

## Determination of Aquifer Protective Capacity and Corrosivity of Near Surface Materials in Yenagoa City, Nigeria

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**Abstract:** Geoelectrical sounding method was adopted in the evaluation of aquifer protective capacity and corrosivity of near surface materials in Yenagoa city, South South, Nigeria. A total of eleven Vertical Electrical Soundings (VES) stations were occupied using the Schlumberger configuration. Five geoelectric layers were identified. Layers four and five are the likely aquiferous horizons with resistivities  $>280 \Omega\text{m}$ . The depth to the aquiferous horizon varied between 6.0-52.0 m, and has a rather irregular distribution and thickness. Corrosivity, isopach and longitudinal unit conductance (S) maps were generated from the combination of first and second order geoelectric parameters. The results indicate that the INC and Opolo areas of the city are characterized by weak protective capacity (0.1-0.2 mhos) while other locations investigated are underlain by materials which could be regarded as moderate (0.2-0.69 mhos) to good (0.7-4.9 mhos) protective capacity. Resistivity values within the second layer (11.0-53.0  $\Omega\text{m}$ ) indicate that this layer is moderately aggressive and may likely form corrosion cells which may lead to significant corrosion failures of shallow subsurface piping facilities. The results of this study highlight a set of environmental factors (corrosivity and protective capacity) that should not be ignored at the planning stages of residential and industrial estates.

**Key words:** Corrosivity, geoelectric, isopach, longitudinal unit conductance, resistivity, transverse unit resistance

### INTRODUCTION

Yenagoa city has witnessed tremendous socio-economic transformation in recent years coupled with increased population with attendant human activities due to rapid urbanization. Though the city is surrounded by water, it lacked the quality for human consumption. This is further compounded by the non-availability of municipal water supply, compelling most residents to depend largely on hand-dug wells and motorized boreholes for their domestic water supply. But more than 75% of these water abstraction wells in the city are shallow dug-wells that tap supply from the water table.

Due to the rapid urbanization, waste generation has increased; hence a common feature in the city is that refuse dumps are ubiquitous. The Tombia road refuse disposal site which was very far from the inhabited areas in the early 90s is now totally within the fully developed metropolis and is still receiving refuse. Aside, the uncontrolled location and leakage of facilities most especially underground storage tanks of petroleum products, septic tanks of various households and shallow subsurface piping facilities are other potent sources that can provoke permanent damage of the underlying aquifers. This suggests that the ground water is

susceptible to pollution if there is leakage of buried underground storage tanks or infiltration of leachate from decomposed refuse dumps. The need therefore arises to evaluate the protective capacity of the overburden materials in the area in order to establish the level of safety of the hydrogeologic system within the city. One of the most effective ways to evaluate this without interfering with the hydrogeologic system is through geophysical studies.

Geophysical methods especially the resistivity technique have been successfully used in groundwater exploration, since it is usually a non-invasive, relatively cheap and a quantitative evaluation technique (Sikander *et al.*, 2010). In addition to its use in groundwater exploration, it is an efficient and economical method of determining the degree of corrosiveness of soils and the spread of a contaminant whose salinity is different from the existing groundwater (Schwartz and Mc-Clymont, 1977; Oladapo *et al.*, 2004; Mogaji *et al.*, 2007). In this study, the electrical resistivity method is employed in and around Yenagoa city to evaluate the protective capacity and corrosivity of near surface materials overlying the aquifer. It is hoped that this will aid in the planning, development and management of the groundwater resource.

