

Downhole Geophysical investigation of Lithological Strata and Water Quality in the Deltaic Plain Deposits and Mangrove Swamps of Niger Delta

Page | 3204

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ABSTRACT

Groundwater which accounts for over ninety percent of the world's supply is a fundamental life sustaining resource. Despite the abundant provision by nature in the Niger Delta, the accessibility of this resource to mankind in quantity and good quality is rapidly on a decline. An attempt is made using geophysical logging technique in this study to probe the subsurface at Otor – Jeremi and Burutu in the Upper Deltaic Plain and mangrove swamps of Niger Delta with the purpose of furnishing information on the subsurface lithology and water quality. One well was logged in each community using the single – point resistance log at depths of 8 – 70 m. The results of lithological evaluation showed that the subsurface formations consist of sandy clay, clay, clayey sand and sand which constitute the aquifer. The results of water quality based on total dissolved solids showed TDS level greater than 500 mg/l at depths of between 8 – 54 m which is an indication of poor water quality. Good quality groundwater can be sourced at depths greater than 25 m in the Upper Deltaic Plain and over 55 m in the mangrove swamps as TDS level fell below the maximum contamination levels of 500 mg/l.

Keywords: Aquifer, groundwater quality, total dissolved solids, depth, clay, leachate.

INTRODUCTION

The thick and extensive sand and gravel aquifer that occupies the deltaic plain has endowed the Niger Delta with rich groundwater resources. Groundwater occurs in the sand lenses which are interbedded with silts and clays. Three main zones have been differentiated and these are a northern zone, a transition zone of intermixing marine and continental materials and a coastal zone of predominantly marine deposits (Etu – Efeotor and Odigi, 1983; Etu – Efeotor and Akpokodje, 1990). The aquifers in the northern zone are shallow comprising predominantly continental deposits. According to Etu – Efeotor and Akpokodje (1990) two types

of swamp lands are observed in the transition zone: the Brackish Mangrove Swamps (BMS) and the freshwater mangrove swamps (FWS). The BMS are associated with tidal inlets and more prominent in areas penetrated by estuaries; thick lensoid marine clays are encountered and saline conditions well noticed. The transition zone is characterized by dynamic activities, intermixing of continental and marine materials; creating a complex condition in which marine conditions penetrate further inland. Aquifers are shallow made up of mainly of sand and gravel materials with clay intercalations which are more prominent in the southern

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coastal zone than the northern zone (Etu – Efeotor and Akpokodje, 1990)

The quality of groundwater in shallow parts of aquifers in the Western Niger Delta is poor because of pollutants from a variety of natural and anthropogenic sources (Ejechi *et al.*, 2007; Amadi, 2010; Etchie *et al.*, 2011; Akpoborie *et al.*, 2015). Etu – Efeotor and Odigi (1983) observed some problems which include: salinity, bacteriological contamination and the presence of some undesirable ion prevalent in the area. A study by Ohwohere – Asuma (2017) around Ogidigben showed increase in groundwater salinity in aquifers adjacent to the coast, estuaries and least prevalent towards the inland. The abundance of thick sandy sequence and shallow water table and poor protective capacity make the aquifer prolific quantitatively and vulnerable qualitatively, many anthropogenic activities impact directly on the aquifer (Aweto, 2014). Geochemistry of groundwater in an aquifer usually influences its suitability as sources of water supply. The concentration of dissolved constituents in water in such aquifer system determines whether such water without prior treatment is suitable for potable water supplies. Also, borehole design is very important to ensure continual supplies from groundwater resources. If design and construction quality is not considered in a bid to save cost; the borehole may not function fully for a long period. In most cases poorly designed boreholes have been abandoned due to inadequate supply, failure of boreholes or contamination of water.

Hence, a detailed and comprehensive evaluation of groundwater resources with the sole aim of locating aquifer(s); its extent, characteristics and groundwater quality is required. This is to ensure a viable development and utilization without any negative side effects. Hence, the objective of this study was to use electric log in determining:

lithological sequence, aquifer characteristics, the distribution of water quality and the position for placement of screens.

