GROUNDWATER INVESTIGATIONS: EXPERIENCES IN PARTS OF SOUTH EASTERN NIGERIA

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Abstract

To serve as the basis for a preliminary estimate of aquifer potential in an area where there has been no successful water borehole, Vertical Electrical Soundings (VES) were carried out in conjunction with hydrogeological study in Okija. The study area is on the Ameki Formation. The interpretation of the resistivity sounding data indicates a depth of 59-81m to the aquifer. Interpretation of the field curves outlines the resistivity values (8955-9964 Ù-m) and the depths (59-81m) to the sand (aquifer) of thicknesses (65-73m) within the silt/sand intercalation of the Ameki Formation. The results also indicate generally the types and thickness of soil materials above the aquifer.

Keywords: *Aquifer potential, vertical electrical soundings, Ameki formation, Okija.*

Introduction

With the increasing population of 10,000 to 13,898 in five years and industralization of Okija and the resultant increase in the pollution of surface waters, the need to consider ground water as a major source of potable water has become not only desirable but compelling so as to meet the water needs of the people. Moreover, the selection of borehole locations and depth to the aquifer by test holes is usually time consuming and expensive. The low survey expenditures and high reliability make geoelectrical surface methods rank among the most important methods used in selecting the location as well as in determining the depth and the soil type above the aquifer.
(Zohdy,1969; Young et.al., 1998 and Kalinski,et.al.,1993).Some other uses of the methods are the determination of the interface between saline water and fresh water (El.Waheidi et.al., 1992; Egwebe and Ifedili,2003 and 2005;Choudhury et.al.,2001); porosity of aquifer (Jackson et.al.,1978); hydraulic conductivity of aquifer(Yadav and Abolfazi,1998; Troisi et.al.,2000); transmissivity of aquifer (Kosinski and Kelly,1981); specific yield of aquifer (Frohlich and Kelly,1987); hydrogeological mapping in karst terrains (Sumanovac and Weisser,2001); contamination of ground water (Kelly,1976; Kaya,2001; Egwebe,2003; Frohlich and Urish,2002).

Brief Geology and Hydrogeology of the Study Area

Okija area, the subject of the study is underlain by the Ameki Formation (Figure 1). The Formation overlies the Imo shales and consists mainly of a series of cross-bedded sandstones, clays, pebbly grit and grey siltstones. Elsewhere at Ozubulu it has been shown to contain grey clay and lignite horizons. East of Ihenbosi, it is also known to pass laterally into the Nanka sands. It comprises of two lithologic units, lower and upper Ameki (Reyment, 1965). The upper beds contain coarses siltstones, while the lower beds consist of massive dark grey mudstone to sandy mudstone.
The Ameki Formation is a thick and permeable aquifer. In areas underlain by the formation, both east and west of the Niger, the aquifer consists of fine-coarse grained sands, clays and lignite strata with local pebble beds. The water table varies from 40 to 49m around Ozubulu to 70 to 83m around Akata and Nempi in Orlu. West of the Niger around Asaba and Ogwashi-Uku, it lies between 46-122m above the sea level. The aquifer is confined and semi-confined in places and because of interbedded clay layers in some places,

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perched aquifer may also occur at 30-60m higher than the main water table(Offodile,2002). These perched aquifers furnish minor springs which emanate in the upper part of the cut back valleys. The yield of the perched aquifers are unreliable and their utilization is not recommended.

At Ozubulu, the water yield from the Ameki formation was 1300 gallons per day (g.pd), at Akata it was 2,400 gpds and at Nempi it was 10,800 gpd. Also the higher the topographic level, the deeper the water table below the ground level (Eziegbo and Obiefuwa,1995). This is an indication that the water table contours follow the topography but with less relief.