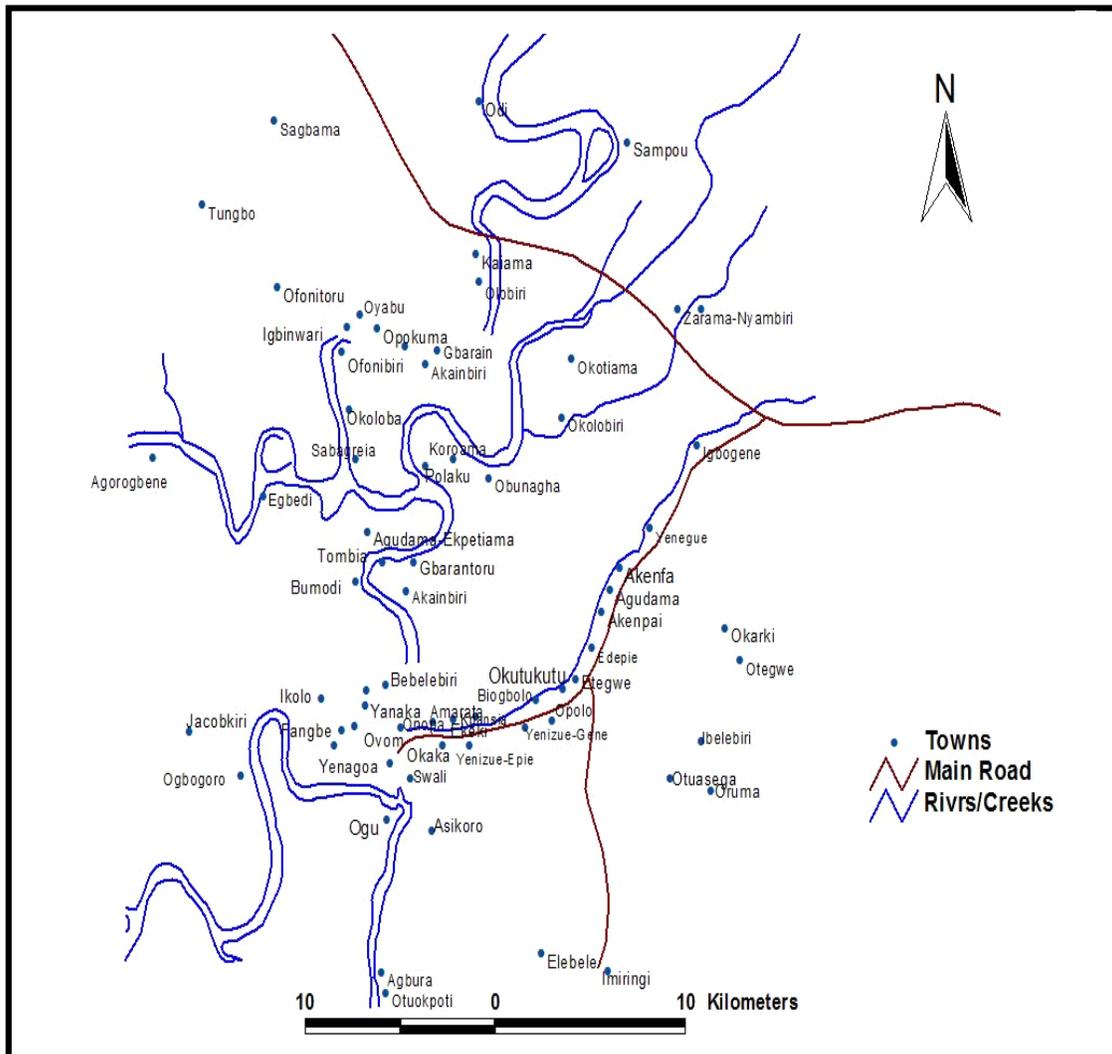


Fig. 1: Map showing study area

**Study area description:** Yenagoa City is one of the rapidly growing urban centers in the South South geopolitical region of Nigeria (Fig. 1). It has an aerial extent of about 70 km<sup>2</sup> bounded by latitudes 4°23.3' and 4° 38.2' N and Longitudes 6°3' and 6°40' E. The city is within the tropical Equatorial climate dominated by abundant rainfall with an annual mean of 3000 mm (Amajor and Ofoegbu, 1988). This ensures a large volume of water input into the environment and with the poor drainage most parts of the city are flooded during wet season, April to October/November.

**Geology and hydrogeology of the study area:** The study area is within the lower section of the upper flood plain deposits of the subearial Niger Delta (Allen, 1965). The deposits are characterized by pebbles and coarse to fine sands with intercalations of silt, mud and clay in places.

