

## **Geoelectric Investigation of Groundwater Resources in Parts of Bayelsa State, Nigeria**

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**Abstract:** Ten Schlumberger Vertical Electrical Soundings (VES) were carried out in parts of Bayelsa State, Nigeria to investigate the subsurface layering with the aim of determining the configuration of the aquifer in the area and thus provide a systematic scientific basis for the siting of prolific abstraction water boreholes using a maximum current electrode separation of about 400-500 m. The data obtained was interpreted by computer iterative modeling using Interpex 1D U.S.A. The most prominent type curve is the H making up the type curve combinations. The results of the study show a laterally and vertically varying succession of high and low resistive geoelectric layers through out the whole area. This indicates sandy formation with intercalations of clay bodies which is typical of the complex depositional environment of the area. Four to five geoelectric layers were identified and layer four is the aquiferous horizon with resistivity values ranging between 12.7 - 2747  $\Omega$ m. The thickness of this layer ranges between 4.5-113.9 m and consists of fine to medium grained sand. Aquifers occur at different depths and they all have a rather irregular distribution and thickness. A value of 9.07 m/day was obtained as a mean hydraulic conductance for the area.

**Key words:** Geoelectric, resistivity, schlumberger configuration, vertical electric sounding

### **INTRODUCTION**

In the Niger Delta, water resources are plentiful but lack the quality for human consumption. Increased population due to rapid growth in the oil and gas industry instigated an increase in the demand for usable water. The emphasis is placed on the exploitation of the groundwater resource. The area under consideration in this paper in the Niger Delta (Bayelsa State) is shown in Fig. 1.

Bayelsa State is within the Coastal alluvium, mangrove and fresh-water swamps hydrogeologic province. In this province, the Coastal Plain Sands which constitute the regional aquifer is highly lenticular and contains irregular lenses of aquitards (Ekine and Osobonye, 1996). The latter partially subdivide the regional aquifer into various units. Also, the problem of high iron content is very significant. Iron stains laundry, imparts objectionable taste and colours food, corrodes casings, pipes and plumbing fixtures, and cooking utensils. However, in spite of these problems, ground water extraction is being done indiscriminately without preliminary geological, geophysical and hydrogeological investigation. The result is often water with high iron content from boreholes, seasonal or temporally functional boreholes, hence abandoned hydrowells is ubiquitous in Bayelsa State. In order to improve the efficiency of siting high yield abstraction boreholes containing good quality water, conventional geophysics which offers remote and non-destructive methods for evaluation of the subsurface have been employed.

The resistivity methods and especially the Vertical Electric Sounding (VES) method have been used successfully for investigating groundwater quality in different lithological settings because the method is well recognised as an effective, quick and economic means of obtaining details of the electrical characteristics of the subsurface at any location. Aside, the instrumentation is simple, field logistics are easy and the analysis of data is straight forward compared to other methods (Zohdy *et al.*, 1974; Ekine and Osobonye, 1996; Sikander *et al.*, 2010). In the present study, an attempt had been made to obtain a general picture of the subsurface layering with the aim of determining the configuration of the aquifer in the area and thus provide a systematic scientific basis for the siting of prolific abstraction water boreholes in this area.

**Geology and hydrogeology of the study area:** The study area lies between Longitudes 6°3' and 6°40' East and Latitudes 4°23.3' and 4°38.2' North and is located in the Coastal area of the transitional environment of the recent Niger Delta (Fig. 1). The topography is invariably gentle. Average elevation stands at about 50 m above Sea level. The average rainfall in the area is about 1700 mm/annum (Ako, 1982), most of which occurs in the rainy season which ensures adequate recharge. There are a number of perennial streams and rivers in the area of survey. They all form a network which empties to the Atlantic Ocean. As a result, most of the terrain is marshy and in some cases form beaches.