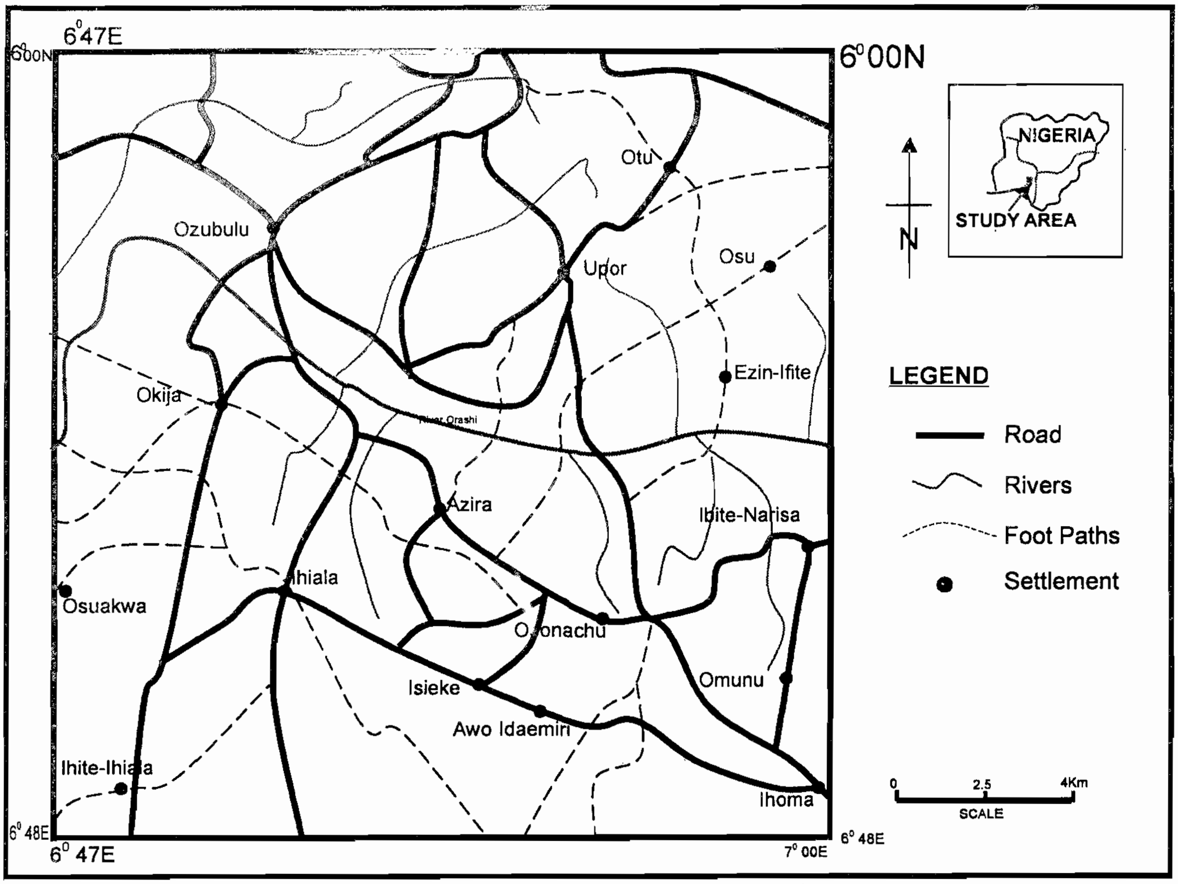

Fig. 1: Map showing Okija and its environs.

Theory

The fundamental theory behind the resistivity method was expounded by Maillet (1947) and the theory has been expanded by Keller and Frischknechnt, 1966; Grant and West, 1965; and Bhattacharyam and Patra, 1968.

