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Hydrogeological Deductions from Geoelectric and Downhole Geophysical Data in Okpara Inland, Western Niger Delta, Nigeria

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Abstract: The integration of geoelectric and downhole resistivity survey can provide an approach to characterize the subsurface properties of aquifer and determination of groundwater quality. This is due to the close relationship between electrical resistivity and some hydrogeological properties of aquifers and the quality of groundwater in these aquifers. Ten (10) Schlumberger vertical electrical soundings (VES) and one (1) single-point resistance logging were carried out in Okpara – Inland. The interpretation of the geoelectric data revealed four layered earth model. The first layer consists of loose top soil, the second is clay/silty clay, the third is fine to medium sand, while the fourth layer is coarse grained sand. The third and fourth layers with thickness ranging between 38.6-72.7m and occurring at depths of between 6.0m to more than 73.9m constitute the aquifer. The results obtained from downhole geophysical logging indicate that potable water can be obtained at depths between 30-40m, where the TDS is less than 500ppm. The results from this study will no doubt give background information for groundwater prospecting and subsequent exploitation.

Key words: Conformably · Interglacial · Quaternary · Reverse osmosis

INTRODUCTION

Supply of clean drinking water is one of the major difficulties facing developing countries like Nigeria. In the early 80's potable water were readily available to urban and rural communities through pipe borne water projects embarked upon by both state and federal governments. But with dwindling economy, increase in population and demand for water, the available pipe borne water facility has not been able to meet the demand of the population. Hence, most individual had resorted to shallow hand-dug wells and boreholes (<30m) as alternative, substitute and complimentary to the supply of pipe borne water. These shallow aquifers are prone to surface and near surface contamination [1, 2]. Thus proper precautions must be taken in locating sites for groundwater development. Hence, it has become absolutely important to do a thorough appraisal of available means of water supply within a community [3]. A complete appraisal of available water resources in any area is accomplished when aspect of water quality are included. Obtaining a sustainable source of water is one thing, ensuring the quality of such water for specific purpose is another.

The water resources available to a particular community comprises of surface and groundwater. In Okpara-Inland, the groundwater is often exploited in forms of hand-dug wells and high capacity boreholes. The quality of groundwater is of vital importance, whether for industrial or domestic purpose. Hence, exploration for groundwater should not be restricted only to location of suitable aquifers using surface investigation techniques to provide data interpretable in terms of aquifer depth, thickness, continuity, areal extent and structure but also the aspect of groundwater quality. This arises from the fact that mineral enrichment from underlying rocks and sediments can change the chemistry of groundwater making it unsuitable for consumption [4, 5]. These ions that slowly dissolve from soil particles, sediments and rocks are referred to as dissolved solids. Some of these dissolved solids may have also originated in precipitation water or river water that recharges the aquifer [6].

The present study is aimed at locating potential aquifer(s) and determining the quality of the groundwater based on total dissolved solids as this would provide necessary information on groundwater conditions and basis for further investigation.

