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The application of geophysics in environmental impact assessment: A case study in Jeddo, Delta State, Nigeria

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Abstract

Geophysical study using the Schlumberger vertical electrical sounding (VES) was conducted with half current electrode spacing ranging from 1-215m. Also five boreholes were drilled to the depths, 15.2-30m close to five of the VES locations for the purpose of comparing the derived geoelectric sections from VES curves with the geologic sections from the boreholes. The results from VES curves showed the presence of clay of thicknesses, 15.2-26.4m at depths 0-4.4m in two VES locations, while sands of thicknesses,12.2-116.1m were exposed in seven VES locations. Also the logs derived from soil samples collected from the boreholes showed clay presence of thicknesses, 15.2-23.9m at depths 0-3m in the two boreholes close to the VES locations where thick clay presence was detected, while three boreholes showed exposed sands of thicknesses, 12.2-30m. The application of geophysics for the purpose of subsurface study in environmental impact assessment has been discussed.

1.0 Introduction

The increasing cases of ground water pollution in the Niger Delta is alarming and the need to detect areas proned to pollution spreads at the event of presence of pollutants which is part of environmental impact assessment has become not only desirable but compelling. Total prevention of pollution occurrence is safer to the aquifer (which in most cases in the Niger Delta are not naturally sealed) than controlling pollution spread (flow of pollutants within the aquifer).

Mazac and Landa [1] reported that it is advisable to locate, identify and quantify polluted areas. Also Mazac and co-workers [2] have documented that the presence of high quality sealing (clay) is a guarantee for low or negligible pollution of the geological environment especially of groundwater. However, to determine the extent of oil pollution by drilling is usually time consuming and difficult, if not impossible due to dense land coverage [3]. Moreover, in environmental impact assessment study, in addition to the reported difficulties and time consuming associated with drilling used boreholes are not back filled with natural sands. And each impact assessments (such as baseline, post impact and potentially polluted assessment studies) are done by independent team, so boreholes are drilled indiscriminately each time and the aquifers are therefore further exposed to pollution by direct vertical flow of pollutants from the earth surface. .

This paper hereby report the usage of geophysics (the VES method) in accessing the quality of the seal (non porous/permeable clayey soil) over the aquifer in Jeddo (see study area in Figure 1) without soil disturbance instead of the borehole approach which had over the years left the aquifer more exposed to pollution.

2.0 Theory

The apparent resistivity of an inhomogeneous formation is given by [4] as;

$$\ell_{a} = 2\pi\left(\frac{1}{r_1}-\frac{1}{r_2}\right)^{-1}\left[1+\left(\lambda^2-1\right)\sin^2\theta\sin^2\alpha\ \right]^{1/2}\frac{\Delta V}{I}=\frac{K\Delta V}{1} \qquad (2.1)$$

where k = geometric factor which depends on the array in use,

α = dip of the anisotropy
θ = angle of strike
λ = coefficient of anisotropy = $(\ell_t/\ell_i)^{1/2}$
ℓ_t = transverse resistivity normal to the bedding plane
ℓ_1 = longitudinal resistivity parallel to the bedding plane
ΔV = potential difference and
r_1, r_2 = distance of surface electric potential from a point source of current, I.

