Journal of the Nigerian Association of Mathematical Physics
Volume **11 (November 2007), 379 - 386**

Geophysical investigation for ground water in Orifite, Anambra State, Nigeria.

Otobo Egwebe[1] and Francis Daudu[2]
[1]*Department of Physics, University of Benin, Benin City*
[2]*Flowline (Nig.) Limited, Benin City.*
[1]**e-mail:** oegwebe@yahoo.com

Abstract

Ten* (10) *vertical electrical soundings (fairly distributed over Orifite and its environs) were conducted using the Schlcumberger array with six points per decade and current electrode spacing of* 1-681*m*. *The results of the Interpretation identified a perched aquifer belonging to Ogwashi-Asaba Formation and much closer to the ground surface* (32-57*m depth with apparent resistivities,* 170-5595Ω*-m, and thicknesses,* 71-146*m*) *as the source of ground water to the borehole. Also, the result showed a second aquifer (the Nanka sand) at depth,* 151-239*m, and of resistivities,* 574-6750 Ω*-m.

1.0 Introduction

The superiority of the geoelectric method over others in the groundwater research is confirmed by the works [1-6]. The ability of the resistivity method to furnish information on the subsurface geology unobtainable by other methods in groundwater studies was reported in [7,8]. They also attested to the ability of the electrical method to provide information on the fresh/salt water interface. The resistivity techniques have been successfully utilized in: assessing water supply potential in basement aquifers [9], exploring aquifer boundaries in the plains of Yemen [10] and the assessment of the groundwater resources potentials within the Obudu basement area of Nigeria [11].

The previous researchers reported the success of geophysics for ground water investigation in other geological formations, but Ogwashi-Asaba Formation and the Nanka sands which are the main aquifers in the east of the River Niger have not been investigated in Orifite. The evidence is the absence of a successful water borehole in Orifite which is either because the existing failed boreholes have not penetrated the deep Nanka sand or the shallower perched aquifer within the Ogwashi-Asaba Formation was screened out during well development due to the lack of the depth and thickness information of the aquifers. Thus, the source of water has been the surface water of Ekulo stream which in most cases is highly iron stained because of the Ogwashi-Asaba Formation the water flows through.

This study reported here was carried out primarily using geophysics to estimate the depth and thickness of the main aquifer and other shallower perched aquifers that may exist within the Ogwashi-Asaba Formation which are sufficient for domestic water supply.

2.0 Local geology and hydrogeology of the study area

Orifite and environs are underlain by the Ogwashi-Asaba and Bende-Ameki Formations (Figure 1). The Ogwashi-Asba Formation is best exposed at the head-waters of

Eluko stream. The Bende-Ameki Formation comprises of two lithologic units, lower and upper Bende-Ameki [12]. It is a thick and permeable aquifer. The aquifer consists of fine to coarse grained sands with minor clays. This formation is the lateral equivalent of the Nanka sands which underlies the Ogwashi-Asaba Formation in the east of the River Niger.

Both the Ogwashi-Asaba and the Bende-Ameki Formations are aquiferous. A number of streams (e.g Eluko stream) acquire their baseflow from springs emanating from Ogwashi-Asaba aquifer. The aquifers in Ogwashi-Asaba Formation consist of fine to coarse grained sands winterbeds of clay lenses, lignite strata and local pebby