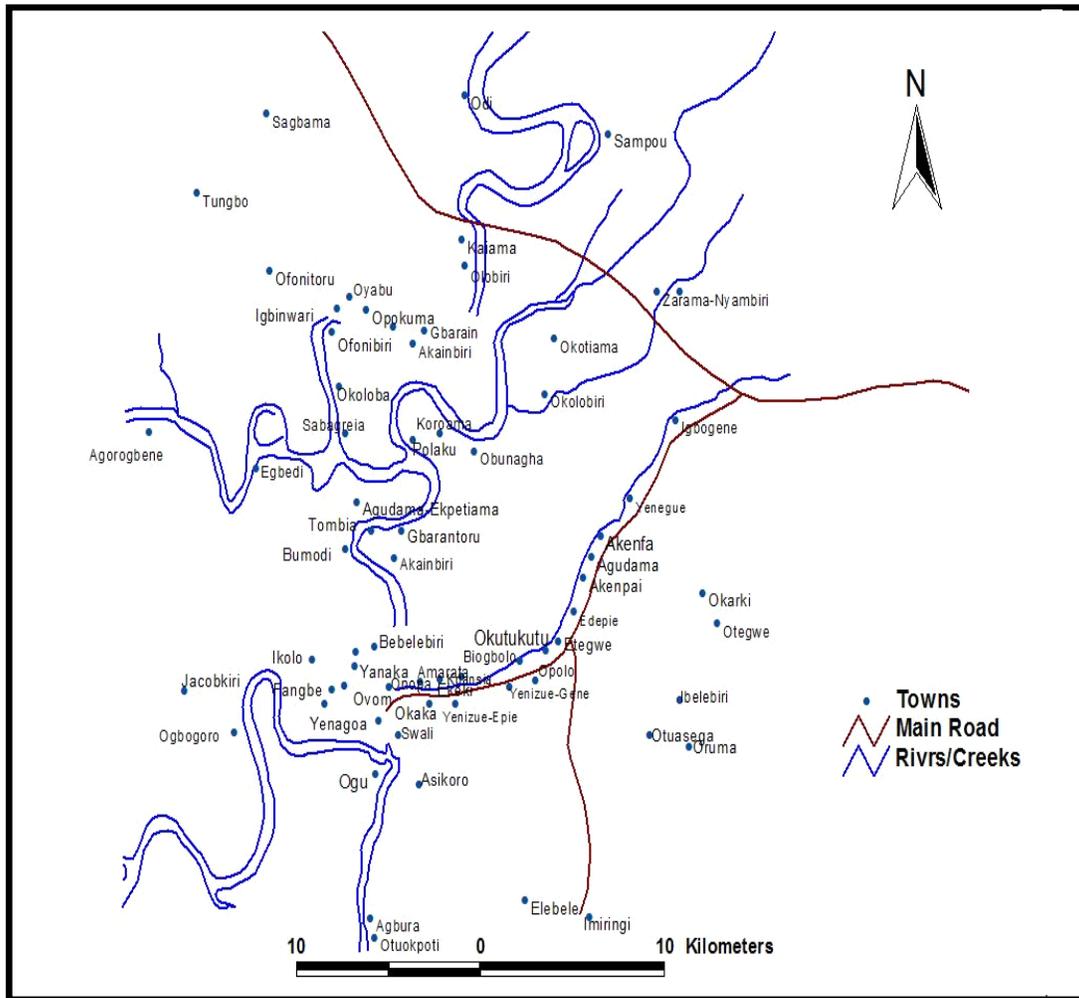


Fig. 1: Map of study area

The area is underlain by the Coastal Plain Sands (Benin Formation). The sediments of the Coastal Plain sands which were deposited during the Late Tertiary - Early Quaternary period is about 2100 m thick (Abam, 1999) and consists of massive lenticular, unconsolidated coarse to medium - fine grained sands with localized clay/shale interbreeding. The sands are generally moderately sorted, poorly cemented, and angular in shape (Mbonu *et al.*, 1991) and have been identified as the fresh water bearing sands. Both confined and unconfined aquifers are encountered at varying depths. The Quaternary deposits about 40-150 m thick overlying the Benin Formation are the superficial sediments making up the present day surface geomorphic zones in the delta and consists of alternating sequences of sand, silt and clay with the latter becoming increasingly more prominent seaward.

## MATERIALS AND METHODS

Vertical Electric Sounding using the Schlumberger electrode configuration was carried out by applying current to the ground through two electrodes (A and B) and then measuring the resultant potential difference (V) between the potential electrodes (M and N). The center point of the electrode array remains fixed but the spacings of the electrodes was increased so as to obtain information about the stratification of the ground (Koefoed, 1979). The Schlumberger data are mostly taken in overlapping segments because at each step of AB spacing, the signals of the resistivity meter become weaker. Therefore, MN spacing was enlarged and two values for the same AB/2 were measured, one for the short and one for the long MN spacing.