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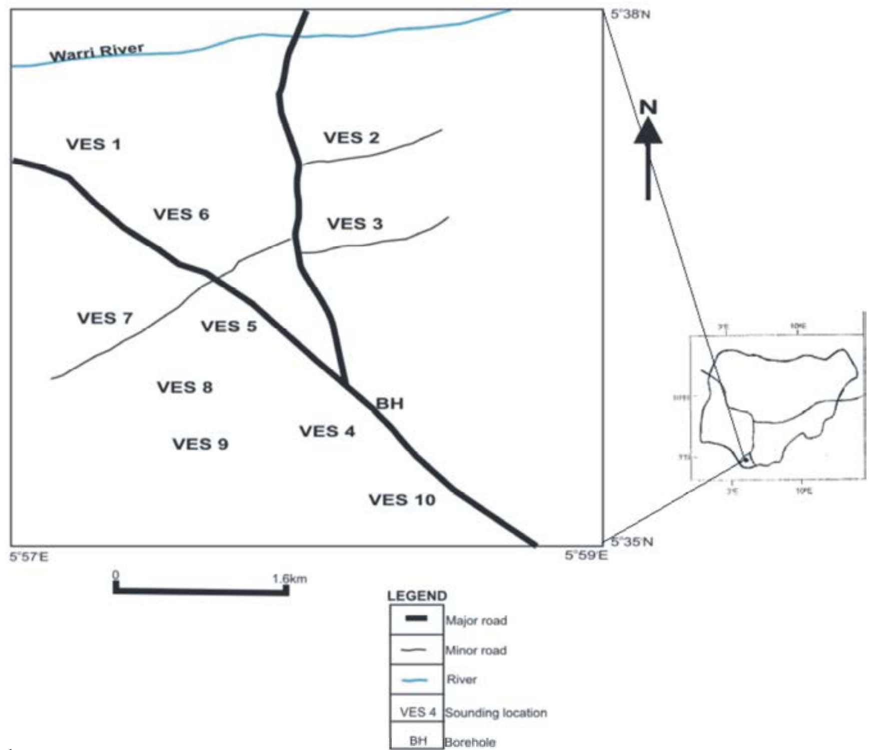


Fig. 1: Map of study area

Location and Geology: Okpara-Inland lies between latitudes 5°35'N, 5°38'N and longitudes 5°57'E, 5°59'E (Figure 1). Okpara-Inland is underlain by the deposits of the Quaternary Sombreiro-Warri Deltaic Plain which consists of fine, medium and coarse grained, poorly sorted sands that occurs sometimes with occasional clay lenses, the thickness of these sands can be up to 30m. The Sombreiro-Warri Deltaic Plain conformably overlies and masks the Benin Formation and is thought to be the recent expression of the Benin Formation [7]. These sequences of fine, medium to coarse grained sands, sandy clays, silts and clay lenses are thought to have been laid down during Quaternary interglacial marine transgression [8]. They have also been shown that they are admixture of fluvial/tidal channel, tidal flats and mangrove swamp deposits [9]. The sands of the Sombreiro-Warri Deltaic Plain are micaceous and feldspathic, sub rounded to angular in texture and they constitute good aquifer. Groundwater occurs generally under water table conditions and sometimes semi-confined conditions where the clay lenses attain adequate thickness.

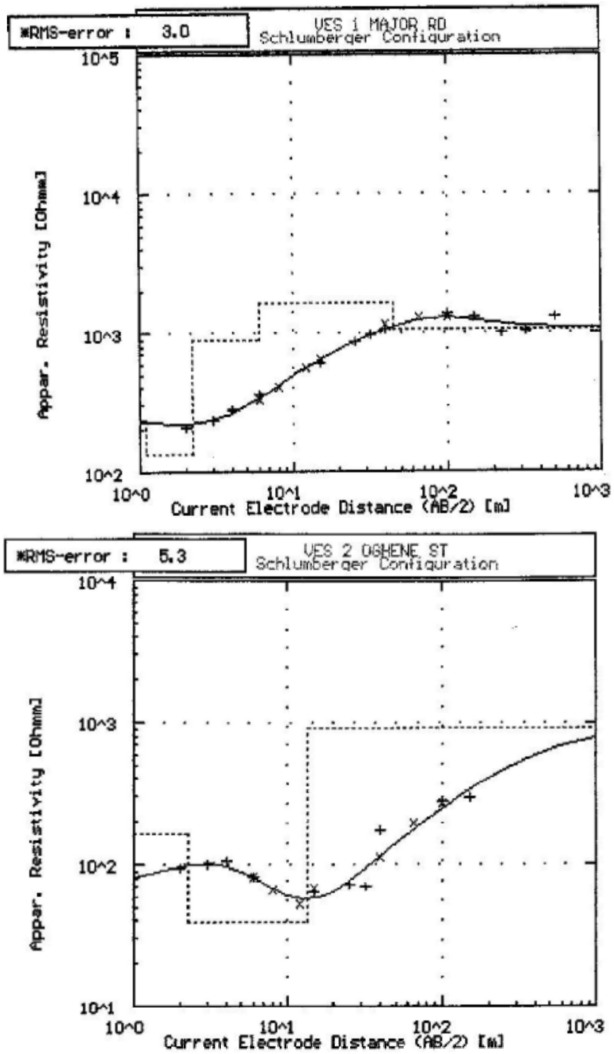
Methodology: Geoelectric and downhole geophysical methods are widely used in hydrogeophysical investigation [10-14]. A total of ten (10) vertical electrical soundings (VES) were carried out, using the Schlumberger array with a maximum current electrode spacing (AB/2) of 150m. For Schlumberger array, apparent resistivity is given by