A variety of depositional environments (point bars, channel fills, natural levees and splay deposits, backswamps, ox-bow fills and palludal deposits) are typical (Short and Stauble, 1967). The thickness of these Quaternary sediments does not exceed 120 m and it is predominantly unconfined. The hydraulic conductivities of the sand vary from  $3.82 \times 10^{-3}$  to  $9.0 \times 10^{-2}$  cm/sec. The specific capacities recorded from different areas within this formation vary from 6700 to 1300 L/h/m (Ofodile, 1991).

Underlying these Quaternary sediments is the Benin Formation which is about 2100 m thick on the average (Short and Stauble, 1967). The formation represents the subsurface continental megafacies of the Niger Deltaic sequence. It is essentially fluvial in origin and comprises of unconsolidated, massive, and porous freshwater bearing sands with localized shale interbeds. All the

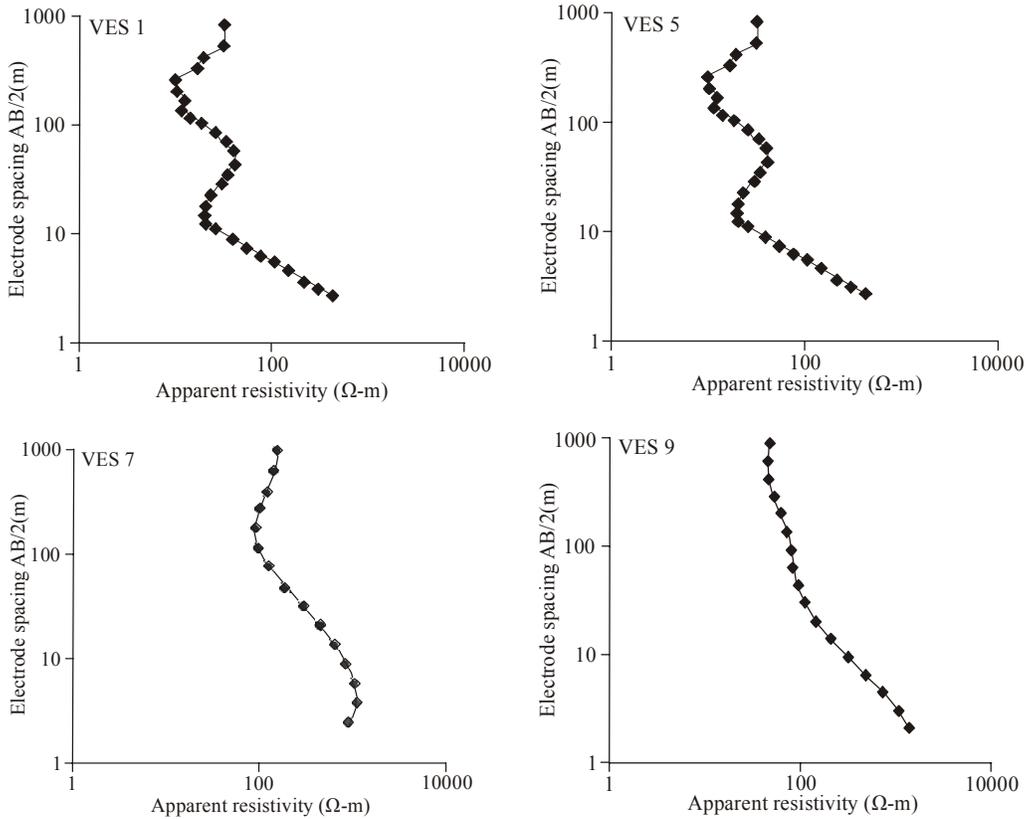


Fig. 2: Examples of the resistivity sounding curves

aquifers in the delta region are located within this lithounit. However, only the upper 200 m has been penetrated by boreholes in the study area. The age ranges from Miocene to Recent.

The underlying paralic Agbada Formation, varies in thickness from 300 to 4500 m. The formation consists predominantly of unconsolidated pebbles, and very coarse to fine grained sand units with subordinate shale beds. Syntectonic growth faults and rollover anticlinal structures are characteristic. These commonly form the major traps for oil and gas in the delta. Age ranges from Oligocene to Recent.