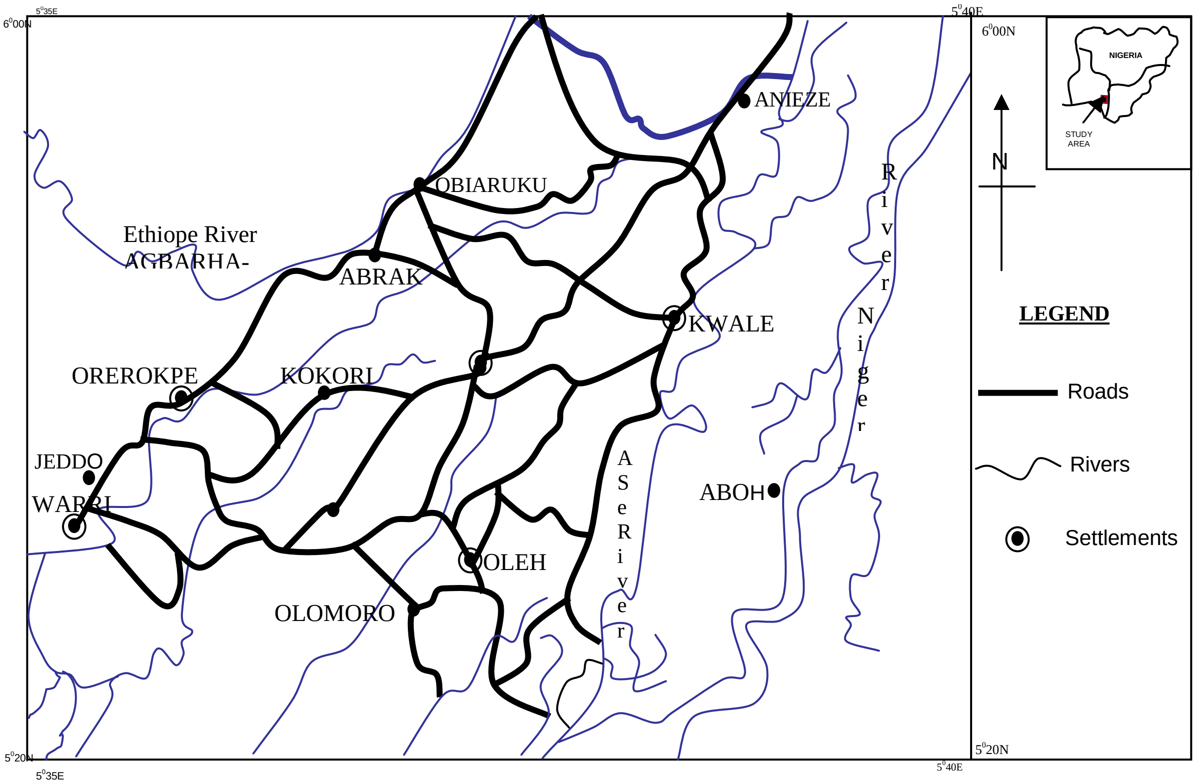

Figure 1: Map Showing the Study Area

The Schlumberger electrodes array was used for the purpose of this research. The geometric factor for the Schlumberger array is given as;

$$k = \pi \left(\frac{a^2}{b} - \frac{b}{4} \right) \qquad (2.2)$$

where a = distance from the center of the array to the current electrode, b = distance between the potential electrodes. The technique of data interpretation used involves seeking a solution to the inverse problem namely the determination of the subsurface resistivity distribution from surface measurements. A very good solution to the inverse problem is the kernel function. It is used in interpreting apparent resistivity measurements in terms of lithological variation with depth. The function assumes the earth to be locally stratified, inhomogeneous and isotropic layers and, unlike apparent resistivity function it is independent of electrode configuration. It cannot be measured in the field but has to be obtained from a transformation of measured apparent resistivities. The kernel function utilized in this work is derived after [5]. If the observed apparent resistivity is given by

$$\ell_a(r) = r^2 \int_0^\infty T(\lambda) J_1(\lambda r) dr \qquad (2.3)$$

Then the kernel function is given by [2.5] as;

$$T(\lambda) = \int_0^\infty (1/r) \ell(r) J_1(\lambda r) dr \qquad (2.4)$$

where J is the first-order Bessel function of the first kind and T (λ) is the transformed resistivity data. Dar-Zarrouk resistivity curve is independent of any underlying layers. The basic mathematics for graphical construction of Dar-Zarrouk curves are given by [6,7]. The curves may be used to give true layer thickness h_j and resistivity ℓ_j by the equation.