The Schlumberger configuration was employed not only because it is faster and less likely to be influenced by

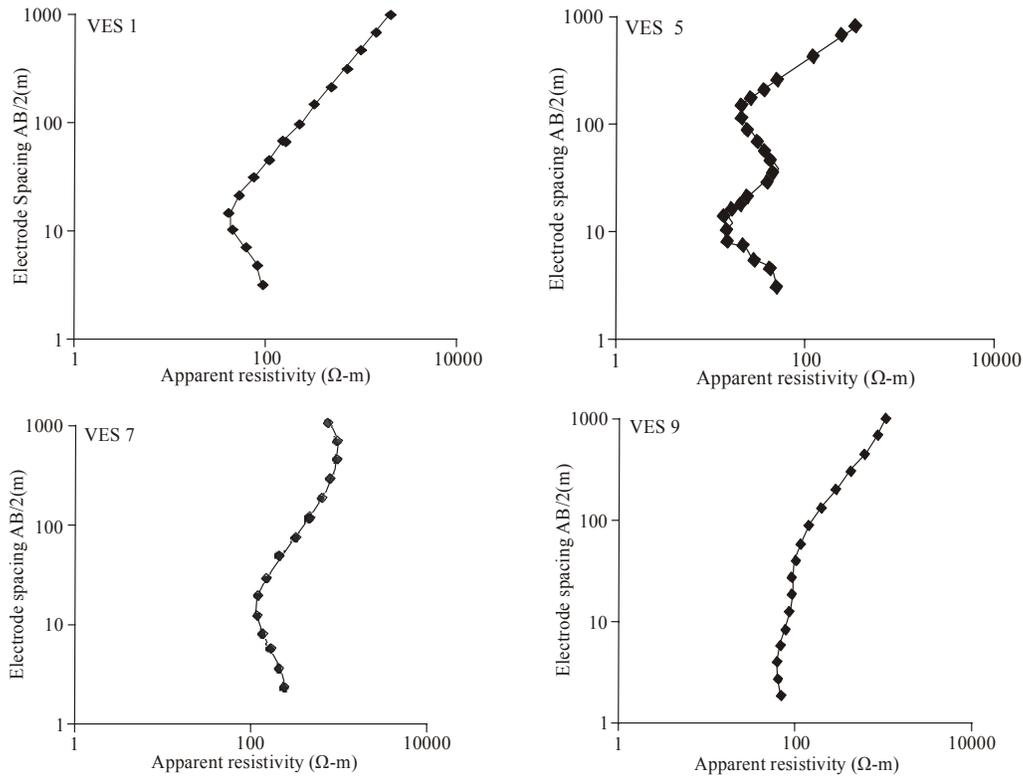


Fig. 2: Examples of the resistivity sounding curves

lateral variations but also because it requires a lower number of operators (as only the current electrodes A and B are displaced). Because of extensive dense forestation and swampy terrain, soundings were carried out along existing foot paths or roads. A total of 10 VES sites were occupied. Array spread for current electrode spacing range between 300 to 500 m. The SAS 1000 was used in this investigation.

Apparent resistivity values were determined by taking the product of the resistance as measured by the Terrameter and the geometrical factor, a parameter which is dependent on the potential and current electrode spacings. Apparent resistivity values are plotted against the half-current spacing ( $AB/2$ ) on log-log scale. Guided by the general trend of the field curves, partial curve smoothening of the field curves were made. These plots constitute the field curves. A qualitative interpretation of these curves is discussed in terms of the resulting geoelectric parameters. The data obtained was later subjected to computer assisted iterative interpretation using a 1-D inversion technique software (1X1D, Interpex, USA). This programme was used to perform quantitative analysis and interpretation of the field curves. The software requires that the operator introduce the number, thickness, and resistivities of the subsurface layers. The theoretical curve for the initial input parameters is compared with the measured data. The

starting model and its corresponding resistivity are transformed, refined or modified by the programme to obtain a best fit relation to the field data. The method of iteration was performed until the fitting error between field data and synthetic model curve became least and constant. Thus, the software yields the number, thickness and resistivity of the various layers.

## RESULTS AND DISCUSSION

**Qualitative interpretation of VES curves:** The qualitative interpretation includes comparison of the relative changes in the apparent resistivity and thickness of the detected layer(s) on the sounding curves. It gives information about the number of layers, their continuity throughout the area and reflects the degree of homogeneity or heterogeneity of an individual layer. Figure 2 shows examples of the resistivity sounding curves in the study area. These soundings are characterized by relatively high resistivity values in the first cycle ( $AB \approx 10$  m) reflecting a relatively dry zone (clay, silt and sand), but the differences are clear in the last cycle ( $AB > 10$  m) reflecting the effect of groundwater on the geophysical parameters (resistivities) as well as the variation in the depths of the layers and their nature. The descending left branch of these curves indicates a resistive topsoil underlain by a conductive material which could

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	0.77	3.8	3.8	50.4	-	107	33	294	4082	11637
2	2.00	5.9	11.8	28.8	-	42	53	117	2981	3950
3	1.80	2.5	1.9	17.8	-	4	21	143	1153	603
4	1.50	8.3	7.3	13.0	-	46	12	56	282	2592
5	1.20	1.4	5.4	17.7	-	61	11	184	12	1849
6	0.55	6.0	6.3	24.7	-	94	35	452	3680	10021
7	1.10	4.5	2.6	37.2	-	54	28	48	532	106
8	1.50	9.6	8.1	32.0	-	71	14	74	208	254
9	1.40	14.1	36.2	113.9	-	18	29	57	1051	185
10	0.50	7.2	47.6	90.3	-	254	49	473	234	523

possibly be wet clays. The gently ascending right branch could correspond to a more resistive substratum presumably aquifer materials (fine-medium-coarse sand).