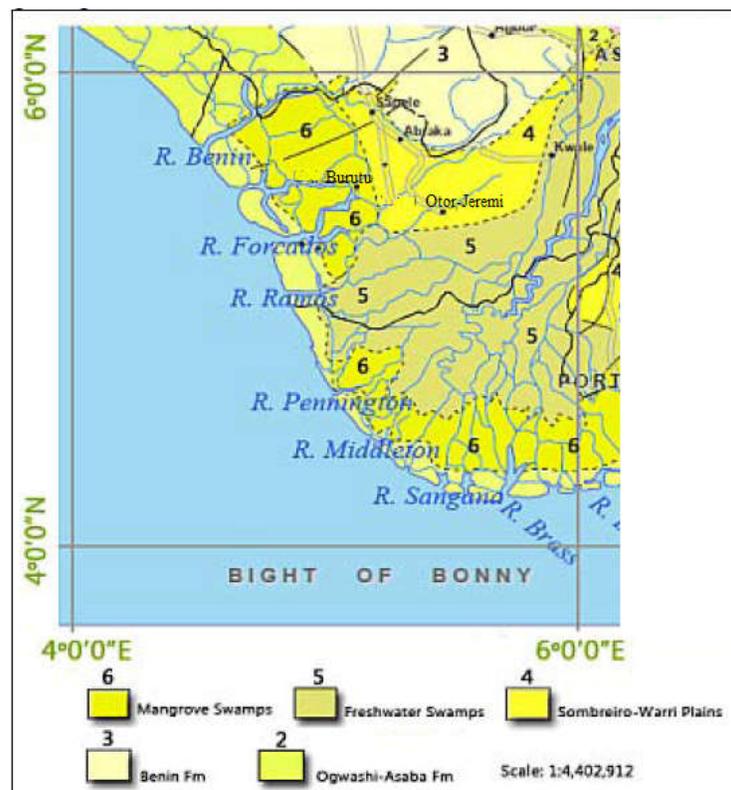


Fig. 1: Map of Study Area (Modified after NGSA, 2004)

MATERIALS AND METHODS

Location and Geology of the study area

This study was carried out in Otor – Jeremi and Burutu, situated in the Niger Delta as shown in fig. 1. It is located within longitudes 5° 50' E and 5° 54' E and latitudes 5° 25' N and 5° 28' N. As described by Allen, 1965; Short and Stauble, 1967; Murat, 1970 and Burke, 1972; the Cenozoic section of the Niger Delta basin is divided into three strongly diachronous lithofacies units which represent a prograding depositional lithofacies differentiated mostly on the basis of ratio of sand to shale. The basal Akata Formation is made up of over pressured and under-compacted shales, turbidite sand

and clays, while the intervening Agbada Formation consists of an alternating paralic sequence of sandstone and shales. The unconformably overlying Benin Formation consists of massive continental/fluvial sands and gravels with small shale intercalations. The Benin Formation is overlain and masked by deposits of the Quaternary Upper Deltaic Plain consisting of alternating succession of sand and silt/clay up to thickness of between 40 and 150 m (Oomkens, 1974).

Field Procedures

The conventional single – point resistance (SPR) logs measures the resistance in ohm between an electrode as it is lowered down a well and an electrode on the land surface (Keys, 1990). Single – point resistance logs are used at contaminated sites as they are useful tools for identifying changes in lithology and water quality (Keys, 1990). This method was selected because the instrumentation is simple and gives excellent information about lithologic change in the subsurface. The ABEM signal averaging system Terrameter SAS 4000 model was used for the well logging. One well was logged in each community at regular intervals of 2 m from a depth of 8 m at the top to bottom at depths of 44 m at Otor – Jeremi and 70 m at Burutu.

The resistance (R) measured from SPR log relates current (I) and voltage (V) from ohms law as follow:

$$R = \frac{V}{I} \dots\dots\dots (1)$$

The apparent or bulk resistivity ρ_b in homogenous medium is given by:

$$\rho_o = G \times R \dots\dots\dots (2)$$

where G is geometrical factor.

Bulk resistivity (ρ_o) is function of porosity (ϕ) and water resistivity (ρ_w) according to Archie’s equation (Archie, 1942).

$$\rho_o = a \rho_w \phi^{-m} \dots\dots\dots (3)$$

where a is coefficient of saturation and m is cementation factor.

Equation 3 can be written as:

$$\rho_o = F \rho_w \dots\dots\dots (4)$$

where F is formation factor given as 5.4 (Aweto, 2013).

The resistivity of formation water determined from the measured bulk resistivity in equation 4 is used to evaluate TDS in mg/l and electrical conductivity (EC) in (μ S/m) using the equation given below:

$$TDS = 0.64 \times \frac{1000}{\rho_w} \dots\dots\dots (5)$$

$$TDS = 0.64 \times EC \dots\dots\dots (6)$$

RESULTS

The single – point resistance logs of the study area, the results of lithological evaluation and water quality based on total dissolved solids deduced from the logs are presented in figs. 2 and Tables 1 & 2.