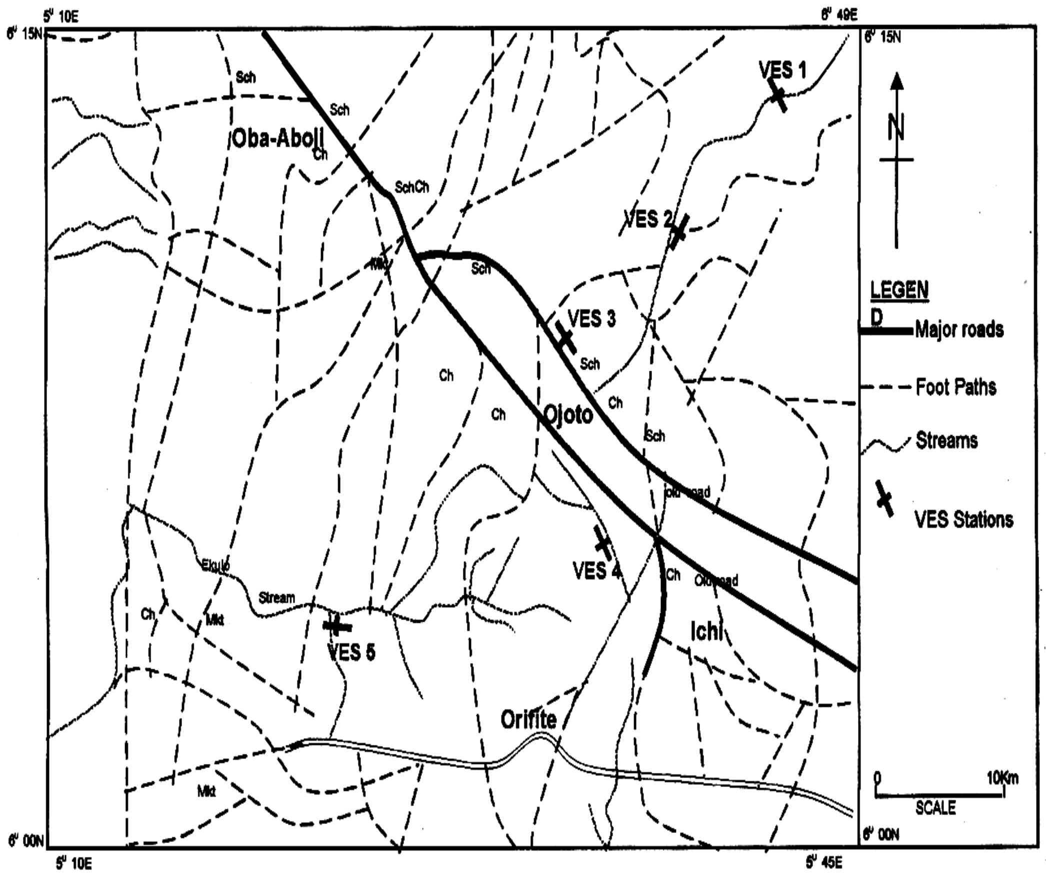

Figure1. Map showing the study area (Orifite and environs)
Source: Federal Surveys Topographic map

ferruginous beds. Because of interbedded clay layers and ferruginous hard pan layers, perched aquifers may occur some 30 to 60m higher than the main aquifer. From visual examination, the spring water appears to contain far less dissolved iron. It was observed, however, that there is marked iron stains at the hard-pan where spring water issues out.

3.0 Theory

The fundamental theory behind the resistivity method was expounded by Maillet [13] and the theory has been expanded by other workers [14-16].

The connection between $\underline{E}$ and $\underline{J}$ is produced by 0hm's law which states that the current density is proportional to the electric field strength. $\underline{J} = \sigma \underline{E}$ (3.1)

The proportionality constant is called conductivity (σ). For an isotropic medium, the conductivity is a scalar quantity so that $\underline{E}$ and $\underline{J}$ are in the same direction. In general $\underline{E}$ and $\underline{J}$ 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 rang, 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:

$$\underline{J} = \sigma_{ij} \underline{E} \qquad (3.2)$$

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:

$$\underline{\nabla} \, x \, \underline{E} = 0 \qquad (3.3)$$

$$\underline{\nabla} \, x \, \underline{J} = 0 \qquad (3.4)$$

And equation (3.3) suggest that the electric field strength may be expressed as the gradient of a scalar potential.

$$\underline{E} = -\underline{\nabla} \, \underline{V} \qquad (3.5)$$

Combining equations (3.2), (3.4) and (3.5), a differential equation which is the basis of all resistivity prospecting with direct current can be written as:

$$\nabla \sigma_{ij} \; \nabla V = 0 \qquad (3.6)$$

In the isotropic case when the conductivity at a point in the ground is independent of direction, equation (3.6) reduces to Laplace's equation.

