Using geoelectric soundings for estimation of hydraulic characteristics of aquifers in the coastal area of Lagos, southwestern Nigeria

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ABSTRACT

Electrical resistivity investigation was carried out at Ibeju Lekki, Southwestern Nigeria. The thrust of this study is to determine the geoelectrical parameters of the shallow aquifer and estimate the hydraulic characteristics of this aquifer unit from the surface geophysics. The area falls within the Dahomey basin of the Nigeria sedimentary terrain. Twenty-one VES were conducted using Shlumberger array with a maximum half current electrode (AB/2) of 100 m giving total spread of 200 m. Data were interpreted using partial curve matching technique and assisted 1-D forward modeling with WINRESIST software. The qualitative interpretation revealed KQ curves ($\rho 1 < \rho 2 > \rho 3 > \rho 4$) and KH curve ($\rho 1 < \rho 2 > \rho 3 < \rho 4$). The geoelectric section generated from the results of the VES revealed a four geo-electric layers; these include topsoil with resistivity ranging from 213-5404 Ωm, dry sand with resistivity values vary from 301to 17178 Ωm, saturated sand with resistivity varying from 110 to1724 Ωm and sand (saline water content) with resistivity values of between 8 and 97 Ωm. The major aquifer in the area occurs at the third geoelectric layer. The depth to this aquifer is of between 0.7m and 6.0m and the layer thickness is between 0.2 m and 19.9 m. The hydraulic characteristics of the aquifer estimated from the geoelectric parameters reveal that the aquifer has porosity values of between 29.4 % and 57.7 %, protective capacities of between 0.00013 and 0.015 mhos, transverse resistance ranges from 345-18502 Ωm^2, transmissivity values vary from 13 to 310 m^2/day and hydraulic conductivity ranges from 0.8-65 m/day. The results show that the aquifer is characterized by high porosity and low protective capacities of overburden layers indicating that it is highly vulnerable to surface contamination. It has high transverse resistance, high transmissivity, and high hydraulic conductivity indicating that the aquifer can transmit water at higher rate and sustain the need of the community. 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 to determine its vulnerability to surface contaminants.

Keywords: Geoelectric parameter; Dar-Zarouk parameters; Hydraulic parameters and pumping; test data

1. INTRODUCTION

Groundwater as one of the main sources of potable water supply for domestic, industrial and agricultural uses has been under intense pressure of degradation and

contamination due to urbanization, Industrial, agricultural related activities and saline water intrusion from the ocean. The impact of these contaminations on soil and groundwater is alarming with years of devastating effects on humans and the ecosystem. Groundwater is said to be contaminated when it is unfit for the intended purpose and therefore constitute a nuisance to the user.

Despite the fact that Lagos coastal environment is surrounded by water, access to potable water has always being their major problem due to saline water intrusion into their fresh water aquifer, which is very common in areas that have hydraulic continuity with the ocean. Due to this problem, the Lagos coastal people depend mainly on surface aquifer to meet their water demand.

Therefore, understanding of saline water intrusion is essential for the management of coastal water resources. The knowledge of the hydraulic characteristics of an aquifer is very important in the determination of its potential as potable water aquifer.

The common method of determining the hydraulic chatracteristics (Hydraulic conductivity, Trasmissivity, Porosity and specific yield) is by carrying out pumping tests on the boreholes of the area. However, the hydraulic characteristics can also be alternatively estimated from geoelectric parameters at an area where pumping test data are not available.
Since the late 1960's surface geolectrictric measurements have been used to determine aquifer characteristics and its protective capacity. Ungemach et.al.(1969) correlated transmissivities determined from the results of six pumping tests in the Rhinc aquifer with transverse resistance.

The aquifer vulnerability index is a method for assessing the vulnerability of aquifers to surface contaminants. In the assessment of aquifer vulnerability to potential contamination, the depth to the aquifer and the types of geologic materials above them are considered.

The objectives of this research are to determine the geolectric parameters of the shallow aquifer, estimate the aquifer hydraulic characteristics from surface geophysics and calculate its protective capacity in the coastal area of Lagos state.

2. LOCATION OF THE STUDY AREA

The study area (Lekki free zone) is located between Latitude 6°25' and 6°27' north of the equator and Longitude 3°57' and 4°03' (Fig. 1). It is found within the sedimentary basin (Dahomey basin) of southern western Nigeria.

The landmass of the study area consists of islands, coastal sand banks, high forest (i.e mangrove or swamp and rain forest).

