surface geophysics in estimating hydraulic characteristics of an aquifer where pumping test data are not available and also to determine its vulnerability to surface contaminants. It is recommended that hydrochemical analysis of water samples from boreholes as well as intensive hydrogeological surveys be carried out in the study area. Borehole resistivity surveying could be employed to detect clayey sand horizons so as to screen only the sand units on installing a borehole.

Alternative methods of geophysical exploration like seismic refraction could be adopted to delineate the subsurface layers to ascertain the credibility of the study. However, this would not change the result of the sounding appreciably as it agrees closely with regional geology and litologic information obtained from the area. The problem of human bias that is inherent in conventional matching technique was taken care of by suitable computer program in the analysis of the field data. The problem of ambiguity in the interpretation of resistivity data was resolved with the aid of additional geological and geophysical information obtained from the area.

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