Journal of the Nigerian Association of Mathematical Physics, Volume 9 (November 2005)

The vertical electrical sounding: A viable tool for the investigation of fresh ground-water in the saline water environment with particular reference to the communities along Warri River.

Otobo Egwebe and S.O. Ifedili
Department of Physics, University of Benin, Benin City.

Abstract

A resistivity survey was carried out in order to study the fresh ground water conditions (such as the depth to the various aquifers) in the major communities along the Warri River. Vertical electrical soundings by Schlumberger array were carried out at Ogbe-Ijoh, Ode-Itsekiri, Ugbodede, Egbokodo and Omadino. The Schlumberger resistivity soundings were carried out with half- electrode spacing in the range 1-681m and six points per decade. The resistivity data were used to determine the depth and nature of the aquifers, and they showed that there are three aquifer zones (top fresh water, middle brackish/saline water and the bottom fresh water aquifers).

pp 437 – 442

1.0 Introduction

The superiority of the geoelectric method over others in the ground water research is confirmed by the work of [1 - 3] who reported on the ability of the resistivity method to furnish information on the subsurface geology unobtainable by other methods in groundwater studies. The resistivity techniques have been successfully utilized in : assessing water supply potential in basement aquifers [4],exploring aquifer boundaries in the plains of Yemen [5], the assessment of the groundwater resources potentials within the Obudu basement area of Nigeria [6],and assessment of the near surface groundwater resources potentials within the eastern Niger Delta [7].

All these results above suggest that the usefulness of vertical electrical sounding (VES) for groundwater assessment in basement areas, however when it was applied in the Niger Delta (within which the study area lies) it was only the near surface aquifer (water source for the hand dug/shallow wells) that was assessed. However, this aquifer is proned to contamination through direct / vertical flow of contaminants [8].

The study reported here was carried out primarily using VES method to determine the depth to the deep fresh water aquifer which is sealed from contamination by impermeable soil materials such as clayey soil. The VES is accurate and less expensive compared to test drilling in such a difficult area.

2.0 Theory

The fundamental theory behind the resistivity method was expounded by [9] and the theory has been expanded by [10 –12]

The connection between E and J is produced by 0hm's law which states that the current density is proportional to the electric field strength:

$$\underline{J} = \sigma \underline{E} \tag{2.1}$$

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, σ_{ij}; where i and j may be any of the *x*, *y*, *z* spatial directions in a rectangular coordinate system. Thus 0hm's law becomes:

$$\underline{J} = \sigma_{ij} \underline{E} \tag{2.2}$$

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 region of the earth, from the Maxwell's equations we can write:

$$\nabla \times \underline{E} = 0 \tag{2.3a}$$

$$\underline{\nabla} \times \underline{J} = 0 \tag{2.3b}$$

And equation (2.3a) suggests that the electric field strength may be expressed as the gradient of a scalar potential

$$\underline{E} = -\underline{\nabla} V \tag{2.3c}$$

Combining equations (2.2), (2.3b) and (2.3c), a differential equation which is the basis of all resistivity prospecting with direct current can be written as:

$$\nabla \sigma_{ij} \nabla V = 0 \tag{2.4}$$

In the isotropic case when the conductivity at a point in the ground is independent of direction, equation (2.4) reduces to Laplace's equation:

$$\nabla^2 V = 0 \tag{2.5}$$

The solutions to equations (2.4) and (2.5) 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 conditions.

However, the resistivity theory and interpretation have long been biased toward an earth model of horizontal, homogeneous and isotropic layer. This is because of the high approximation to the real earth, especially in ground water-environments and due to natural mechanism of sedimentation.

By applying separation of variables to Laplace's equation in cylindrical co-ordinates [13] we arrived at a general solution for the potential at the surface of an n-layer earth having arbitrary resistivities and thicknesses;

$$V(r) = \frac{I\ell_1}{2\pi}\left[\frac{1}{r} + 2\int_0^\infty \theta_n(\lambda) J_0(\lambda_r)\, d\lambda\right] \tag{2.6}$$

where *V*(r) is the potential at the surface of the earth at a distance, r, from the current source, I, ℓ_1 is the resistivity of the first layer, J_0 is the zero-order Bessel function of the first kind and $\theta_{n,}$ called kernel function, is a function of the thickness and reflection coefficients for an assumed earth model.