$$\nabla^2 V = 0 \qquad (3.7)$$

The solutions to equations (3.6) and (3.7) 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 [17] arrived at a general solution for the potential at the surface of an n-layer earth having arbitrary resistivities and thicknesses;

$$V(r) = \frac{I\ell_1}{2\pi}\left[\frac{1}{r} + 2\int_0^\infty \theta_n(\lambda) J_0(\lambda r) d\lambda\right] \qquad (3.8)$$

where *V*(*r*) is the potential at the surface of the earth at a distance, *r* from the current *I*, source, ℓ_1 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 (3.8), the Schlumberger apparent resistivity over an n-layered earth becomes:

$$\ell_a(r) = \ell_1\left[1 + 2r^2 \int_0^\infty \lambda \theta_n(\lambda) \, J_1(\lambda r) \, d\lambda\right. \qquad (3.9)$$

where J_1 is the first order Bessel function of the first kind. The evaluation of the integral in equation (3.9) 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 [17] was introduced by [18] and equation (3.9) can be expressed as follows:

$$\ell_a(r) = r^2 \int_0^\infty \lambda T(\lambda) \, J_1(\lambda r) \, d\lambda \qquad (3.10)$$

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

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

$$T(\lambda) = \int_0^\infty r^{-1} \ell_a(r) J_1(\lambda r)\, dr \qquad (3.11)$$

Equation (3.11) 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:

$$\ell_a(i) = \sum_i b_i T_{m-i} \qquad (3.12)$$

This model 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.

3.1 Experimental Work

The equipment used in this study is a commercially available ABEM Tetrameter, SAS 300C with booster SAS 2000. This is a resistivity meter with a reasonably high sensitivity. The equipment is rugged, portable, and used friendly and has been proven in many site investigations in Nigeria. Schlumberger array was employed for all the sounding. Measurements were taken at expanding current electrodes distance such that in theory, the injected electrical current should be penetrating at greater depth. The end result of the field measurement is the computation of the apparent resistivity (ℓ_a)

$$\ell_a = k \frac{\nabla V}{I} \qquad (3.13)$$

where k = geometric factor which depends on the array in used

Δ = potential difference and I = current.

For the Schlumberger electrodes array, the geometric factor is given as:

$$k = \pi \left(\frac{a^2}{b} - \frac{b}{4} \right) \qquad (3.14)$$

where a = distance from the centre of the array to the current electrode and b = distance between the potential electrodes. The apparent resistivity values are plotted against the half-current spacing (a) using log-log sheet. These plots constitute the field curves which where immediately interpreted qualitatively in the field and later subjected to computer-assisted iterative interpretation. The program used for the purpose of computing theoretical resistivity model given a set of layer parameters employ a 9-point digital linear filters [13]. This relies on the transformation of a VES curve into its corresponding resistivity transform (or kernel function) curve using forward filters such as those developed by [14, 13]. And the resulting set of layer parameters are interpreted in terms of their lithologic equivalents.

4.0 Results and Discussion

The results of the geophysical survey are presented as field curves (Figure 2), the geoelectric sections showing the number of layers, thicknesses of layers, depth to the layers and the inferred lithologies are as shown in Table 1, and Table 2 and 3 showed the derived lithology from a borehole logs at Nnewi a neighbouring town to Orifite.

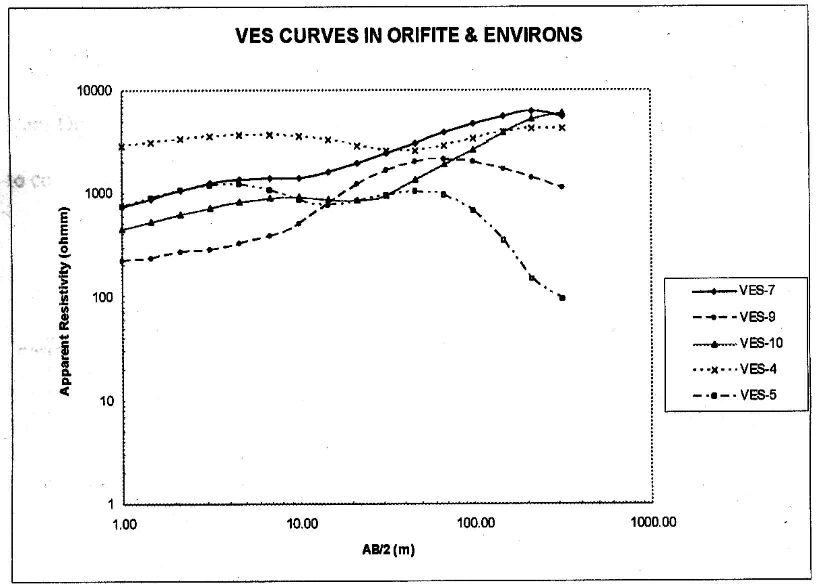

Figure 2: Typical VES curves in Orifite and environs.