**MATERIALS AND METHODS**

Eleven Vertical Electrical Sounding (VES) points were occupied utilizing the Schlumberger electrode configuration. The electrode spacing was varied from 300-800 m. Field measurements were made with SAS 1000 Resistivity Meter. The VES data were utilized in generating field curves. The data obtained was later subjected to computer assisted iterative interpretation using a 1-D inversion technique software (1X1D, Interpex, USA). First order geoelectric parameters derived

from the iteration were utilized in deriving the second order geoelectric parameters or the Dar Zarrouck parameters (Maillet, 1974). The second order parameters of interest in this study are, Longitudinal unit conductance (S<sub>i</sub>) and Transverse unit resistance (T<sub>i</sub>). The second order parameters are derived thus (Zohdy *et al.*, 1974). For n layers:

The longitudinal unit conductance: 
$$S = \sum_{i=1}^n \frac{h_i}{\rho_i}$$

The total transverse unit resistance: 
$$T = \sum_{i=1}^n h_i \rho_i$$

Using the longitudinal unit conductance/protective capacity rating in Table 3, the longitudinal unit conductance values were classified into weak/poor, moderate and good protective capacity. The values of the overburden thickness, longitudinal unit conductance and resistivity values of the second layer were utilized in generating the isopach, aquifer protective capacity and corrosivity maps of the study area.

Table 1: Summary of modeling results for all soundings

VES no.	Thickness of layers (m)					Resistivity of layers ( $\Omega$ -m)				
	1	2	3	4	5	1	2	3	4	5
1	0.80	1.9	16.5	11.0	-	145	45.3	106.5	252.6	5570.6
2	0.77	3.8	3.8	50.4	-	107	33	294	4082	11637
3	2.00	5.9	11.8	28.8	-	42	53	117	2981	3950
4	1.80	2.5	1.9	17.8	-	4	21	143	1153	603
5	1.50	8.3	7.3	13.0	-	46	12	56	282	2592
6	1.20	1.4	5.4	17.7	-	61	11	184	12	1849
7	0.55	6.0	6.3	24.7	-	94	35	452	3680	10021
8	1.10	4.5	2.6	37.2	-	54	28	48	532	106
9	1.50	9.6	8.1	32.0	-	71	14	74	208	254
10	1.40	14.1	36.2	113.9	-	18	29	57	1051	185
11	0.50	7.2	47.6	90.3	-	254	49	473	234	523

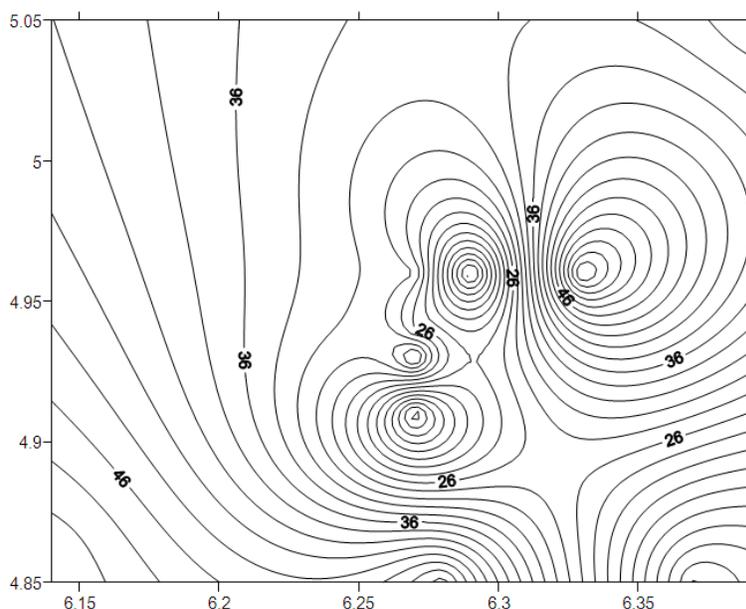


Fig. 3: Isopach map of study area

### RESULTS AND DISCUSSION

The results of the study are presented as sounding curves, tables and maps. The form of the geoelectrical sounding curves varies considerably throughout the study area but having more of the HA, HK, and HKH types (Fig. 2). The most prominent type curve is the H making up the type curve combinations for ten out of the eleven different sounding curves in the study area. In a typical H curve, the descending left branch of the curve indicates resistive topsoil underlain by a conductive material which could possibly be wet clays. The gently ascending right branch could correspond to a more resistive substratum presumably aquifer materials (fine-medium-coarse sand). The interpretive models for each VES station are shown in Table 1. Generally Table 1 shows a widely irregular variation in resistivity both vertically and laterally. This is an indication of the very complex depositional environment of the delta. The results indicate that the area