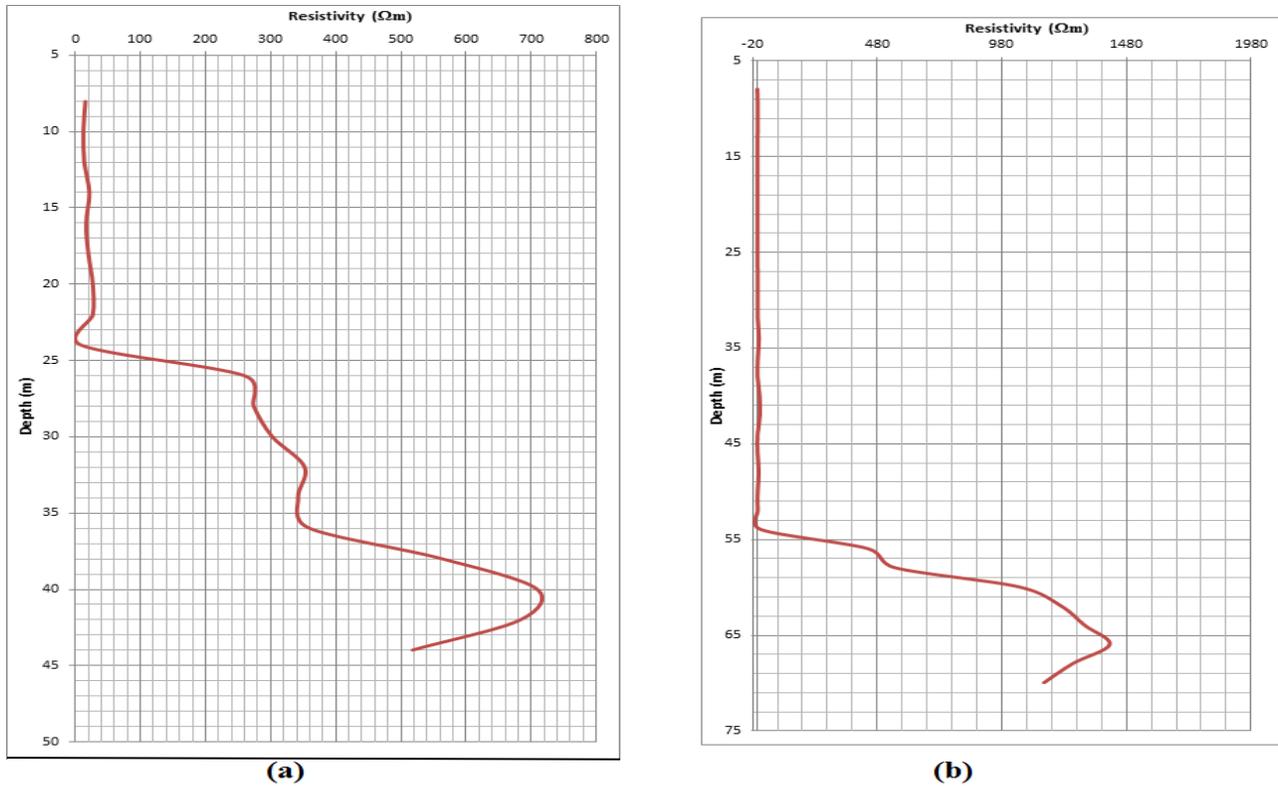


Fig. 2: Single-point resistance log data at (a) Otor – Jeremi (b) Burutu

Table 1: Single-point Resistance Log Data at Otor – Jeremi Motor Park

Depth (m)	$\rho_o(\Omega m)$	$\rho_w(\Omega m)$	EC ($\mu S/m$)	TDS (mg/l)
8	14.6318	2.7096	3690.58	2362.00
10	11.5695	2.1425	4667.44	2987.17
12	13.0297	2.4129	4144.39	2652.42
14	20.6561	3.8252	2614.24	1673.10
16	15.7966	2.9253	3418.45	2187.81
18	19.2407	3.5631	2806.54	1796.20
20	26.0750	4.8287	2070.95	1325.40
22	25.9513	4.8058	2080.82	1331.73
24	8.5968	1.5920	6281.41	4020.12
26	258.9500	47.9537	208.53	133.46
28	273.0289	50.5609	197.78	126.58
30	301.4918	55.8318	179.11	114.63
32	351.3981	65.0737	153.67	98.35
34	341.1985	63.1849	158.27	101.29
36	358.3947	66.3694	150.67	96.43
38	561.4947	103.9805	96.17	61.55
40	708.0516	131.1207	76.27	48.81
42	683.1634	126.5117	79.04	50.56
44	516.8896	95.7203	104.47	66.88