By differentiating equation (2.6), the Schlumberger apparent resistivity over an n-layered earth becomes;

$$\ell_a(r) = \ell_1\left[1 + 2r^2 \int_0^\infty \lambda \theta_n J_1(\lambda r)\, d\lambda\right] \tag{2.7}$$

where J_1 is the first-order Bessel function of the first kind. The evaluation of the integral in equation (2.7) has been done in a number of ways.

[14] introduced a novel approach to the problem of computing sounding curves for stratified models by starting with the integral formula of [13] and equation (2.7) becomes

$$\ell_a(r) = r^2 \int_0^\infty \lambda T(\lambda) J_1(\lambda r)\, d\lambda \qquad (2.8)$$

where $$T(\lambda) = \ell_1 \left[1 + 2\theta_n(\lambda)\right]$$

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

$$T(\lambda) = \int_0^\infty r^{-1}\, \ell_a(r)\, J_1(\lambda r)\, dr \qquad (2.9)$$

Equation (2.8) is a convolution integral. Therefore, it is possible to determine a linear digital filter $\{b_i\}$ which converts resistivity transform samples into apparent resistivity values for theoretical models:

$$\ell_a(i) = \sum_i b_i\, T_{m-i}$$

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

3.0 Experimental Work

The field work was carried out in the major communities along the Warri River. A total of five Schlumberger Electrical Soundings in five communities were conducted using the ABEM SAS 300C Terrameter and the SAS 2000 Booster with VES 1 in Ogbe-Ijoh, VES 2 in Ugbodede, VES 3 in Egbokodo, VES 4 in Omadino and VES 5 in Ode-Itsekiri (Big Warri). Current Electrode Separation (AB) varied from 1m to 68lm. The direction of expansion of the electrodes was constrained by the Warri River, and all arrays were therefore expanded parallel to the Warri River.

The end result of the field measurement is the computation of an apparent resistivity for each VES. The resulting data were plotted as curves of apparent resistivity (ℓ) in 0hm-m against electrode separation (AB/2) in metre using log-log sheet. These curves constitute the VES field curves which were interpreted qualitatively and quantitatively. The quantitative interpretation was curve matching and computation techniques.

4.0 Results and discussion

Results from the VES are presented in form of curves in Figure 1, with VES 1 representing Ogbe-Ijoh, VES 2 (Ugbodede), VES3 (Egbokodo), VES 4 (Omadino) and VES 5 (Ode-Itsekiri). The multi-layered nature of the studied area is reflected by the multi-segmented VES field curves. The observed depths of sounding curves range from 5-8 layers type curves (Table 1). All the curves have ascending right most segments showing that the deep fresh water aquifer was encountered at current electrode spacing (i.e. AB values) of (464-681) m.

The summary of the interpreted VES curves in Table 1 showed that the depth to the first aquifer is (0.5 - 3.2)m, the thickness of the first aquifer (fresh water) is (1.0 - 47.6)m and the high value of 47.6m at Ogbe-Ijoh indicates that Ogbe Ijoh is farthest from the saline water environment than the other locations. Table 1 also showed that the depth to the deep fresh water increases with decrease in the thickness of the saline water aquifer and the depth ranges from 33 – 237m below the earth surface.

The apparent resistivities of the top soil and the first aquifer (all > 100 Ohm-m) are within the resistivity range of sands which means that the first aquifer is in direct hydraulic communication with the top soil and it is therefore phreatic. Thus,the hand dug wells are not recommendable as source of potable water since they tap the first aquifer which is highly proned to contamination by direct infiltration of contaminants from the surface. It is worth noting that the near surface water bodies (first aquifer) around Ode-Itsekiri, Egbokodo, Umadino and Ugbodede become brackish or dry up during dry seasons, hence the deep boreholes which tap the deep fresh water aquifer are recommended for potable water.

