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Investigation of Aquifer Quality in Bonny Island, Eastern Niger Delta, Nigeria using Geophysical and Geochemical Techniques

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Abstract

The deterioration of aquifer quality in the coastal areas of Eastern Niger Delta, Nigeria was investigated in this study using geophysical and geochemical methods. Vertical Electrical Soundings (VES) were carried out in the Bonny Island utilizing surface Schlumberger electrode configuration with an ABEM Terrameter (SAS 1000) while soil and groundwater samples were collected and analyzed for relevant for relevant geochemical parameters. The computer modeled curve generated from the VES indicates a saline (30–90 m) and ferruginous (90–180 m) subsurface. Freshwater less in salt and iron content are found at depths between (180–300 m). The study has shown that Schlumberger sounding resistivity method is an efficient tool for investigating the saltwater-freshwater interface in coastal areas. It is recommended that down-the-hole geophysical logging should be carried out after drilling so that the screen can be installed at appropriate non-saline aquiferous zone

Keywords: *vertical electrical sounding, geochemistry, aquifer quality, bonny island, Eastern Niger-Delta, Nigeria*

INTRODUCTION

Increasing urbanization is taking place along the coastlines and this has resulted to the deterioration of groundwater quality in the coastal areas either by natural means such as saltwater intrusion or by anthropogenic interference (Amadi, *et al*., 2010; Adepelumi, *et al*., 2008; Batayneh, 2006; Edet and Okereke, 2001). Salinity arising from seawater intrusion is the most common and widespread form of groundwater contamination in coastal areas, leading to the abandonment of water wells in many instances (Frank-Briggs *et al*., 2006).

Sea water intrusion is a natural process, but it becomes an environmental problem when excessive pumping of groundwater from the aquifer reduces the water pressure thereby drawing salt water into new areas. In any coastal environment, it is necessary to understand the pattern of movement and mixing between freshwater and saltwater as well as the possible factors that can influence these processes. Considering the water resources in areas bordering the sea, coastal plain-sand aquifers becomes inevitable source of groundwater (Matimula, 2003). The aquifer constitutes a hydrological unit formed by alluvial and fluvial deposits and characterize by high permeability, porosity and shallow watertable, which makes it vulnerable to contamination (Amadi and Olasehinde, 2009). The potential impact of inadequately controlled groundwater withdrawal on coastal environment includes seawater intrusion, degradation of aquifer/groundwater quality due to high infiltration rates and up-coning of the saline water layer at the saltwater-freshwater interface (Oteri, 1988).

Many communities in Eastern Niger Delta especially in Bonny Island are facing an acute shortage of potable water due to the problem of high iron-water, saltwater intrusion and tidal influence and consequently a lot of boreholes have been abandoned in the area (Nwankwoala and Udom, 2008). Upsurge in the population density and urbanization in the area have resulted to increase in groundwater exploitation and the nearby rivers that could have supplemented the groundwater are heavily polluted by the various human activities in the area such as oil spillage and poor sanitation habits (Amadi, 2011; Nwankwoala, 2010; Nwankwoala and Shalokpe, 2008). The objective of the present study is to apply geophysical and geochemical techniques to delineate formations bearing iron-water, freshwater and saltwater as well as to establish the depth to freshwater saltwater interface. These objectives were achieved through the collection and interpretation of geological, geophysical, lithologic and hydrochemical data.

MATERIALS AND METHODS

Geomorphology, Geology and Hydrogeology of the Area

Bonny Island falls within the Beach ridges on-shore geomorphic sub-environment of the Niger Delta and lies between 4°52'N to 5°02'N and longitudes 6°56'E 7°04'E. Geologically, it comprises of Pleistocene to Recent sediments deposited by fluvial and shallow continental shelf hydrodynamic processes. The area is characterized by strong wave and tidal action, which further compacts the sediments. Plant growth on beach ridges over the years has resulted in the formation of extensive primary tropical freshwater forest. Energy conditions decrease from shore face to outer edge. The litho facies include the delta tip, mainly evenly laminated fine to medium grained sand (Amadi, 2010). The hydrogeology of the area is highly influenced by the presence of ferruginous sandy formation due to high oxidation condition of the near surface aquifers, and predominant saline water intrusion. The sand forms the major aquifer in the area while the clay forms the aquitard. The water table in the area varies with season. The area has a declining water table during the dry season. Generally, watertable in the area is dynamic and ranges between 0.1–3 m depending on the season.