The connection between and $\underline{E}$ and $\underline{J}$ is produced by 0hm's law which states that the current density is proportional to the electric field strength.

$$\underline{J} = \sigma \underline{E} \qquad (1)$$

The proportionality constant is called conductivity (σ). For an isotropic medium, the conductivity is a scalar quantity so that $\underline{J}$ and $\underline{E}$ are in the same direction. In general $\underline{J}$ and $\underline{E}$ are not in the same direction because conduction might be in one direction rather than another. Such a medium is said to be anisotropic and the conductivity is a tensor of second rank, $_{ij}$, where *i* and *j* may be any of the x, y, z spatial directions in a rectangular coordinate system. Thus ohm's law becomes:

$$J = \sigma_{ij} \underline{E} \qquad (2)$$

The resistivity method operates in the absence of a field of induction and is based on observations of an electric field maintained by direct current. For a source free regions of the earth, from the Maxwell's equations we can write:

$$\underline{\nabla} x \, \underline{E} = 0 \qquad (3)$$

$$\underline{\nabla} x \, \underline{J} = 0 \qquad (4)$$

And equation (3) suggests that the electric field strength may be expressed as the gradient of a scalar potential.

$$\underline{E} = - \underline{\nabla} V \qquad (5)$$

Combining equations (2), (4) and (5), a differential equation which is the basis of all resistivity prospecting with direct current can be written as:

$$\nabla\sigma_{ij}\ \nabla V = 0 \qquad (6)$$

In the isotropic case when the conductivity of a point in the ground is independent of direction, equation (6) reduces to Laplace's equations:

$$\nabla^2 V = 0 \qquad (7)$$

The solutions to equations (6) and (7) may be developed for a particular model of the earth by selecting a co-ordinate system to match the geometry of the model and by imposing appropriate boundary condition.

By applying separation of variables to Laplace's equation in cylindrical co-ordinate Stefanesco, et. al., (1930) arrived at a general solution for the potential of the surface of an n-layer earth having arbitrary resistivities and thicknesses;

$$V(r) = \frac{I1_1}{2\pi}\left[\frac{1}{r} + 2\int_0^\infty \theta_n(\lambda) J_0(\lambda r)\, d\lambda\right] \qquad (8)$$

where V(r) is the potential at the surface of the earth at a distance, r, from the current source, I, is the resistivity of the first layer, J_0 is the zero-order Bessel function of the first kind and θ_n called kernel function, is a function of the thickness and reflection coefficients for an assumed earth model.

By differentiating equation (8), the Schlumberger apparent resistivity over an n-layered earth becomes;

$$1_a(r) = 1_1\left[1 + 2r^2\int_0^\infty \lambda\theta_n(\lambda) J_1(\lambda r)\, d\lambda\right] \qquad (9)$$

where J_1 is the first order Bessel function of the first kind. The evaluation of the integral in equation (9) has been done in a number of ways.

A novel approach to the problem of computing sounding curves for stratified models by starting with the integral formula of Stefanesco et. al., (1930) was introduced by Ghosh (1971) and equation (9) can be expressed as follows:

$$1_a(r) = r^2\int_0^\infty \lambda T(\lambda) J_1(\lambda r)\, d\lambda \qquad (10)$$

where $T(\lambda) = 1_1\left[1 + 2\theta_n(\lambda)\right]$

The function $T(\lambda)$ is called the resistivity transform because it is defined by a Hankel transformation

$$T(\lambda) = \int_0^\infty r^{-1}\, 1_a(r) J_1(\lambda r)\, dr \qquad (11)$$

Equation (11) is a convolutioin integral. Therefore, it is possible to determine a linear digital filter $\{b_1\}$which converts resistivity transform samples into apparent resistivity values for theoretical models:

$$1_a(i) = \sum_i b_i T_{m-i} \qquad (12)$$

This model is accurate, fast, simple in operation and has small computer storage requirement. In addition, depths are no longer restricted to integral multiples and may take any arbitrary values.

Methods

Vertical Electrical Sounding was carried out in the study area with an ABEM Terrameter SAS 300C with a booster SAS 2000. The equipment is light and powerful for deep penetration. The resistivity survey was completed with 16 (sixteen) sounding stations. The VES was conducted by using the Schlumberger array with a maximum current electrode spacing (AB) of 928m. The field data acquisition was generally carried out by moving two or four of the electrodes used, between each measurement. Details on the method can be found in standard text books of exploration geophysics (e.g. Telford, et. al., 1976).