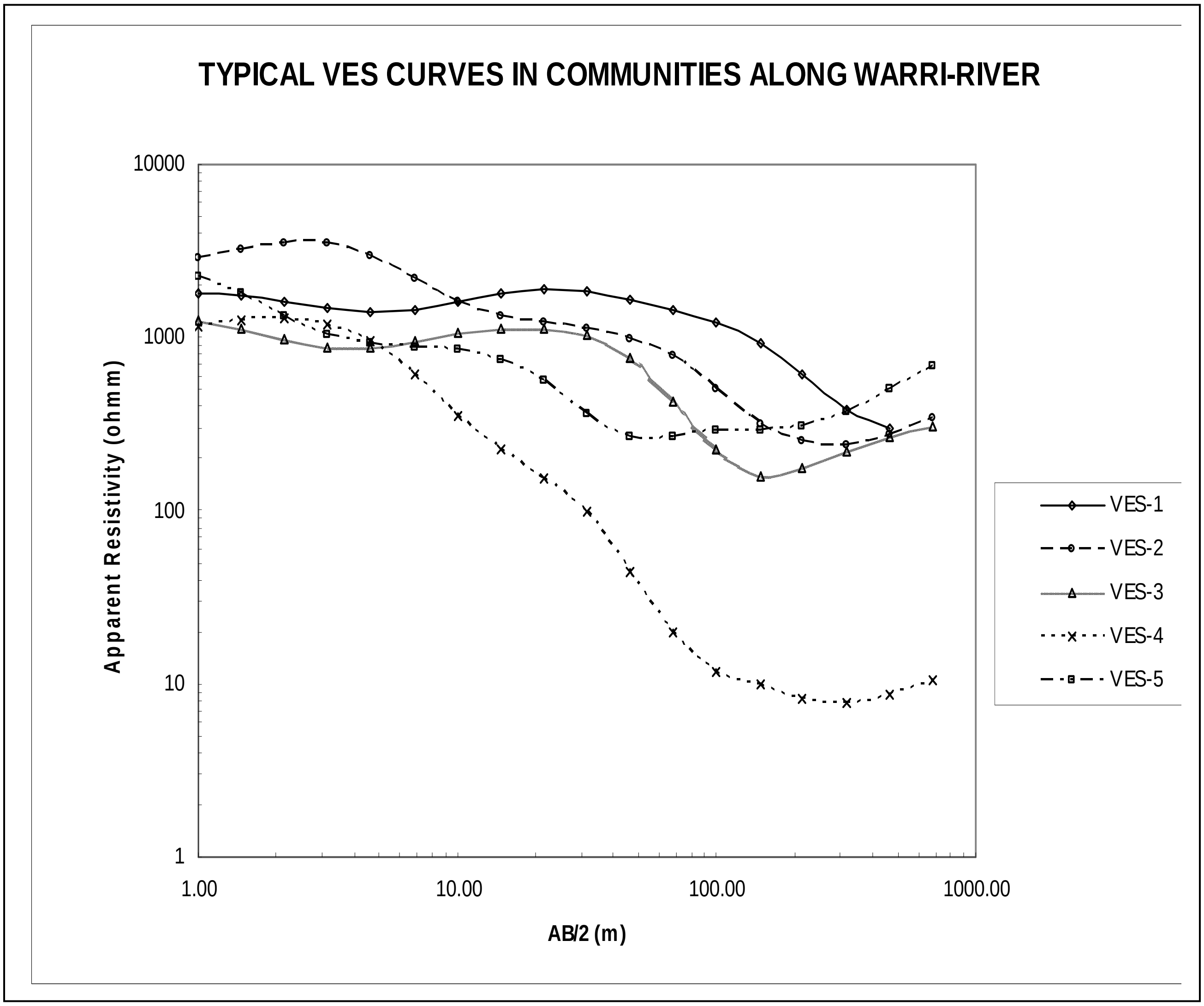

Figure 1: Typical VES curves in Communities along Warri River.