Geophysical and Geochemical Investigation

Pre-drilling geophysical investigation using was carried out in selected location and the survey provided information about the nature of the sub-surface geology in terms of lateral and temporal variation. The geophysical survey was also aimed at acquiring information on the hydrogeology in order to predict the thickness of the aquifer and the depth to freshwater-saltwater interface. An ABEM SAS 4000 Terrameter was used for the electrical resistivity survey. The VES data was collected with a signal Averaging System instruments (ABEM SAS 4000 Terrameter). Averaging, as used above, is a system specially designed, whereby consecutive readings are taken automatically and the result averaged continuously. The Schlumberger configuration (Fig. 1) was used for the sounding in accordance with Parasnis, (1979) and Zohdy, (1974). The C_1 and C_2 are the current electrodes while P_1 and P_2 are the potential electrodes. The Vertical Electrical Sounding was carried out and the total electrode spread was 700m, (AB/2 = 350m). It works under the principles of the wider the current electrodes, the deeper the current penetration. The field data obtained was interpreted using WinResist and IpI2win Computer softwares and the result were correlated with the manual curve matching method of interpretation of the apparent resistivity values.

Water samples were collected in clean polyethylene bottles from boreholes in the area. The samples were analyzed for different parameters as pH, electrical conductivity (EC), hardness, total dissolved solid (TDS), calcium (Ca^{2+}), sodium (Na^{+}), magnesium (Mg^{2+}), potassium (K^{+}), iron (Fe^{2+}), bicarbonate (HCO_3^-), chloride (Cl^-) and sulphate (SO_4^{2-}) by using standard techniques (USEPA, 1996).

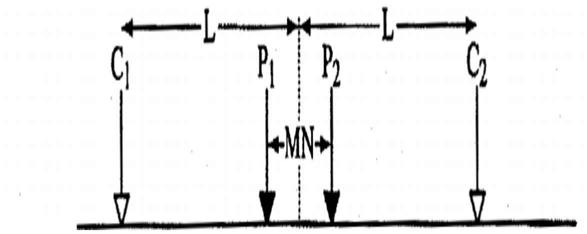

Fig. 1: A schematic illustration of Schlumberger configuration

RESULTS

The values of the Vertical Electrical Sounding (AB/2, in meters), apparent resistivity (ohm-m) and depth (m) values are presented in Tables 1 while the computer modeled curve generated is shown in while figure 2. The geo-electric section generated obtained is shown in figure 3 while the results of the chemical analysis are summarized in Table 2.

Table 1: Results of Vertical Electrical Sounding, Apparent Resistivity and Depth

AB/2 (m)	Resist. (Ohm)	AB/2 (m)	Resist. (Ohm)	AB/2 (m)	Resist. (Ohm)	App. Resist. (Ohm-m)	Depth (m)
1.00	931.840	10.0	1598.34	100	137.896	901.41	1.00
1.47	1701.64	14.7	3729.55	147	271.240	6481.32	3.00
2.15	3371.90	21.5	7255.00	215	406.392	2818.50	14.00
3.16	6779.50	31.6	5006.40	316	323.423	5859.50	30.00
4.64	1351.20	46.4	87.8280	464	000.000	148.00	90.00
6.81	2815.32	68.1	58.2480	681	000.000	412.00	200.0

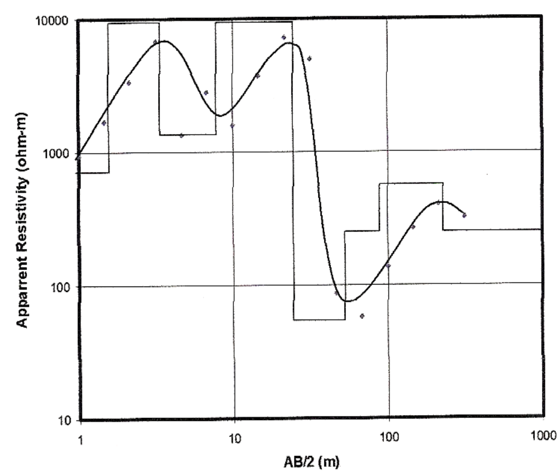

Fig. 2: A typical computer modeled VES Curve of the study area

Table 2: Summary of groundwater physico-chemical parameters in parts of Bonny Island