The VES curves of the 16 sounding stations were obtained by plotting the calculated apparent resistivity against electrode spacing. Computer programs for reducing a geoelectrical sounding curves into thickness and resistivity of individual layers are described by Zohdy and Bisdorf (1989). The field curves were interpreted by the well-known method of curve matching. The field curves and the result of curve matching were then subjected to computer assisted iterative interpretation. The program used for the purpose of computing the theoretical resistivity model given a set of layer parameters, employs a 9-point digital linear filters (Koefoed, 1979).

The resulting sets of layer parameters were interpreted in terms of their lithologic equivalents. Thus allowing geologic interpretation to be ultimately done.

Results

Computed interpreted VES results are presented in Table 1 and Figure 2.

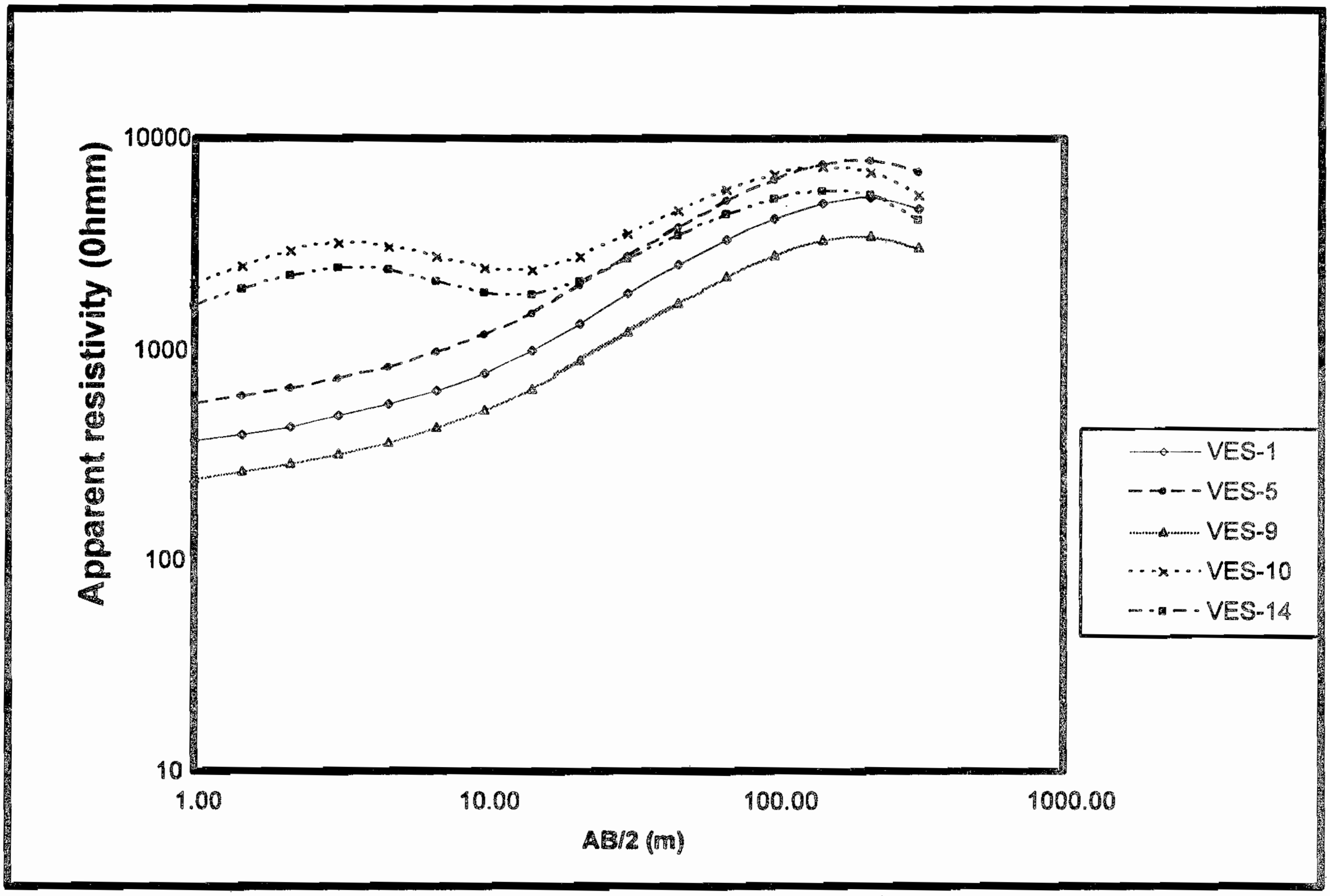

Fig. 2: VES curves for okija and its environs

Table 1 show the derived geoelectric sections for Okija and environs. They are 6 geoelectric layers with geoelectric layer 5 (GL 5) which is likely the saturated sand/silt (aquifer). The field curves have ascending left segments and bell-shaped right segments, and the inferred subsurface stratification at the VES 1-16 are represented by six sampled VES curves in Table 1.

Discussion and Conclusion

From the result in Table 1 and Figure 2, it is clear that the specific resistivity of GL-5 in the 16 VES corresponds to the usual saturated sands, and the aquifer zone is within this geoelectric layer. The underlying GL-6 consists of the argillaceous materials of the Imo clay-shale Formation. It should be noted that due to the heterogeneous nature of the Ameki formation, the aquifer depth position ranges from 58.58 79.74m and its thickness ranges from 65.16-73.21m (Table 1). It is also clear from the geological interpretations that GL-5 contains the aquiferous layers.