$$\mathrm{h}_{\mathrm{j}} = \ell_{\mathrm{j}}\left[\frac{\mathrm{L}_{\mathrm{m,j}}}{\ell_{\mathrm{m,j}}} - \frac{\mathrm{L}_{\mathrm{m,j-1}}}{\ell_{\mathrm{m,j-1}}}\right], j = 1,2,3,\cdots,n \qquad (2.5)$$

$$\ell_{\mathrm{j}} = \left[\frac{\mathrm{L}_{\mathrm{m,\,j}}\ell_{\mathrm{mj}}}{\mathrm{L}_{\mathrm{mj}}/\ell_{\mathrm{mj}}} - \frac{\mathrm{L}_{\mathrm{m,\,j-1}}\ell_{\mathrm{m,\,j-1}}}{\mathrm{L}_{\mathrm{m,\,j-1}}/\ell_{\mathrm{m,\,j-1}}}\right] \qquad (2.6)$$

$$h_1 = L_{mj}, \text{ and } \ell_1 = \ell_{\mathrm{m1}} \qquad (2.7)$$

where $\ell_{\mathrm{mj}} = (T_j/S_j)^{1/2}$, $L_{mj} = (T_j S_j)^{1/2}$, $\mathrm{Tj} = \sum_{i=1}^{j} ti$ and $Sj = \sum_{i=1}^{j} Si,\ i = 1,2,\cdots,n$,

S = the total longitudinal conductance of a section of horizontal layers of thickness, h_j, and resistivity, ℓ_i, T= total transverse resistivity of the same layer above. The importance of Dar-Zarrouk function is that it is uniquely related to the apparent resistivity function.

3.0 Method of study

The vertical electrical resistivity sounding (VES) method involves injecting an artificially generated direct current or low frequency alternating current into the ground through two current electrodes. The resulting potential difference is measured by another pair of potential electrodes in the vicinity of the current flow. Although resistivity generally increases as porosity decreases, the electrical properties are controlled more by water quality than by the resistivities of the rock matrix [8].

Vertical electrical resistivity soundings were conducted using a Schlumberger array. Nine (9) vertical electrical sounding stations were occupied using the ABEM SAS 300C Terrameter with booster SAS 2000, with an electrode separation of 1 - 215m; the resulting sounding curves were interpreted by partial curve matching [9], using two-layer model curves with the corresponding auxiliary curves and computer-iteration technique of [5].

4.0 Results and discussion

Figure 2 showed typical sounding VES curves in Jeddo, with the exception of VES 5 and VES 6 curves, all the VES curves have initial ascent indicating an exposed sandy soil dominated subsurface, while VES 5 and 6 have initial descent indicating an exposed clayey soil dominated subsurface. However, all the curves have ascending right most segments indicating the presence of deep fresh water saturated sands.

Tables1,2,3,4 and 5 showed the lithologies derived from the VES curves (called geoelectric sections) and that derived from soil samples collected from the boreholes 1,4,5,3 and 2 (called geologic sections) drilled close to VES 3,5,6,7 and 8 locations respectively. Table 1 showed a subsurface dominated by sands at depths, 0-15.2m, for borehole 1 (BH-1) and 0-15.4m for VES 3 with a clayey-sand at depths, 15.4-122.9m, for the VES. Table 2 showed a subsurface dominated by clayey soil at depths, 0-22.9m, for VES 5 and 0-30.9m for borehole 4 (BH-4) and also a deep sandy soil at depths, 22.9-30m, and 30.9-78.1m for BH-4 and VES 5 respectively. Table 3 showed an exposed clayey soil dominated subsurface of thicknesses 15.2m and 34.6m for borehole 5 (BH-5) and VES 6 respectively. Table 4 showed an exposed sandy soil dominated subsurface of thicknesses 30m and 38.4m for VES 7and borehole 3 (BH-3) respectively. Table 5 showed a sandy soil dominated subsurface with a surface clayey- sands of thicknesses 1.5m and 0.9m for borehole 2 (BH-2) and VES 8 respectively, and below this layer is a sandy substratum.