The greater part of the rain forest is interspersed with farms and villages. The exception so far is the swamp forest in which conditions are too harsh for farming (Agabi*et. al*; 1994) but which are now being exploited for farming and fishing. The area is accessible through the major road that cut across Lekki-Free zone, Mobido and Idaso.
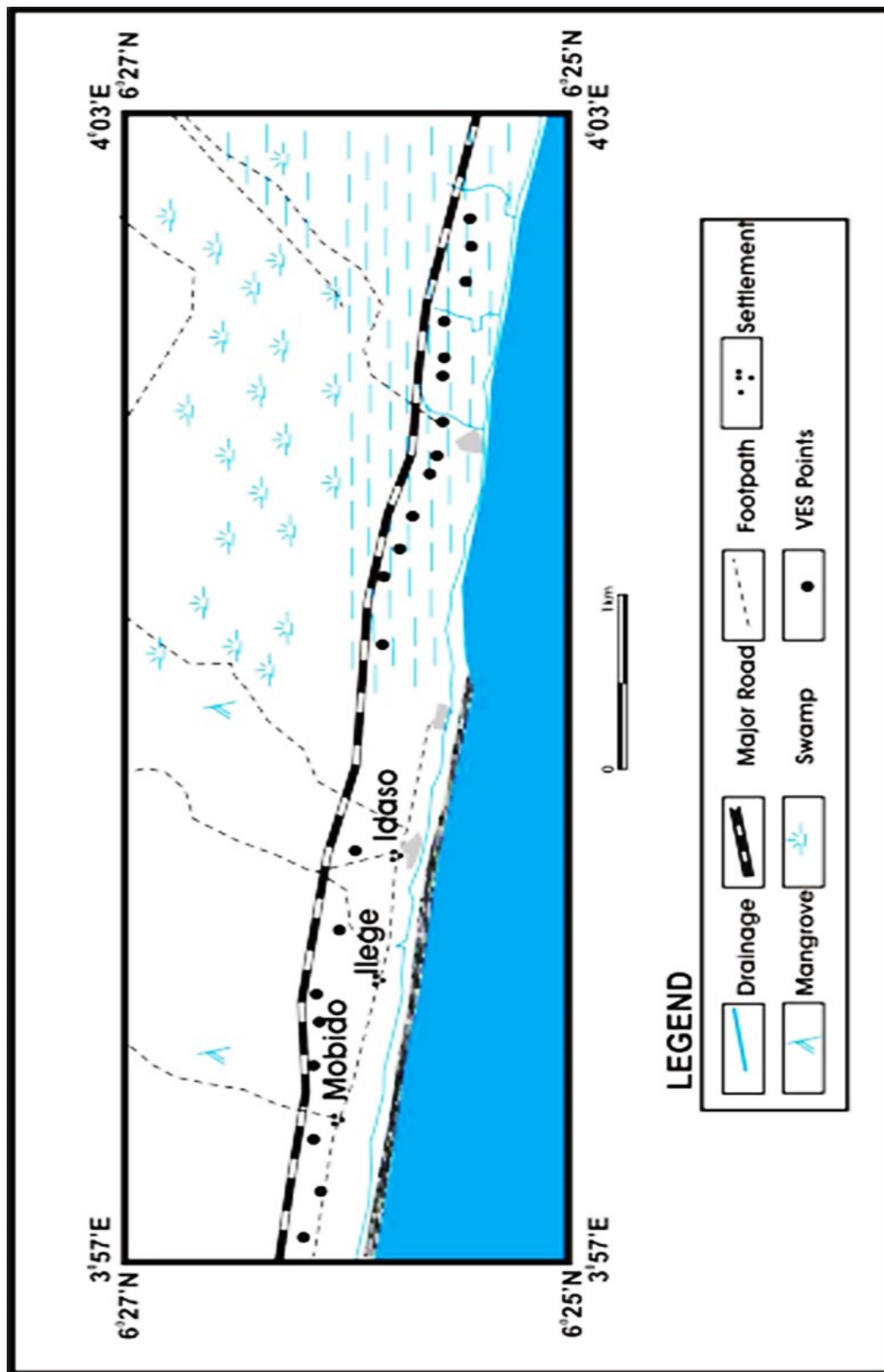
Fig. 1. Location map of the study area showing the VES Points.