Information on relief of VES 10 and VES 16 locations with respect to Orashi River bed (72m and 73m respectively) shows that the depth to the interpreted aquifer zone at VES 10 and VES 16 (72.92m and 73.74m respectively) are in good agreement. The Orashi River bed serves as the base elevation for the area, and it is therefore likely that the aquifer encountered at GL-5 is confined and will have subartesian characteristics.

Therefore, based on the results of field measurement and computer interpretation drilling of conventional borehole is recommended in Okija since the Ameki aquifer is very pervasive in the area. However, to achieve success in the water supply project, drilling should be done by a competent contractor with a drilling machine (rig) capable of drilling up to 73m depth or more, supervised by a competent hydrogeologist also geophysical logging will greatly help the hydrogeologist in choosing the appropriate aquifer horizon within GL-5, and pump testing should be conducted after well development so as to determine the aquifer characteristics.

The foregoing presentation and discussion have shown that it is possible to make inferences from VES results on subsurface stratification, as well as identify possible aquifers (with depth and thickness) in Okija area.

Table 1: Summary of the interpreted six sampled VES curves.

Geoelectric Layer	VES 1 Thickness (m)	VES 1 Depth (m)	VES 5 Thickness (m)	VES 5 Depth (m)	VES 9 Thickness (m)	VES 9 Depth (m)	VES 10 Thickness (m)	VES 10 Depth (m)	VES 14 Thickness (m)	VES 14 Depth (m)	VES 16 Thickness (m)	VES 16 Depth (m)	InferredLithology/ Apparent Resistivity ranges ((Ω-m) in bracket
1	0.59	0	0.61	0	0.53	0	0.59	0	0.69	0	0.48	0	Top soil (155-34Ω-m)
2	1.30	0.59	1.28	0.61	1.32	0.53	1.30	0.59	1.28	0.69	1.35	0.48	Lateritic sand (441-570Ω-m)
3	6.80	1.89	6.68	1.89	6.91	1.85	10.95	1.89	11.05	1.97	9.89	1.83	Dry sands/silts (708-1762Ω-m)
4	50.40	8.69	51.03	8.57	49.82	8.76	67.08	12.84	68.12	13.02	68.02	11.72	Dry sands/silts (10444-11565Ω-m)
5	71.29	59.09	70.73	59.60	73.21	58.58	67.90	72.92	66.89	81.14	65.16	73.74	Saturated sand/silt (Aquifer) (8955-9964Ω-m
6	-	130.38	-	130.33	-	131.79	-	147.82	-	148.03	-	144.90	Silts (307-633Ω-m)

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References

Bhattacharyam, P.K., and Patra, H.P. (1986): Direct Current Geoelectric Sounding. Elsevier Amsterdam, 135p.