Tables 1-5 are summarized in Table 6, where VES (5 and 6) and their respective nearby boreholes (2. 4 and 2.5) showed clayey soil presence of thicknesses 15.2-26.5m for the VES curves and 15.2-23.9m for the boreholes. Moreover, the depths to the clay is 0-4.4m for the VES and 0-3m for the boreholes. Also, VES 3,7 and 8 with their respective nearby boreholes 1,3 and 2 all showed sandy soil dominated subsurface.

Finally, comparison of the geoelectric sections with the geologic sections showed that the deduced lithologies from the VES curves and the borehole logs are in good agreement as demonstrated below: VES 3 and BH-1 showed sandy soil at depths, 0-15.2m; VES 5 and BH-4 showed clayey soil at depths,0-22.9m, and sandy soil at depths, 22.9-30m; VES 6 and BH-5 showed clayey soil at depths, 0-1.5m and 3.0-15.2m with clayey-sand at depths, 1.5-3.0m; VES 7 and BH-3 showed sandy soil at depths,0-30m; and VES 8 and BH-2 showed clayey-sands at depths, 0-1.5m and sandy soil at depths, 1.5-12.2m. However, VES 1,2,4 and 9 curves were interpreted as sandy dominated subsurface with thick-ness 28.4-116.1m, though no boreholes were drilled close these VES locations the good agreement which has been established between the VES and boreholes results gives credibility to these geoelectric sections.

Figure 2: Typical VES curves in Jeddo.

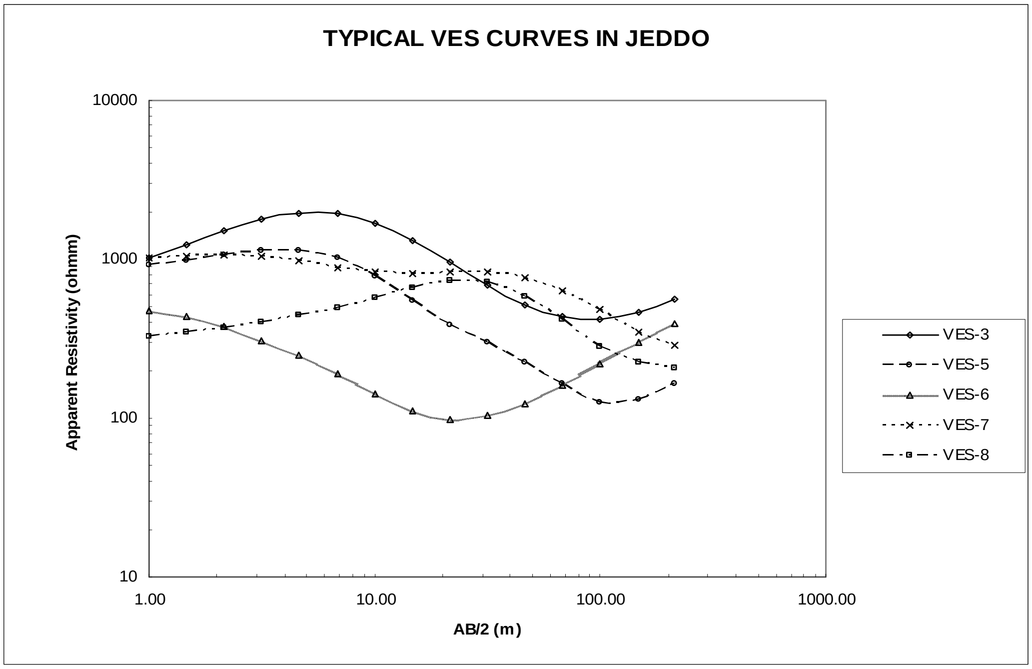

Table 1: Derived geoelectric section of VES 3 with the geologic section of a nearby borehole-1.