3. GEOLOGY OF THE AREA

Lagos which falls within Dahomey basin and lies on the stratified series of sedimentary rocks made up of silt, clay and sand of various sizes and composition basins (Whiteman, 1982). The studied area (Lekki free zone) is made up of Benin formation (Miocene to Recent), Recent littoral alluvial, lagoon and Coastal Plain Sands deposits. The fluctuation of the sea level during the Quaternary times affected the formation of the alluvial deposits. A common feature of the alluvium sediments found in the area is that they consist of mainly sands, littoral and lagoon sediments formed between an old barrier beach and a relatively younger barrier beach as well as Coastal Plain Sands. The sediments range in size from coarse to medium grained, clean white loose sandy- soil that graded into one another towards the lagoon and near the mouth of the larger rivers.

4. METHODOLOGY

Twenty-one VES points were occupied by the side of the major road that runs through the study area using the Schlumberger electrode array. The investigation was carried out with the aid of Pasi Digital Earth Resistivity Meter. The current electrode is symmetrically increased while potential electrode is fixed at its initial distance until the resistance measured becomes too small. At any point, the criterion $AB/2 \geq 5(MN/2)$ was satisfied. AB/2 was increased to a maximum spread of 100 m and MN/2 to a maximum of 5m.

The apparent resistivity (Pa) is plotted against the corresponding half electrode spacing (AB/2) on a bi-logarithm graph to generate the sounding curves. The sounding curves were interpreted by partial curve matching and computer assisted 1-D forward modeling with WINRESIST software. The results were presented as geoelectric section.

Dar-Zarrouk Parameters

Dar-Zarrouk parameters consist of the transverse resistance and longitudinal conductance. Niwas and Singhal (1981) show that the Dar-Zarrouk parameters for the horizontal, homogenous and isotropic layer could be obtained as follows:

Transverse Resistance:

$$R_T = \sum h_i \times p_i$$

Longitudinal Conductance:

The longitudinal conductance (S_L) gives a measure of the impermeability of a layer.

$$S_L = \sum {}^{h_i}/_{p_i}$$

where:
ρ is the layer resistivity in Ωm.
h is the layer thickness in m.
R_T is the transverse resistance in Ωm^2.
S_L is the longitudinal conductance in mhos.

Protective Capacity

The values of the longitudinal conductance were used in evaluating the protective capacity of the aquifer. Mogaji et al (2007)., states that the earth medium act as a natural filter to percolating fluid and that its ability to retard fluid is a measure of its protective capacity.

$$P_c = \sum {}^{hi}/_{pi} \, (\sum S_L \text{ of the overburden layers}).$$

where:
P_c = Protective capacity in mhos.
P_i = Resistivity of the overburden layer.
h_i = thickness of the overburden layer.
S_L = longitudinal conductance.

The rating of Protective capacity of an aquifer was described by Oladapo and Akintorinwa (2007) as expressed in Table 1 below.

Table 1. Rating of Protective capacity.

Protective capacity (mhos)	Rating
> 10	Excellence
5 – 10	Very good
0.7 – 4.9	Good
0.2 – 0.69	Moderate
0.1 – 0.19	Weak
< 0.1	Poor

5. HYDRAULIC CONDUCTIVITY

The hydraulic conductance is directly proportional to the layer resistivity (Kosinski and Kelly, 1981). Therefore, the region with low resistivity value in the study area which is assumed to be the interface of salt water intrusion will automatically have low hydraulic conductivity. Hilmi S. Salem (1999) says that hydraulic conductivity is proportional to Permeability. Thus, the portion of the aquifer with high hydraulic conductivity would be highly permeable to fluid flow and easy circulation of contaminant.

In a porous aquifer, the relationship between the hydraulic conductivity and layer resistance is given by the equation below (Johansen, 1977):

$$K \text{ (in m/s)} = 10^{-5} \, X \, 97.5^{-1} x \, p^{1.195}$$

$$K \text{ (in m/day)} = 60 \times 60 \times 24 \times [K \text{ in (m/s)}]$$

Transmissivity of the Aquifer

Transmissivity is a major property of an aquifer which helps in the characterization of rocks as water conducting media. The aquifer transmissivity (T in m^2/day) is expressed as the product of the hydraulic conductivity and layer thickness.

$$T = K \times h$$

where:
K is the hydraulic conductivity (in m/day)
h is the layer thickness (in m)

Porosity and Formation factor

Archie's experiments revealed that the formation factor could be related to the porosity of an aquifer by the formula below.

$$F = a / \Phi^m$$

Thus, $$\Phi = [a/F]^{1/m}$$

Senthil Kumar et al. (2001) relate the formation factor to the hydraulic conductivity by the formula below:

$$F = [k/a]^{1/m}$$

where:
F is the formation factor
K is the hydraulic conductivity (m/day)
Φ is the aquifer porosity
a = 0.62 {Tortousity factor for   unconsolidated sands}
m = 2.15 {Cementation exponent}

6. RESULTS AND DISCUSSION

The results of the interpretation of the sounding curves are presented as geoelectric section (Fig. 2). All the 21VES points reveal 4 major geoelectric layers with 20 of it are characterized by KQ curve type where $P_1 < P_2 > P_3 > P_4$.