is characterized by curves that are diagnostic of low to poor groundwater potential and/or quality at shallow depths. Layers four and five show relatively higher resistivity values implying a low concentration of conducting minerals and thus of higher water quality and are considered likely aquiferous horizon in the area in most of the VES points. The thickness of overburden materials and second layer resistivity values are used in generating the overburden thickness and corrosivity maps respectively (Fig. 3 and 4). The second order parameters derived from the sounding interpretation results are presented in Table 2. The total longitudinal unit conductance (S) values obtained in the table are utilized in generating the aquifer protective capacity map of the study area (Fig. 5). The overburden thickness map of the study area (Fig. 3) shows thickness to be in excess of 25 m at the western (INC area) to the northern (Ogbogene community) parts of the study area. Overburden materials are generally less than 25 m in the areas around Oloibiri,

Table 2: (Provide self explanatory caption)

VES no.	Longitudinal unit conductance (mhos)	Transverse unit resistance ( $\Omega$ )
1	0.245850	4737.92
2	0.136506	2058753.79
3	0.269455	87630.10
4	0.597772	20854.80
5	0.900732	4243.40
6	1.651293	1294.60
7	0.197930	94005.30
8	0.305176	20100.60
9	0.970147	7496.30
10	1.212298	122206.40
11	0.635439	44124.80

Table 3: Longitudinal conductance/protective capacity rating (after Henriot, 1976)

Total longitudinal unit conductance (mhos)	Soil protective capacity classification
< 0.10	Poor
0.1-0.19	Weak
0.1-0.20	Weak
0.2-0.69	Moderate
0.7-4.90	Good
5.0-10.0	Very good
> 10.0	Excellent

Azikoro and Kpansia communities in the central portion of the study area. This suggests that the area is of less hydrogeological appeal. The resistivity values obtained from the second layer at all VES stations are utilized in the evaluation of corrosivity of the near surface materials (Fig. 4). This is because burial of utilities and underground storage tanks are restricted to shallow depths. The results show that throughout the whole area,

the second layer which could presumably be wet clay is moderately aggressive (10-60  $\Omega$ m). Corrosion cells which may lead to significant corrosion failures of shallow subsurface piping facilities may occur in this layer. The formations of large corrosion cells which can lead to severe corrosion failures are associated with low resistivities. Low resistivities are indicative of good electrical conducting paths usually due to reduced aeration and excessive electrolytes or wetness in the soil, or mineralization.

The total longitudinal unit conductance values were utilized in evaluating overburden protective capacity in the area. This is because according to Oladapo *et al.* (2004), the earth medium acts as a natural filter to percolating fluid and that its ability to retard and filter percolating fluid is a measure of its protective capacity. Henriot (1976) suggested that the protective capacity of an overburden overlying an aquifer is being proportional to its hydraulic conductivity. High clay content which impeded fluid movement is generally characterized by low resistivity values and low hydraulic conductivities and thus low longitudinal unit conductance. Table 3 presents longitudinal conductance/protective capacity ratings. This longitudinal conductance/protective capacity rating table after Henriot (1976) enables the classification of the study area into weak, moderate and good protective capacity zones. The longitudinal unit conductance map (Fig. 5) therefore presents the protective capacity distribution of the study area. The map generally shows that the aquifer protective capacity of some locations for