Table 2. Single-point Resistance Log Data at Burutu

Depth (m)	ρ_o (Ω m)	ρ_w (Ω m)	EC (μ S/m)	TDS (mg/l)
8	0.0729	0.0135	740,740.74	474,074.07
10	1.8603	0.3445	29,027.58	18,577.65
12	1.4834	0.2747	36,403.35	23,298.14
14	0.4606	0.0853	117,233.29	75,029.31
16	0.6242	0.1156	86,505.19	55,363.32
18	0.4655	0.0862	116,009.28	74,245.94
20	0.5778	0.1070	93,457.94	59,813.08
22	0.7366	0.1364	73,313.78	46,920.82
24	0.5492	0.1017	98,328.42	62,930.19
26	0.6496	0.1203	83,125.52	53,200.33
28	1.8916	0.3503	28,546.96	18,270.05
30	0.9353	0.1732	57,736.72	36,951.50
32	1.8079	0.3348	29,868.58	19,115.89
34	6.1560	1.1400	8,771.93	5,614.04
36	2.2453	0.4158	24,050.02	15,392.02
38	0.8894	0.1647	60,716.45	38,858.53
40	8.6848	1.6083	6,217.75	3,979.36
42	10.3162	1.9104	5,234.51	3,350.08
44	0.9191	0.1702	58,754.41	37,602.82
46	0.9445	0.1749	57,175.53	36,592.34
48	5.4081	1.0015	9,985.02	6,390.41
50	1.4747	0.2731	36,616.62	23,434.64
52	1.5930	0.2950	33,898.31	21,694.92
54	14.0681	2.6052	3,838.48	2,456.63
56	443.6132	82.1506	121.73	77.91
58	552.8099	102.3722	97.68	62.52
60	1,051.1731	194.6617	51.37	32.88
62	1,217.5920	225.4800	44.35	28.38
64	1,311.0714	242.7910	41.19	26.36
66	1,411.3461	261.3604	38.26	24.49
68	1,263.1473	233.9162	42.75	27.36
70	1,148.5524	212.6949	47.02	30.09

DISCUSSION

Lithological Evaluation

The lithological sequence at Otor – Jeremi shows that the first layer is made up of clayey sand top soil which is about 2.2 m thick. The layer is directly underlain by another clayey sand layer of about 11.6 m thick. Beneath this layer at depths of 13.8 m are clays of about 10.2 m thick extending to a depth of 24 m. The resistivity of the clayey layers above is less than 26 Ω m. At depths of between 25 and 36 m, the lithology changes to fine sand as resistivity values of the single – point resistance log increases to between 258.95 and 358.4 Ω m. At depths between 37 and 44 m, the formation translates to medium/coarse sands.

The lithological sequence at Burutu indicates a first layer of top soil made up of sand about 1.1 m thick. This layer is followed by a layer of sandy clay about 10.4 m thick and clay about 16m thick extending to depths of 11.5 m and 27.5 m respectively. These layers are directly followed by a layer of clayey sand extending to depths of 42 m; a fifth layer made up of clays about 11 m thick extend to depths of 54 m. At depths of between 55 and 58 m; as resistivity increases to magnitude of hundreds, the lithology changes to fine sand and at depths between 60 and 70 m, the lithology is medium to coarse sands.

The underlying sandy horizon with variable grain size of fine – coarse sand is considered the aquiferous unit in the study

area. The depth to this aquiferous unit at Otor – Jeremi and Burutu is 25 and 55 m respectively.

Water Quality

The results of water quality based on total dissolved solids evaluated from the single – point resistance log at Otor – Jeremi (Table 1 and Fig. 2a) shows that TDS level at depths of 8 and 24 m varied from 1325.4 to 4020.12 mg/l. However from depths of 26 to 40 m, the TDS concentration varied from 48.81 to 133.46 mg/l. The result indicates that groundwater quality at depths between 8 and 24 m is poor and as a result may not be potable as TDS concentration is way above the stipulated standard of 500 mg/l. The source of elevated TDS may be due to indiscriminate disposal of wastes in open dumps which is the commonest and cheapest way of waste disposal in the Niger Delta. One adverse effect of dumping wastes in the open is the generation of leachates from biodegradation of wastes. These leachates subsequently enter the aquifer by infiltration and pose serious health hazards.