The geoelectric section (Fig. 2) revealed four geo-electric layers; these include topsoil with resistivity ranging from 213-5404 Ωm, dry sand with resistivity varying from 301-17178 Ωm, saturated sand with resistivity value of between 110 and 1724 Ωm and sand (saline water content) with resistivity values ranging between 8-97 Ωm. The major aquifer unit in the area is the third geoelectric layer. The depth to the aquifer ranges from 0.7 m to 6.0 m and the layer thickness is between 0.2 m and 19.9 m.

Table 2 displays the summary of the Dar-zarrouk parameters and the Hydraulic characteristics estimated from the geoeletric parameters of the aquifer.
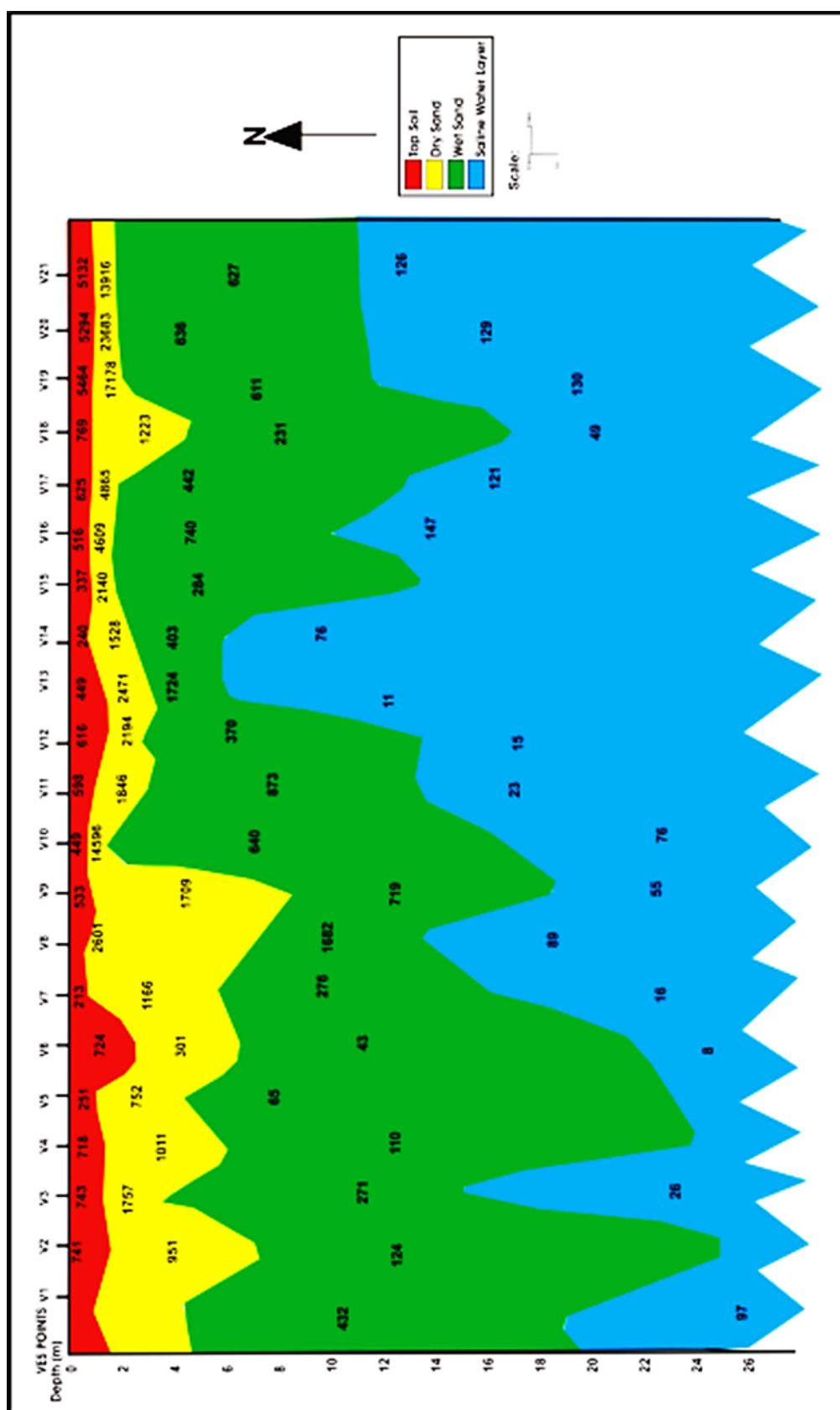
Fig. 2. Geoelectric Section Generated from the 21 VES Points.