Table 1: Borehole-1 logs at Nnewi

Geologic layer	Thickness (m)	Depth (m)	Lithology
1	12.20	0	Clayey sand
2	6.10	12.20	Sand
3	3.05	18.30	Lignite
4	4.57	21.35	Clay
5	7.62	25.92	Clayey silt
6	7.62	33.54	Sandy clay
7	13.72	41.16	Clayey sand
8	3.05	54.88	Fine sand
9	1.52	57.93	Silty clay
10	7.62	59.45	Fine sand

Table 2: Summary of the interpreted six sample VES curves

Geoelectric layer	VES 4		VES 5		VES 7	
	Thickness (m)	Depth (m)	Thickness (m)	Depth (m)	Thickness (m)	Depth (m)
1	0.59	0	0.59	0	0.90	0
2	8.46	0.59	2.20	0.59	1.35	0.90
3	23.30	9.05	5.90	2.79	14.74	2.25
4	59.40	32.35	25.51	8.69	77.07	16.99
5	147.00	91.75	146.30	34.20	115.60	94.06
6	-	238.67	-	180.50	-	161.69

Geoelectric layer	VES 8		VES 9		VES 10		Inferred Lithology/ Apparent Resistibility Ranges (Ω-m) in brackets
	Thickness (m)	Depth (m)	Thickness (m)	Depth (m)	Thickness (m)	Depth (m)	
1	**0.85**	**0**	**0.80**	**0**	**0.90**	**0**	**Top soil (190-2619Ω-m)**
2	**2.38**	**0.85**	**2.80**	**0.80**	**1.60**	**0.90**	**Lateritic sand with silts (307-6714Ω-m)**
3	**15.00**	**3.23**	**7.00**	**360**	**5.60**	**2.50**	**Sands with silts and lignites (381-5510Ω-m)**
4	**32.03**	**8.23**	**28.21**	**10.60**	**49.00**	**8.10**	**Sands with hard pan (49997-7875Ω-m)**
5	**71.03**	**50.26**	**132.00**	**38.81**	**62.50**	**57.10**	**Saturated sand with silt (Nanka sand) (170-5895Ω-m)**
6	**-**	**121.29**	**-**	**170.81**	**-**	**119.60**	**Sands (1071-6750Ω-**

Table 3: Borehole-2 logs at Nnewi

Geologic layer	Thickness (m)	Depth (m)	Lithology
1	22.26	0	Coarse sand
2	7.62	22.26	Sand with grit
3	15.85	29.88	Clay with Lignite
4	3.05	45.75	Clay
5	39.02	48.78	Coarse grit with sand
6	4.88	87.80	White clay
7	74.70	92.68	Coarse grit with sand
8	2.13	167.39	Yellow clay

Result of the VES interpretation showed that high resistive layers is limited to VES 4. The Nanka sands are exposed in VES 5 – 5 sites. Ogwashi-Asaba Formation is exposed at VES 5, although, it is rather thin such that signals from the underlying Nanka sands were picked up in VES 5. The lithology exposed in VES 9 site could very well be Ogwashi-Asaba, although the deeper layers of VES 10 are indicative of Nanka sands. VES 4 site is likely to be totally underlain by Ogwashi-Asaba Formation.

From the foregoing presentation of the results it is possible to construct a geologic section which synthesizes all the available geologic information gathered so far. Nanka sands are exposed at the north-east portion of the study area while the Ogwashi-Asaba Formation occupies the south western portion of the area. The friable nature of Nanka sands led to the formation of a fairly undulating topograph with lower drainage density along the side slopes of Idemili River. The south western area which is inferred to be underlain by the Ogwashi-Asaba Formation, on the other hand, has a markedly lower terrain transmissibility as expressed by deep incision of Ekulo stream especially at its headwaters. This topographic feature supports the inference that the underlying rocks materials are different to those exposed at the north eastern section. The western lowland in the study area is underlain by Quaternary Alluvium deposits derived from the River Niger flooding.