Electrical resistivity imaging profiles in studies by Aweto (2014) and Aweto (2017) have shown that groundwater in the shallow part of the aquifer in the Niger Delta may have been contaminated up to 12 m by leachates from dumpsites infiltrating into the subsurface and lateral migration by subsurface runoff (inter-flow and base-flow). The poor and weak protective capacity of overburden above the aquifer in most parts may have enhanced contamination (Aweto, 2014). Water quality at depths greater than 24 m appears to be good and potable as TDS level fell below 500 mg/l.

The water quality result at Burutu (Table 2, and Fig. 2b) indicates that the TDS concentration at depths of between 8 and 54 m varies from 3,350.08 to 474,074.07 mg/l. At depths of between 56 and 70m, the TDS concentration ranges from 27.36 to 77.91 mg/l. The result shows improved water quality with depths; this is because when TDS decreases, water

quality increases (Turcan, 1966). Hence, potable water may be obtainable at depths greater than 54 m. Electrical conductivity and TDS values from single – point log at depths of between 8 and 54 m were generally high (3,838.48 to 740,740.75 $\mu\text{S}/\text{cm}$ and 3,350.08 to 474,074.07 mg/l respectively) indicating that the groundwater is fresh to slightly brackish. However, Ohwohere – Asuma *et al.* (2014) reported chloride content of between 6.67 and 53.9 mg/l in groundwater indicating fresh water. The work of Akpoborie and Aweto (2012) emphasized that groundwater condition in Ughoton which also lies within the mangrove swamp is not saline with mean chloride of 25.24 mg/l. The presence of freshwater swamp vegetation in Burutu also contradicts the assumption of saltwater. However, most of the freshwater is not of good quality due the presence of iron and cadmium at concentrations above the maximum contamination limits (MCL's) of 0.3 mg/l and 0.003 mg/l respectively. Their study have shown that groundwater in 60 % and 30 % of the area is contaminated by iron and cadmium respectively. A study by Akpoborie and Aweto (2012) also showed high lead, chromium and cadmium in groundwater of the Deltaic Plain deposits. Similar occurrences of these heavy metals in shallow groundwater have been reported by (SPDC, 1998; NDDC, 2005) from the Saghara Beach area of the Forcados estuary. According to Richdrill (2009) groundwater samples from depths of 300 m are free of these heavy metals at Ogulagha also on the Forcados estuary; an indication that these heavy metals are confined only to the shallow aquifer in the Sombreiro-Warri Deltaic Plain deposits and mangrove swamps.

Elevated TDS in groundwater may also be due to clayey materials within the aquifer being able to contribute to high TDS in freshwater (Aweto, 2013). Lithological evaluation from the logs and geoelectric section at Burutu in a study by

Aweto (2014) confirms the presence of clayey materials between 10 and 45 m thick. High TDS may result from cation – exchange processes in clays which can have significant impact on the commensurate concentration of the various cations in water associated with them (Aweto *et al.*, 2015). Aweto and Akpoborie (2011) also established the significance of water – rock interactions in ascertaining the chemistry of shallow groundwater in the Niger Delta. Hence, High TDS level in groundwater is an indication of high concentration of major constituents which can cause significant impairment of groundwater for potable use. For good water quality and optimum yield, at least a 16 m length screen should be positioned at depths greater than 25 m at Otor – Jeremi while at least a 12 m length screen can be placed at depths greater than 55 m at Burutu. The screens will allow water to percolate in the boreholes and exclude particles from entering the borehole thereby ensuring the efficiency of the boreholes.

CONCLUSION

The results of this study delineated the subsurface lithology comprising of sandy clay, clay, clayey sand and sand which constitute the aquifer. The study also showed high total dissolved solids at depths between 8 – 24 m and 8 – 54 m at Otor – Jeremi and Burutu respectively indicating poor water quality. Groundwater quality however, improved with depth as total dissolved solid level fell below the maximum contamination levels of 500 mg/l. Depth to good quality groundwater increased from 25 to over 55 m moving from the Sombreiro – Warri Deltaic plain deposits towards the mangrove swamps. The results of TDS are consistent with findings from geochemical analysis in the study area which showed higher level of heavy metals such as lead (Pb), iron (Fe), cadmium (Cd) and chromium (Cr). The sources of

elevated TDS include anthropogenic activities such as waste disposal and mineral enrichment from underlying geologic materials.

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