$$\rho_a = \pi R(a^2 / b - b / 4) \text{ [15]}$$

Where
a = half current electrode spacing
b = potential electrode spacing

The apparent resistivity (ρ_a) values obtained from the measurements were plotted against half the electrode spacing (AB/2) on a log-log graph. The field curves were interpreted by partial curve matching and the corresponding auxiliary curves [16, 17]. The resistivities and thicknesses obtained from the partial curve matching were used for computer iteration using the winResist version 1.0 software [18].

A total of 17 readings were recorded from the bottom (40m) to the top (8m) of the well at a regular interval of 2m. Since the formation resistivity factors of depends on the lithology of the aquifer and usually consistent for a given sedimentary unit within a depositional basin and is given by



No	Res	Thick	Depth
1	230.9	1.1	1.1
2	135.6	1.1	2.2
3	893.4	3.8	6.0
4	1653.3	38.8	44.9
5	1074.1	-.-	-.-

* RMS on smoothed data

No	Res	Thick	Depth
1	71.3	0.8	0.8
2	163.4	1.5	2.3
3	33.3	11.4	13.7
4	925.6	-.-	-.-

* RMS on smoothed data

Fig. 2: Sounding curves obtained from the study area

$$F = Ro / Rw$$

Where Ro is the true resistivity of the formation
Rw is the resistivity of formation water.

Using relationship established between the lithological description and the formation factor determined by laboratory analysis of samples, the formation factor can be established according to lithology at certain depths. Then the water resistivity, Rw is obtained by dividing the resistivity signal of a single-point resistance log by this formation factor.

$$Rw = Ro / F$$

Water quality is indicated by the resistivity of the formation water, Rw. The calculated water resistivity, Rw can be used for estimating the total dissolved solids (TDS) in ppm of the formation water that is given by

$$TDS = 0.64 \times EC$$
$$= 0.64 \times \frac{10,000}{Rw}$$

Where EC is electrical conductivity of the formation water in micromhos /centimeter (µs/cm).

RESULTS AND DISCUSSION

Groundwater Potential: The interpretation of the sounding curve at Okpara-Inland shows the following curve types: KH (60%), KHK (20%) and HAK (20%) (Fig. 2). The geoelectric sections (Fig. 3) shows four distinct geoelectric layers namely: topsoil, silty clay and fine-coarsed grained sand.

The first geoelectric layer corresponds to the top soil with resistivity values ranging from 71.3-475.5Ωm with thickness ranging between 0.6-1.2. The second layer