Table 2. The Dar-zarrouk parameters and hydraulic characteristic of the aquifer.

VES	P_a (Ωm)	h_a (m)	R_T (Ωm²) $P_a x h_a$	S_L (mhos) h_a/P_a	Pc (mhos) [SL_1 + SL_2]	K (m/day) $\frac{10^{-5}Pa^{1.195}}{97.5}$ x 86400	T (m²/day) K x ha	F [k/a]$^{1/m}$ a = 0.62 m = 2.15	Φ (%) [a/F]$^{1/m}$%
1	432	15.5	6696	0.036	0.00303	12.5	193.751	4.04	41.80
2	124	18.9	2344	0.152	0.00811	2.8	53.16304	2.02	57.72
3	271	11.1	3008.1	0.041	0.00327	7.2	79.47498	3.12	47.16
4	110	17.0	1969	0.163	0.00674	2.4	43.6341	1.89	59.54
5	65	19.9	1293.5	0.306	0.00744	1.3	25.86984	1.41	68.21
6	43	15.8	679.4	0.367	0.01508	0.8	12.53606	1.12	75.90
7	276	11.2	3091.2	0.041	0.00646	7.3	81.96218	3.15	46.94
8	1682	11.0	18502	0.007	0.00067	63.4	697.8529	8.61	29.42
9	719	9.9	7118.1	0.013	0.00588	23.0	227.4759	5.37	36.65
10	640	15.5	9920	0.024	0.00091	20.0	309.9031	5.03	37.77
11	873	10.2	8904.6	0.012	0.00198	29.0	295.5434	5.98	34.85
12	370	12.9	4773	0.035	0.00268	10.4	133.9985	3.71	43.51
13	1724	0.2	344.8	0.0001	0.00348	65.3	13.06776	8.73	29.23
14	403	2.5	1007.5	0.006	0.00403	11.5	28.75999	3.90	42.56
15	283	11.9	3367.7	0.042	0.00309	7.5	89.73066	3.20	46.64
16	740	7.9	5846	0.011	0.00114	23.8	187.8746	5.45	36.37
17	442	11.3	4994.6	0.026	0.00119	12.8	145.1668	4.10	41.56
18	506	9.5	4807	0.019	0.00159	15.1	143.447	4.41	40.1
19	611	9.9	6048.9	0.016	0.00015	18.9	187.268	4.90	38.22
20	536	9.5	5092	0.018	0.00013	16.2	153.6684	4.56	39.54
21	627	9.7	6081.9	0.015	0.00016	19.5	189.2411	4.97	37.97

The hydraulic characteristics of the aquifer calculated from the geoelectric parameter shows that the aquifer has porosity ranges from 29.4-57.7 %, protective capacities ranges from 0.00013-0.015 mhos, transverse resistance varies from 345-18502 Ωm^2, transmissivity ranges from 13-310 m^2/day and hydraulic conductivity ranges from 0.8-65 m/day. A linear relationship was established when the aquifer hydraulic characteristics were plotted against each other on a log-log graph.

7. ESTABLISHED RELATIONSHIP

A linear relationship was established when the following aquifer parameters were ploted against each other on a log-log graph.
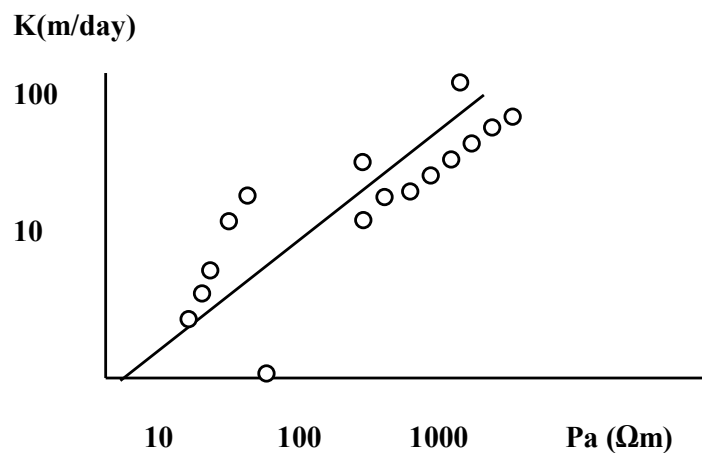