B/H	pH	EC (μS/cm)	Hardness (mg/l)	TDS (mg/l)	Ca^{2+} (mg/l)	Na^{+} (mg/l)	Mg^{2+} (mg/l)	K^{+} (mg/l)	Fe^{2+} (mg/l)	HCO_3^- (mg/l)	Cl^- (mg/l)	SO_4^{2-} (mg/l)
BH1	7.00	102.11	11.30	60.81	12.31	3.00	4.34	4.72	0.32	68.30	17.17	11.04
BH2	6.92	93.20	6.45	40.01	9.50	5.60	4.67	2.67	0.11	51.31	6.91	4.33
BH3	6.81	98.31	7.81	78.30	12.00	5.40	3.78	1.55	0.35	72.50	12.03	5.72
BH4	6.55	101.22	9.77	56.79	10.20	7.83	6.81	3.71	0.10	81.33	7.91	3.00
BH5	6.40	73.40	13.42	52.84	6.21	3.55	2.78	1.09	0.22	63.20	20.10	4.91
BH6	6.72	90.81	10.71	97.32	6.78	4.24	4.77	2.04	0.08	54.54	11.80	9.02
BH7	6.44	134.50	9.91	83.00	15.17	6.11	5.33	1.98	0.45	42.50	14.20	4.77
BH8	6.93	120.17	2.35	70.51	9.34	4.38	4.21	23.23	0.23	98.10	15.31	3.72
BH9	6.33	97.78	10.53	82.17	6.80	7.27	6.73	4.05	0.05	71.05	37.07	3.40
BH10	6.72	117.21	3.00	88.41	11.31	6.54	7.22	2.37	0.21	80.21	41.01	14.01
BH11	6.88	124.00	7.10	90.01	6.88	5.44	5.66	1.06	0.52	64.16	32.01	3.78
BH12	6.81	107.55	10.80	110.22	20.04	4.50	4.52	1.57	0.32	66.15	24.25	14.91
BH13	6.93	150.18	22.30	98.30	18.12	15.70	52.31	3.73	0.48	69.16	18.80	10.33
BH14	7.21	130.11	21.03	90.00	11.23	14.00	33.11	3.61	0.31	82.17	23.01	14.08
BH15	7.13	71.71	12.40	31.81	9.34	5.72	8.11	1.97	0.24	89.13	15.40	3.40
BH16	7.22	67.81	17.93	28.77	10.33	4.33	7.20	2.05	0.28	55.30	29.30	5.00
BH17	7.23	80.57	16.37	36.74	6.66	3.25	6.47	2.24	0.39	62.61	37.90	4.80
BH18	7.10	104.79	6.21	81.78	8.91	5.70	3.09	1.79	0.46	70.12	40.11	4.01
BH19	7.09	95.60	8.48	79.14	11.10	3.92	5.50	3.71	0.06	88.30	22.50	11.00
BH20	6.83	98.41	6.70	82.91	21.52	4.22	6.63	2.03	0.28	99.01	35.60	4.05
BH21	6.60	108.57	8.41	108.00	24.31	22.81	37.81	4.22	0.24	48.91	11.92	3.10
BH22	6.73	170.23	22.47	130.33	27.04	24.24	54.19	2.01	0.20	64.31	6.51	10.34
BH23	6.57	153.40	17.94	120.04	23.17	23.10	52.70	1.78	0.37	98.07	20.50	6.50
MAX.	7.23	170.23	22.47	130.33	27.04	24.24	54.19	23.23	0.48	98.10	41.01	14.91
MIN.	6.40	67.81	3.00	28.77	6.21	3.25	2.78	1.08	0.05	42.50	6.51	3.00
MEA111	6.54	108.33	11.82	73.01	14.63	8.06	14.02	3.44	0.27	76.72	29.78	6.92
NSDWQ	6.5-8.5	1000	500	1000	200	200	150	-	0.3	-	250	200