The form of the geoelectrical sounding curves varies considerably throughout the study area but having more of the HA, HK, AA and HKH types. The most prominent type curve is the H making up the type curve combinations for nine out of the ten different sounding curves in the study area. The interpretive models for each VES station as well as the percentage relative root mean square (r.m.s) errors which provide quantitative assessment on the quality of the interpretation method 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 interpretation of the resistivity sounding led to the detection of four to five layers.

**Quantitative interpretation:** The VES curves were also interpreted quantitatively though from a purely theoretical view point to delineate the subsurface succession of the geoelectric layers in the area. The results of the data analysis show that the area under investigation can generally be interpreted as a four to five layered region down to the depth of investigation. Main features of each of the layers is as follows:

- **First layer:** The resistivity of the surface layer ranges between 6.2-298.0  $\Omega$ m and are typically indicative of dry alluvial deposits (sand, silt and clay). This layer reaches its maximum thickness at VES 1 (1.01 m) and about 0.2 m at VES 5.
- **Second layer:** The second layer is characterized by relatively low resistivity values (4.4-8.5  $\Omega$ m). These resistivity values represent saturated fine-grained materials such as clay. The water table varies between 2-6 m in the study area (Mbipom and Archibong, 1989). The thickness of this layer varies greatly from one locality to another where its maximum thickness (14.1 m) was recorded at VES 7 and its minimum thickness (0.6 m) at VES 6.
- **Third layer:** The resistivity range of this layer (19.3-414  $\Omega$ m) was interpreted as clayey sand. The

variation of the resistivity within this layer indicates lateral lithologic changes from clay to sandy clay. The thickness of this layer varies from 2.6 at VES 4 to 36.2 m VES 7.

- **Fourth layer:** The resistivity values of this layer varies between 12.7-2747  $\Omega$ m. We attribute the increase in resistivity to water saturation in the sand bodies. An exceptionally low value of 12.7  $\Omega$ m was recorded at VES 3. This very low specific resistivity could be indicative of clay or water bearing sandy material with a high concentration of constituent conducting minerals. Resistivity variations inside the waterbearing sandy series can be interpreted as a result of variations in the electrolyte concentration. The thickness of this layer varies between 4.5-113.9 m. This is the likely aquiferous horizon in the area in most of the VES points.
- **Fifth layer:** The Fifth layer exhibit resistivities ranging from 7.2-3996  $\Omega$ m. An exceptionally low value of 7.2, 33.04, 43.4 and 78.8  $\Omega$ m was recorded at VES 6, VES 2, VES 3 and VES 5, respectively. As mentioned above, these low resistivity values might be due to the presence of clay or water bearing sandy material with high electrolyte concentration. Due to spread lengths constrain, the thickness of this layer cannot be delineated in all stations.

## CONCLUSION

In the study area of the Niger Delta, the Quaternary aquifer forms the major promising aquifer having generally fresh to brackish water. It consists of sand which is intercalated by several lenses of clay. From the geoelectric survey, four to five geoelectric layers were identified down to the depth of investigation. The resistivity of the first layer ranges between 6.2-298.0  $\Omega$ m and are typically indicative of dry alluvial deposits. The thickness of this layer varies from 0.2-1.01 m. The second layer is characterized by relatively low resistivity values (4.4-78.5  $\Omega$ m) indicative of wet clay. The thickness of this layer varies from 0.6-14.1 m. The resistivity of the third layer ranges between 19.3-414  $\Omega$ m and is interpreted as clayey sand. The thickness varies from 2.6 to 36.2 m. The resistivity values of the fourth layer varies between 12.7-

2747  $\Omega\text{m}$ . Extremely low specific resistivity in this layer could be indicative of clay or water bearing sandy material with a high concentration of constituent conducting minerals. The thickness of this layer varies between 4.5-113.9 m. This is the likely aquiferous horizon in the area. The resistivities of the fifth layer ranges from 7.2-3996  $\Omega\text{m}$ . A mean value of 9.07 m/day was obtained as the mean hydraulic conductance value for the area.

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