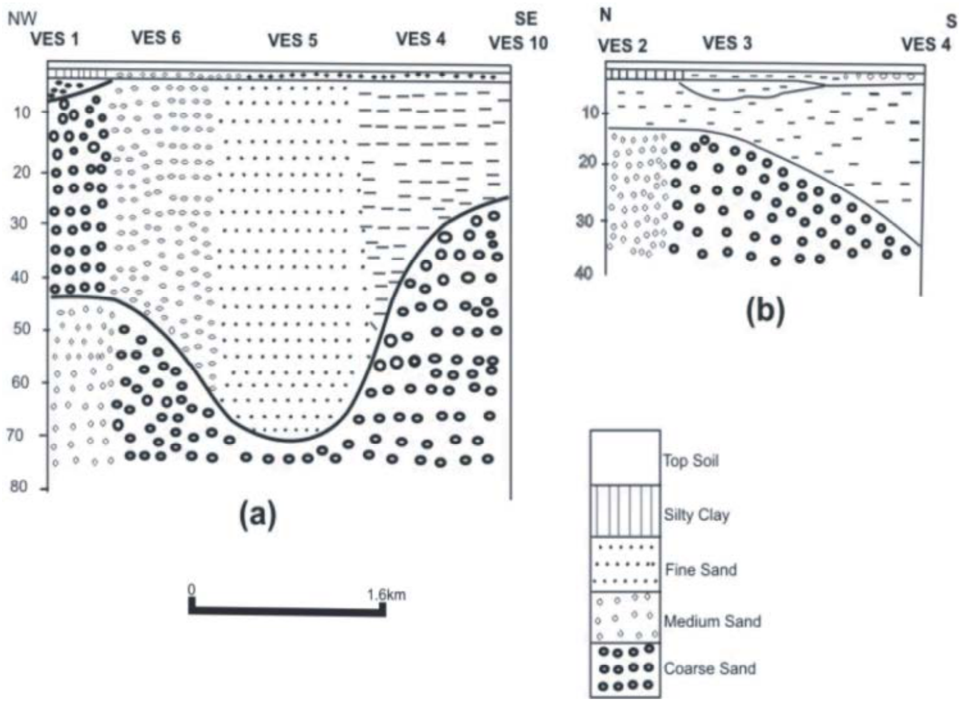


Fig. 3: Geoelectric section of the study area

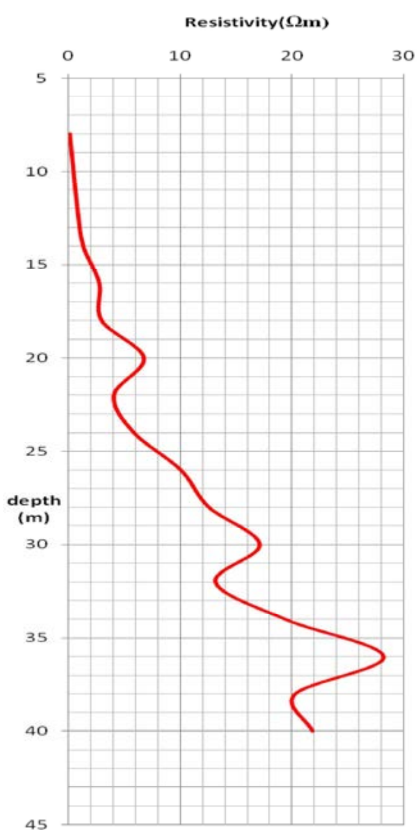


Fig. 4: Single point resistance log of the study area

consists of clay, silty clay and medium grained sand. The resistivity of the clay and silty clay overburden ranges from 15.7 – 163.4Ωm with thickness of 2.2-2.5Ωm while the resistivity of the medium grained sand ranges from 995.2-1089.3Ωm with thickness of 1.3-2.5m. The third geoelectric layer is composed of clays and fine-medium grained sands. The resistivity values of the clays range from 10.8.5Ωm and having a thickness of 6.2-33.9m while the sands have resistivity values ranging from 238-893.4Ωm with thickness of 6.0-72.7m. The sand of the third layer corresponds to the aquifer at VES 1, 5, 6, 7, 8 and 9. The clays of the third layer as shown in Figure 3 play a role of confining beds around VES 2, 3 and 4 and also protect the aquifer beneath them from surface and near surface contaminants. The fourth layer constitutes the aquifer at VES 2,3, 4 and 10 and it comprises of medium to coarse grained sands with resistivity values ranging from 925.6-3913.7Ωm. The thickness of this layer could not be determined as the current terminated with this layer.

Groundwater Quality: Water quality is indicated by resistivity of the formation water, Rw [19]. The quality of groundwater in this study was assessed based on total dissolved solids (TDS) and the results are presented in Table 1 and Fig. 4. Water with a moderate to high TDS content is not suitable for domestic and industrial uses and would require purification or treatment.