The fact that the Ogwashi-Asaba Formation overlies the Nanka sands at Orifite allows explanation for any occurrence of high dissolved iron content in the groundwater. The Ogwashi-Asaba Formation contains lignite beds with high pyrite content. The leaching of the pyrites and the downward movement of the leachates, accumulated from several lignite beds within the Ogwashi-Asaba Formation is believed to have lead to the high dissolved iron content at the Nanka aquifer of Ichi a nearby town to Orifite. It is likely therefore that perched aquifers within the Ogwashi-Asaba Formation, especially those closer to the ground surface will have less dissolved iron content. However, the Nanka sand aquifer is very prolific. Borehole records showed that yields can go as high as 10000gph. Ogwashi-Asaba aquifers have much less yield although good enough for domestic purposes.

5.0 Conclusion

This work demonstrated the usefulness of VES for the delineation of the aquifer types (perched aquifer within the Ogwashi-Asaba Formation and Nanka sand aquifer). While the perched aquifer reveled at the depths 32-57m is only recommended for domestic water supply, the prolific Nanka sand aquifer at depths 151-239m is recommended for large scale water supply.

It is also recommended that the development of both aquifers must be carried out by competent borehole driller and supervised by an experienced hydrogeologist who will identify the various aquifers reveled in the VES results. And to determine the exact level at which screening should be done we recommend that geophysical logging be done before final casing, screening and gravel packing.

References

[1] Pulawaki, B and Kurth, K., (1977). Combined use of resistivity and seismic refraction methods in groundwater prospecting in crystalline area" study project, Kenya, DANIDA, pp. 33-35.

[2] Egwebe, O. and Ifedili, S.O. (2004). Journal of the Nigerian Institute of Production Engineers. Vol. 8, No. 1, pp. 92-102.

[3] Egwebe, O. and Ifedili, S.O. (2004). Nigerian Journal of Applied Science. Vol. 22, pp. 31-36.

[4] Egwebe, O., and Aigbedion, I. and Ifedili, S.O., (2004). Nigerian Journal of Applied Science. Vo. 22. 146-150.

[5] Egwebe, O. and Ifedili, S.O. (2005). Journal of the Nigerian Association of Mathematical Physics. Vol. pp. 437-442.

[6] Egwebe, O., Aigbogun, C.O. and Ifedili, S.O., (2006). Journal of the Nigeria Association of Mathematical Physics. Vol. 10, pp. 77-82.

[7] Zohdy, A.A.R., (1973). Geophysics, 34, pp. 713-728.

[8] Zohdy, A.A>R., Eaton, C.P. and Mabey, D.R., (1974). Application of Surface Geophysics to Groundwater Investigation, Tech. Water Resources Investigation, Washington, U.S., Geological Survey, p. 116.

[9] Chilton, P.J. and Foster, S.S.D., (1995). HydrogeologicalJournal, 3.36-46.

[10] Van Overmeeren, R.A., (1989). Geophysics, Vol. 54 No. 1, pp. 38-48.

[11] Okwueze, E.E., (1996). Global J. Pure & App. Sci. Vol. 2, pp. 210-211.

[12] Reyment, R.A., (1965). Aspects of the Geology of Nigeria Univ. of Ibadan Press.

[13] Maillet, R., (1947). Geophysics. Vol. 12, No. 4, pp. 529-556.

[14] Keller, G.V. and Frischknecht, F.C., (1966). Electrical methods in geophysical prospecting. Pergamon Press Oxford, 517p.

[15] Grant, F.S., and West, GF., (1965). Interpretation theory in applied geophysics. McGraw Hill, New York, 583p.

[16] Bhattacharyan, P.K. and Patra, H.P., (1968). Direct current geoelectric sounding Elsevier Amsterdam, 13p.

[17] Stefanesco, S., Schlumberger, C., and Schlumberger, M., (1930). J.de physique et le Radium . Series 7, Vol 1, pp. 132-140.

[18] Koefoed, O., (1979). Geosounding Principles 1, Resistivity Sounding Measurements, Elsevier Science Publishing Company, Amsterdam, 276p.

[19] Ghosh, D.P., (1971). Geophys. Prosp. Vol. 19, No. 4, pp. 769-775