Geologic Section		Geoelectric Section	
Depth(m)	**lithology**	**Depth(m)**	**lithology**
0 - 1.5 :	: top soil (sand)	0 - 1.2 :	: top soil
1.5 - 4.7 :	: fine grained sand	1.2 - 4.1 :	: sand
4.7 - 7.6 :	: medium grained sand	4.1 - 15.4	: sand
7.6 - 13.7	: :fine-medium grained sand	15.4 - 122.9	: clayey-sand
13.7 - 15.	: 2medium grained sand		

Table 2: Derived geoelectric section of VES 5 with the geologic section of a nearby borehole-4

Geologic Section		Geoelectric Section	
Depth(m)	**lithology**	**Depth(m)**	**lithology**
0 - 1.5 :	: top soil (silty clay)	0 - 0.8	: clay
1.5 - 3.0 :	: clay	0.8 - 4.4 :	: clayey-sand
3.0 - 6.1 :	: clayey-sand	4.4 - 30.9	: clay
.61 - 22.9	: : clay	30.9 - 78.1	: sand
22.9 - 30.0	: sand		

Geologic Section		Geoelectric Section	
Depth(m)	**lithology**	**Depth(m)**	**lithology**
0 - 1.5	silty clay (top soil)	0 - 1.0	clay
1.5 - 3.0	clayey-sand	1.0 - 4.0	clayey-sand
.0 - 15.2 :	clay	4.0 - 34.6	clay

Table 4: Derived geoelectric section of VES 7 with the geologic section of a nearby borehole-3.

Geologic Section		Geoelectric Section	
Depth(m)	**lithology**	**Depth(m)**	**lithology**
0 - 1.5	top soil (very fine sand)	0 - 38.4	sand
1.5 - 4.6	medium-coarse sand		
4.6 - 7.6	fine-medium grained sand		
7.6 - 10.1	medium-coarse sand		
10.1 - 19.8	fine-medium grained sand		
19.8 - 22.9	medium grained sand		
22.9 - 29.0	fine-medium grained sand		
29.0 - 30:	fine grained sand		

Table 5: Derived geoelectric section of VES 8 with the geologic section of a nearby borehole-2.

Geologic Section		Geoelectric Section	
Depth(m)	**lithology**	**Depth(m)**	**lithology**
0 - 1.5	topsoil (clayey sand)	0 - 0.0.9	:clayey sand
1.5 - 4.6	fine sand	0.9 - 23.9	sand
4.6 - 9.1	fine-medium grained sand		
9.1 - 12.2	medium grained sand		

Table 6: Summary of VES and borehole results

VES NO.	VES RESULTS			BOREHOLE RESULTS			
	Dominant Soil type	Thickness of dominant soil type (m)	Depth to the dominant soil type(m)	Borehole number	Dominant soil type	Thickness of dominant soil type (m)	Depth to the dominant soil type(m)
3	Sand	15.4	0.0	1	sand	15.2	0.0
5	Clay	26.5	4.4	4	clay	23.9	3.0
6	Clay	>15.2	0.0	5	clay	15.2	0.0
7	Sand	>30.0	0.0	3	sand	30.0	0.0
8	Sand	>12.2	0.0	2	sand	12.2	0.0
1	Sand	54.5	0.0				
2	Sand	116.1	0.0				
4	Sand	42.8	0.0				
9	Sand	28.4	0.0				

5.0 Conclusion

The high correlation between the vertical electrical sounding results (geoelectric sections) and borehole results (geologic sections) revealed that an area can be successfully characterized using the VES without necessarily drilling boreholes. Moreover, the inferred subsurface stratification from this site characterization conformed with the known subsurface geology of the area as documented by [10]. It is therefore strongly recommended that a geoelectric (geophysical) study is sufficient for the purpose of subsurface lithologies in any type of environmental impact assessment especially in the Niger Delta instead of boreholes which further expose the aquifers to direct pollution.

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