EC-electrical conductivity; TDS-total dissolved solid,

DISCUSSION

The electrical resistivity method was applied in this study due to its efficiency in detecting the slightest changes in pore water conductivity, which denotes the freshwater-saltwater interface in coastal regions. The result of the geophysical survey reveals that the top subsurface aquifers are rich in iron content and it can be attributed to infiltration through the ferrugenized sand into the water table (Fig. 3). Saltwater intrusion exists between 30–90 m of the aquiferous zone while freshwater free from iron and saline water is found at aquifer layer between 180–300 m (Fig. 3). The pH values ranges from 6.40 to 7.23 with a mean value of 6.54 while the concentration of the electrical conductivity varies from 67.81 μS/cm to 170.23 μS/cm with an average value 108.33 μS/cm. These values falls within the permissible limit of 6.50-8.58 for pH and 1000.00 μS/cm for electrical conductivity as given by the Nigerian Standard for Drinking Water Quality, (NSDWQ, 2007). The mean concentration of total dissolved solid (TDS) and hardness are 73.01 mg/l and 11.82 mg/l and these values are below the permissible limit of 500.00 mg/l and 200.00 mg/l for TDS and hardness as postulated by NSDWQ, (2007). The concentrations of the major cations (Ca^{2+}, Mg^{2+}, Na^{+} and K^{+}) and anions (HCO_3^-, Cl^- and SO_4^{2-}) in (figures 4 and 5; Table 2), falls within the permissible limit for a safe drinking water outlined by (NSDWQ, 2007). However, concentration of iron was high in some locations, which may be due to the leaching and percolation of rainwater through the porous and permeable overlying formation into the groundwater system. This observation via geochemical analysis of the groundwater samples agreed with the findings of geophysical survey, which indicated lateritic and ferrugenized-sand formations in the geo-electric section. Excessive withdrawal of fresh groundwater through numerous boreholes has grossly disturbed the hydrodynamic equilibrium in the aquifer and has caused a reduction of groundwater gradients thereby causing saltwater intrusion.

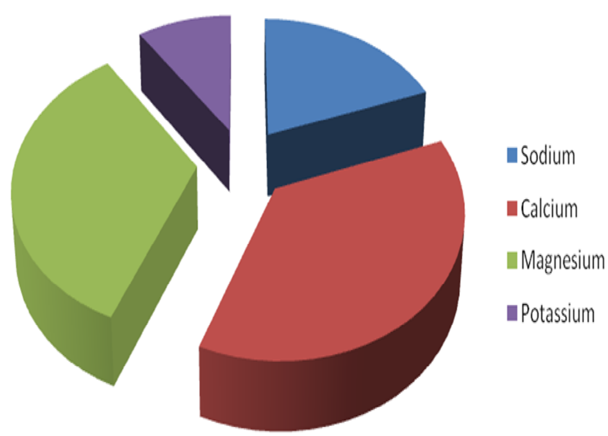

Fig. 4: A pie chart showing the mean concentration of major cations in the area

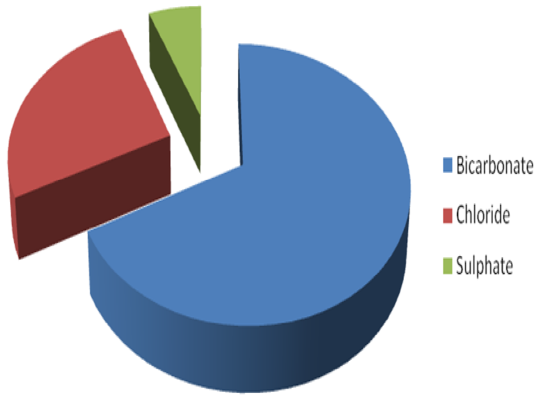

Fig. 5: A pie chart showing the mean concentration of major anions in the area

Piper Diagram

This method was devised by Piper in 1944 to outline certain fundamental principles in a graphic procedure which appears to be an effective tool in separating analytical data for critical study with respect to sources of the dissolved constituents in water. The concentration of 8 major ions (Na^+ ,K^+, Mg^{2+}, Ca^{2+}, Cl^-, CO_3^{2-}, HCO^-_3 and SO_4^{2-}) are represented on a trilinear diagram by grouping the K^+ with Na^+ and the CO_3^{2-} with HCO_3, thus reducing the number of parameters for plotting to 6. On the Piper diagram, the relative concentration of the cations and anions are plotted in the lower triangles, and the resulting two points are extended into the central field to represent the total ion concentrations. The degree of mixing between freshwater and saltwater can also be shown on the Piper diagram. The Piper diagram (Fig. 6) can also be used to classify the hydrochemical facies of the groundwater samples according to their dominant ions. The water in the area is Ca-Cl^-/Mg-HCO_3^- type which indicates a marine origin. This has also confirmed with the saltwater intrusion between the intervals of 30–90 m as captured in the geo-electric section.