Table 1: True Resistivity of the Formation, Resistivity of Formation Water and TDS

Depth (m)	True Resistivity of the formation (Ωm)	Resisitvity of formation water (Ωm)	Total Dissolved Solid (TDS) ppm
8	0.1125	11.367757	56,843.4
10	0.4411	44.571771	14509.2
12	0.7869	79.513664	8133.2
14	1.3057	131.936702	4901.6
16	2.751	277.979527	2327.2
18	2.9602	299.118501	2162
20	6.7473	681.792534	948.5
22	4.062	410.451777	1575.6
24	5.8476	590.8808	1094.5
26	10.0445	1014.964	615.1
28	12.5753	1270.693	508.9
30	15.1379	1529.6351	373.4
32	13.1643	1330.2093	486.2
34	19.4237	1962.7012	329.5
36	28.2394	2853.4987	226.6
38	20.28	2049.2275	315.6
40	21.868	2209.6897	292.7

The Maximum Contamination Limits (MCL's) set by United States Environmental Protection Agency is 500ppm [20]. At depths of 8-24m, the total dissolved solids (TDS) ranges from 1094.5-56,843.4ppm. The high TDS could be due to the presence of clay of the third geoelectric horizon and ferrous minerals in solution. Hence, the water quality at these depths is low and not suitable for domestic and industrial uses and requires critical treatment. At depths of 26-28m, the TDS ranges from 508.9-615.1ppm. Water from these depths is not potable and requires minor treatment. However at the depths of 30-40m, the TDS ranges from 292.7-373.4m. The quality of water here appears to be very potable as the TDS fell within the limits of less than 500ppm. Water with high TDS (>500ppm) is undesirable for consumption as it may taste bitter, salty and may have unpleasant odours. High TDS water is less thirst quenching. When TDS levels exceed 1000ppm, it is generally considered unfit for human consumption and may cause corrosion of pipes and plumbing systems.

Most often, high level of TDS are caused by the presence of K^+, Cl^- and Na^+. These ions have little or no short term effects, but toxic ions of (Lead, Arsenic, Cadmium and Nitrates) which pose a variety of health hazards may also be dissolved in the water. Arsenic is ubiquitos and can be found in rocks, water and soils. Arsenic contaminated water and endemic exposure with this pollutant emerged a single catastrophe affecting people worldwide [15]. If agricultural land is located hear a well, nitrates are contaminants potentially found at land surface which could be transported to the subsurface [21, 22]. Thus, a high level of TDS is an indicator of potential concerns and warrants further investigation to ascertain the individual components or nature of the dissolved solids.

Other sources of TDS include organic sources such as leaves, industrial wastes and sewages, runoff from urban area, fertilizers and pesticides used on farms and inorganic materials such as sediments and rocks. To remove TDS to acceptable levels, a water softener with a reverse Osmosis (R/O) system is usually effective.

CONCLUSION

Geoelectric and single-point resistance survey were conducted in Okpara-Inland. The result of the geoelectric survey showed four-layer earth model. The groundwater occurs in the third and fourth layers; the thickness of the aquifer is between 38.6-72.7m and occurs at depths of about 6 to more than 73.9m. Around the central part of the study area, the presence of clays with thickness ranging from 11.4 – 31.4m plays the role of confining layer.

Total dissolved solid computed from the single point resistance log showed that the TDS at depths between 8-28m ranges from 508.9-56,843.4ppm. The high values indicate that the water quality is poor and the high TDS could be attributed to the presence of clay (clays occur at depths up to 33.9m as confirmed by the geoelectric data), human wastes, agricultural wastes and mineral enrichments from underline rocks and sediments. But however, at depths of 30-40m, the TDS ranges from 292.7-373.4ppm. The water at these depths is of high quality and suitable for both domestic and industrial purposes.

It is therefore recommended that screens should be placed at depths of between 30-40m and mini-treatment plant installed in boreholes drilled in the study area.

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