Table 1: Summary of VES results in the Communities along the Warri River

Location	Maximum AB/2 value (m)	VES No	Curve shape	Depth to the first aquifer (freshwater) or top soil (m)	Thick-ness of first aquifer (m)	Depth to the second aquifer (saline water) (m)	Thick-ness of the second aquifer (m)	Depth to the deep aquifer(fresh water) (m)	Number of layers
Ogbe-Ijoh	417	1	AKQ	1.3	47.6	48.9	40.0	137.8	5
Ugbodede	650	2	KHKQQH	0.8	1.0	1.8	36.2	39.8	8
Egbokodo	650	3	KKHA	3.2	22.1	25.3	70.0	120.6	6
Omadino	681	4	KQQH	0.5	16.8	17.3	202.8	237.4	6
Ode-Itsekiri	681	5	QHKHA	2.7	8.36	11.06	11.31	33.43	7

5.0 Conclusion

This paper has shown that useful delineation of the aquifer types (fresh water and saline water aquifers with their thicknesses and depths based on the sharp resistivity contrasts) can be developed with the use of the VES in a typical saline water environment such as the studied area, thus establishing the presence of fresh groundwater. However, with the detected deep fresh water aquifer below the saline/brackish water, an effective drilling operation can guarantee the supply of potable water to the inhabitants of the areas and any saline water environment.

It is recommended that the development of the deep freshwater aquifer must be carried out by a competent contractor, with a drilling machine capable of drilling up to 100-250m of depth or more and such drilling should be supervised by a competent hydrogeologist who will monitor the operations and log the drilled cuttings. Geophysical logging must be conducted before well casing and screening so that dry sands and brackish / saline water intruded sand bodies could be distinguished from fresh water sand bodies. Pumping test must be conducted to allow for the understanding of the aquifer characteristics so that indiscriminate pumping habits that will induce brackish / saline water intrusion are avoided.

6.0 Acknowledgement

This study has been made possible, through a financial assistance from the University of Benin Research and Publications Committee. This financial help is gratefully acknowledged.

References

[1] Pulawski,B. and Kurht,K. (1997).Combined use of resistivity and seismic refraction methods in groundwater prospecting in crystalline area.Study project , Kenya,DANIDA,pp.33-55.
[2] Zohdy, A.A.R (1973): Geophysics, 34 pp. 713-728
[3] Zohdy, A.A.R, Eaton, C.P., Mabey, D.R. (1974), Application of Surface geophysics to groundwater investigation. Tech. water resources investigation Washington, U.S. geology survey, P.116.
[4 Chilton,P.J, and Foster,S.S.D (1995).Hydrogeological Journal,3:36-49.
[5] Van Overnmeeren, R.A. (1989). Geophysics, Vol. 54, No.1, pp.38-48.
[6] Okwueze,E.E.(1996).Global J.Pure and App.Sci. 2:210-221.
[7] Etu-Efeotor, J.O,Michalski,A. and Alabo,E.J.I (1989). Journal of Mining and Geology,Vol.25,No.1&2, pp.51-54.
[8] Otobo Egwebe,(2003). Environmental Geophysics: Site characterization of the Delta State region of the Niger Delta by Electrical resistivity method. Ph.D thesis, University of Benin.
[9] Maillet,R.,(1947). Geophysics, Vol. 12, No. 4, pp. 529-556.
[10] Keller, G.V. and Frischknecht, F.C.,(1966). Electrical methods in geophysical prospecting: Pergamon Press. Oxford.
[11] Grant, F.S. and West, G.F.,(1965). Interpretation theory in applied geophysics. McGraw Hill, New York.
[12] Bhattacharyam, P.K. and Patra, H.P.,(1968). Direct current geoelectric sounding. Elsevier Amsterdam.

[13] Stefanesco, S., Schlumberger, C. and Schlumberger, M.,(1930). J. de physique et. Le Radium. Series 7, Vol. 1, pp. 132-140.
[14] Ghosh, D.P.,(1971). Geophs. Prosp., Vol. 19, No. 4, pp. 769-775.