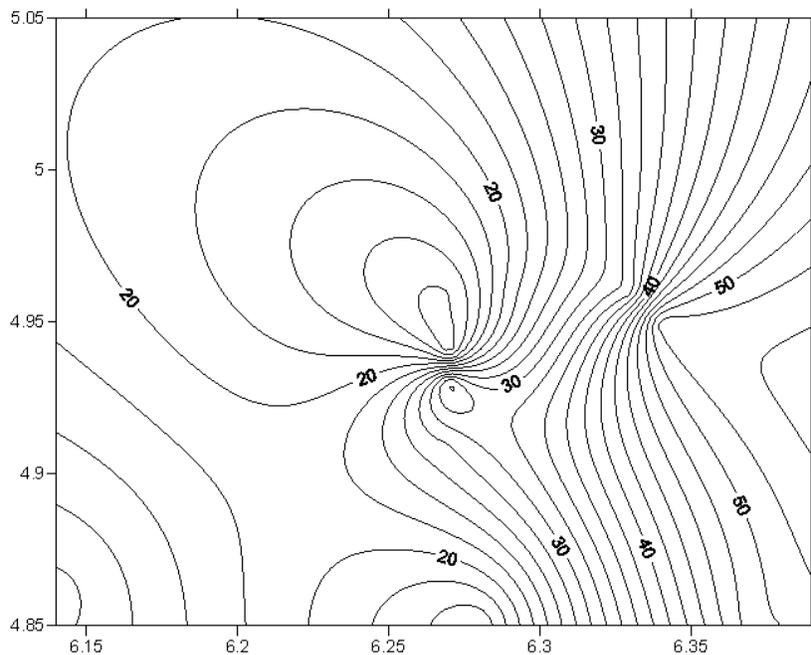


Fig. 4: Corrosively map of study area

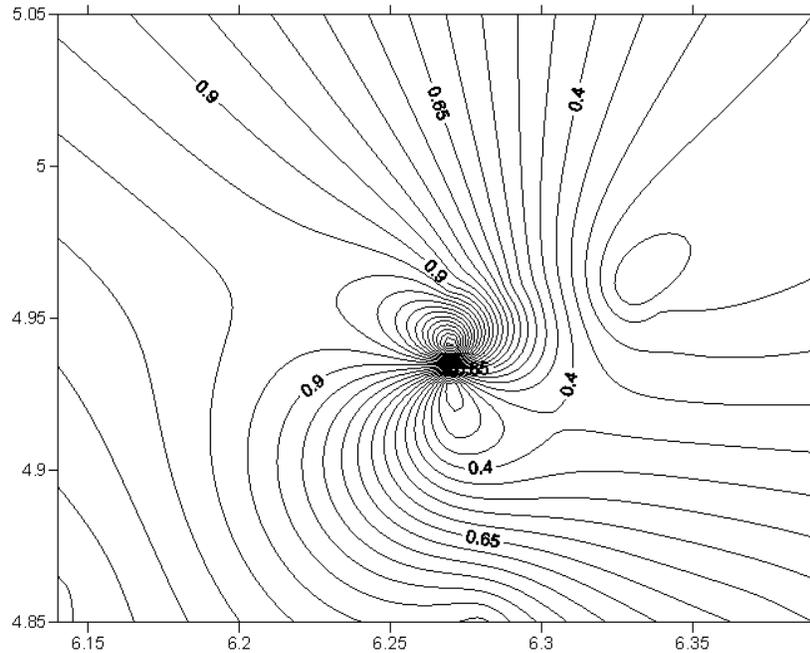


Fig. 5: Aquifer protective capacity map of the study area

instance the central portion (Opolo) and western flanks (INC areas) of the study area is rated weak (0.1-0.2 mhos). All other locations are classified as moderate (0.2-0.69 mhos) or good (0.7-4.9 mhos) protective capacity.

### CONCLUSION

In this study, the protective capacity and corrosiveness of the overburden soil materials overlying the aquiferous horizon was estimated. The study reveals that central portion (Opolo) and the western flank (INC areas) are underlain by weak protective capacity. The groundwater in areas of weak protective capacity is therefore vulnerable to pollution if there is leakage of buried underground storage tanks. Other locations are underlain by materials of moderate to good protective capacity. These areas coincide with zones of appreciable overburden thickness with clayey columns thick enough to protect the groundwater in the area. Corrosion cells which may lead to significant corrosion failures may occur in the second layer due to its low resistivity values. The results of this study have highlighted a set of environmental factors (corrosivity and protective capacity) that should not be ignored at planning stages of residential and industrial estates by estate managers.

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