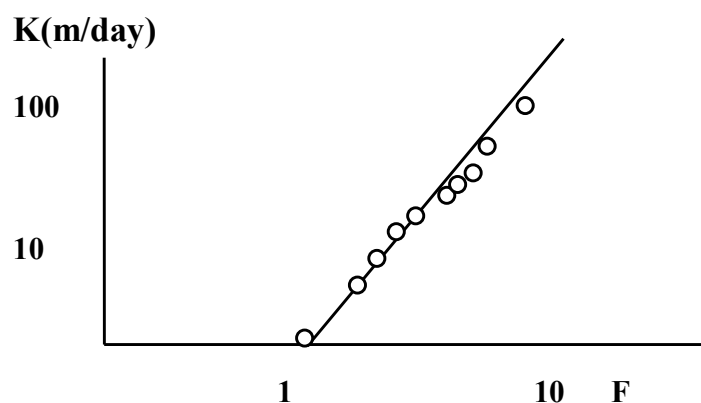**Fig. 3.** Relationship between Hydraulic Conductivity and Aquifer Resitivity.

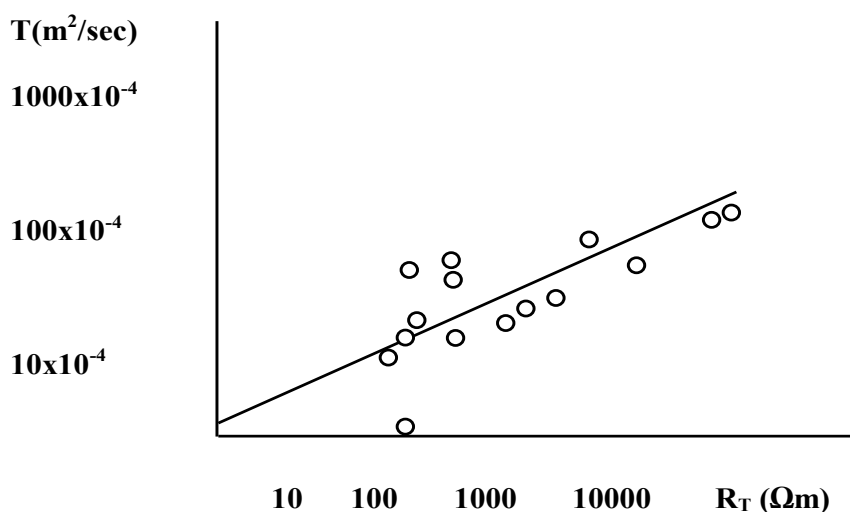**Fig. 4.** Relationship between Hydraulic Conductivity and Formation Factor.

Fig. 5. Relationship between Transmissivity and Tranverse Resistance.

8. CONCLUSION

The results signifies that the aquifer is characterized by high porosity and low protective capacities of overburden layers indicating that it is highly vulnerable to surface contamination. It has high transverse resistance, high transmissivity, and high hydraulic conductivity which are diagnostic of aquifer that can transmit water at high rate to satisfy the yarn of the coastal communities for potable water. 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.

References

[1] Johansen H. K., *Geophysical Prospecting* 25(4) (1977) 667-691.

[2] Kelly W., *Ground Water* 15(6) (1997) 420-424.

[3] Kosinski W. K., Kelly W. E., *Ground Water* 19(2) (1981) 163-171.

[4] Mogaji K. A., Adiat K. A. N., Oladapo M. I., *Online Journal of Earth Sciences* 1(2) (2007) 76-84.

[5] Oladapo M. I., Akintorinwa O. J., *Global Journal of Pure and Applied sciences* 13(1) (2007) 55-61.

[6] Salem H. S., Chilingarian G. V., *Journal of Petroleum Science and Engineering* 23(2) (1999) 83-93.

[7] Ungemaeh P., Mostaghimi F., Duprat A., *Bult. Int. Assoc. Sci. Hydrol.* XIV(3) (1969) 169-190.