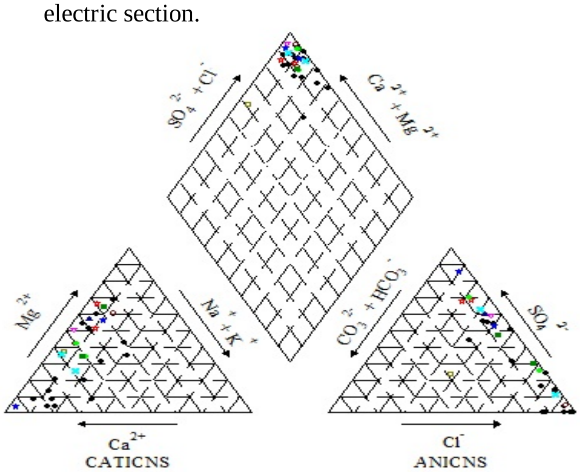

Fig. 6: Piper diagram for the study area

CONCLUSION

As resistivity is a fundamental electrical property of rock material closely related to their lithology, the determination of the subsurface distribution of resistivity from measurements on the surface can yield useful information on the structure or composition of buried formation. In this paper, results from electrical resistivity survey and chemical analysis of groundwater were correlated and it was revealed that leaching through the ferruginous sandy formation is the major source of iron in the groundwater. The study also reveals that the problem of saltwater intrusion in the area is caused by in increased abstraction of groundwater which disturbs the natural freshwater/saline water equilibrium. The synergy in correlating geophysical survey with geochemical investigation has been successfully demonstrated in this study.

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APPENDIX

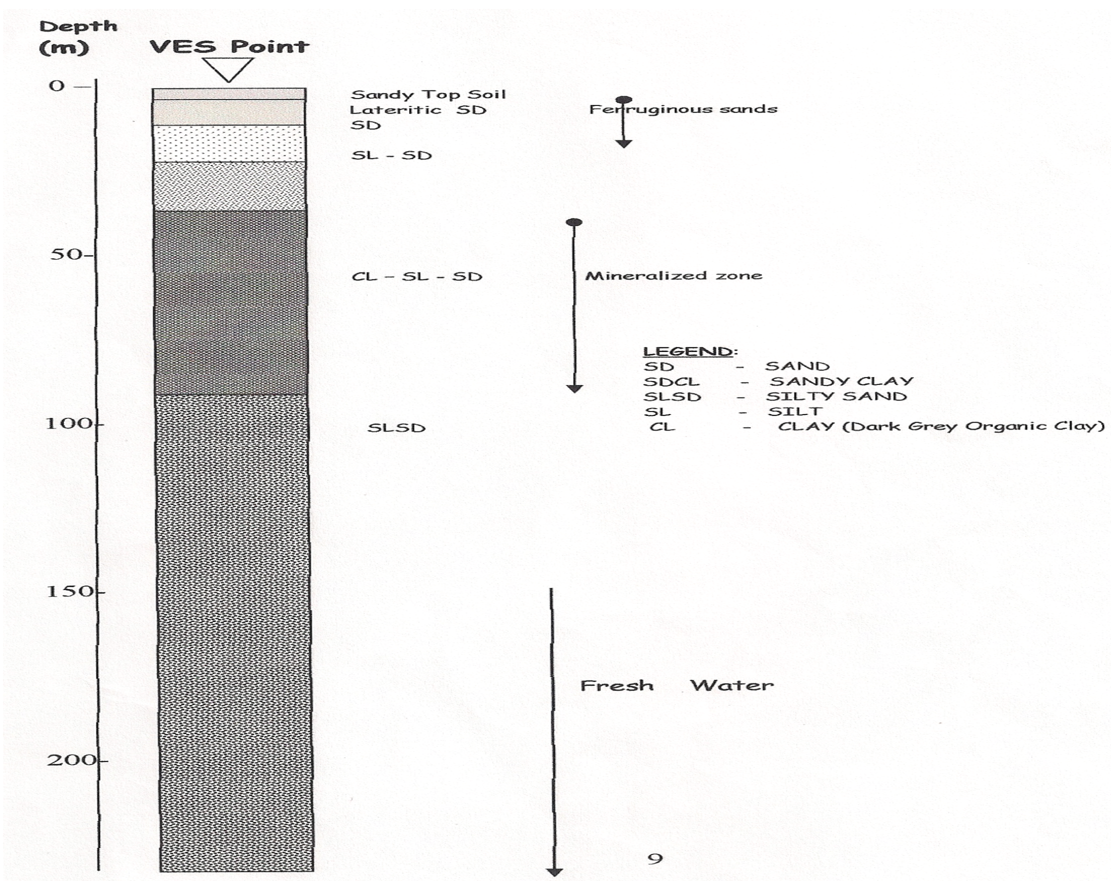

Fig. 3: A typical geo-electric section for the area