Choudhury, K., Saha, D.K. and Chakrabarty, P. (2001): Geophysical Study for Saline Water Intrusion in a Coastal Alluvial Terrain. Journal of Applied Geophysics, 46,189-200.

Egwebe,O. (2003): Environmental Geophysics: Site Characterization of the Delta State Region of the Niger Delta by Electrical Resistivity Method. Ph.D. Thesis, Department of Physics,University of Benin, Benin City. 306p.

Egwebe, O. and Ifedili, S.O. (2003): Hydrogeophysical Evaluation of the Fresh Groundwater Potentials in Saline Water Environment: Case Study from Communities Along Benin River. N.I. Prod. E. Technical Transactions, 8(1), 88-98.

Egwebe, O. and Ifedili, S.O. (2005): The Vertical Electrical Sounding: A viable Tool for the Investigation of Fresh Groundwater in the Saline Water Environment with Particular Reference to the Communities Along Warri River. Journal of the Nigerian Association of Mathematical Physics, 9, 437-442.

El-Waheid; M.M., Merlanli, F. and Pavan, M. (1992): Geoelectrical Resistivity Survey of the Central part of Azrag Basin (Jordan) for Identifying Salt Water/Fresh Water Interface. J. Applied Geophysics, 29,125-133.

Frohlich, R.K. and Kelly, W.E. (1987): Estimates of Specific Yield with the Geoelectric Resistivity Method in Glacial Aquifers. Journal of Hydrology, 97,33-44.

Frohlich, R.K. and Urish, D. (2002): The Use of Geoelectric and Test wells for the Assessment of Ground Water Quality of a Coastal Industrial Site. Journal of Applied Geophysics, 50,261-278.

Ghosh, D.P. (1971): The application of Linear Filter Theory to the Direct Interpretation of Geoelectrical Resistivity Sounding

Measurements. Geophys. Prosp., 19, 192-217.

Grant, F.S. and West, G.F. (1965): Interpretation Theory in Applied Geophysics. McGraw Hill, New York.

Jackson, P.N., Taylor Smith, D., and Stanford, P.N. (1978): Resistivity-Porosity-Particle Shape Relationships for Marine Sands. Geophysics, 43,1250-1268.

Kalinski, R.J., Kelly, W.E., and Bogardi, S. (1993): Combined use of Geoelectrical Sounding and Profilling to Quatify Aquifer Protection Properties. Ground Water, 31,538-544.

Kaya, G.K. (2001): Investigation of Groundwater Contamination using Electric and Electromagnetic Methods at an Open Waste Disposal Site: A Case Study from Isparta, Turkey, Environmental Geology, 40,725-731.

Keller, G.V. and Frischknecht, F.C. (1966): Electrical Methods in Geophysical Prospecting. Pergamon Press. Oxford.

Kelly, W.E. (1976): Geoelectric Sounding for Drilling Groundwater Contamination, Ground water, 14,6-11.

Koefoed, O. (1979): Geosounding principles, Resistivity Sounding Measurements Elsevier

Science Publishing Co. Inc. New York, U.S.A. 276p.

Kosinski, W.K., and Kelly, W.E. (1981): Geoelectric Sounding for Predicting Aquifer Properties. Groundwater ,19,163-171.

Reyment, R.A. (1965): Aspects of the Geology of Nigeria, University of Ibadan Press. 145p.

Stefanesco, S., Schlumberger, C. and Schlumberger, M.(1930): Sur. La Distribution

Electrique Potentielle en tour d'une prise de terre pon etuele dens un terrain a couches Horizontales, Homogene et isotropes. J. de Physique et. le. Radium Series 7, 1, 132-140.

Summanovac, F. and Weisser, M. (2001): Evaluation of Resistivity and Seismic Methods for Hydrogeological Mapping in Karst Terrains, Journal of Applied Geophysics, 47,13-28.

Telford, W., Geldart, L., Sherrif, R. and Keys, D. (1976): Applied Geophysics, Cambridge University Press.680p.