

AN APPROACH TO ESTIMATE TOTAL DISSOLVED SOLIDS IN GROUNDWATER USING ELECTRICAL RESISTIVITY SOUNDING AND GEOCHEMICAL METHODS

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ABSTRACT

Electrical resistivity method gives somewhat reliable results in hydrogeophysical deductions, in which the disposition of aquifers can be suitably deciphered. The present study was conducted to validate the use of geoelectric sounding in estimating total dissolved solids (TDS) in groundwater. Twenty (20) resistivity measurements obtained have been interpreted by curve matching and computer iteration and converted to formation resistivities and thicknesses. The resistivities of the aquifer delineated were subsequently used to estimate TDS in groundwater which was correlated with those derived from previous geochemical analyses of ten (10) groundwater samples taken near sounding locations. The result shows a strong correlation ($R^2 > 0.8$) indicating that the TDS determined by geoelectric sounding and geochemical method give similar results.

KEYWORDS: Total dissolved solid; groundwater; geoelectric; geochemical; aquifer

INTRODUCTION

Groundwater is a replenishable resource found in aquifer, it is a major source of fresh water which is generally used for domestic, industrial and agricultural purpose in many parts of the world. Groundwater aquifer is being assaulted with an ever increasing number of soluble chemicals (Oladunjoye, *et al.*, 2011). Changes in the concentrations of these chemical constituents in the water of the aquifer system which may be natural or anthropogenic causes determines its geo-chemical character and may alter the suitability of the aquifer system as a potential source of water (Oteze, 1991). The issue of ensuring useable water in sufficient quantities to meet the needs of the growing human population has emerged as one of the primary challenge of the 21st century. Obtaining useful information on groundwater quality of an area is necessary for managing and sustaining the resource for managing and sustaining the resource for various use (Gowd, 2005; Ozcan *et al.*, 2007; Dar *et al.*, 2011).

Potable water standards are based on certain criteria which include taste, odour, colours and presence of dissolved substance with adverse side effect (Davis and De Wiest, 1966). The aquifers in the Niger Delta are usually exploited without resource evaluation (Aweto and Akpoborie, 2015). Many groundwater resources have been developed and exploited in the region with attention paid to geochemical characteristics of the groundwater (Amadi *et al.* 1989). Water quality data may not be readily available mainly because the boreholes were completed without geochemical analyses. In such instance geoelectric sounding may serve a useful purpose in estimating total dissolved solids (TDS)

concentration (Aweto *et al.*, 2015). High TDS level is a factor that excludes a formation from being considered a practical source of potable water. Usually, an aquifer with TDS content greater than 500 mg/l TDs are rarely utilized for drinking water supply (Olkowski, 2009). Electrical resistivity method is sensitive and can be used to determine groundwater quality (Kelly, 1976; Urish 1983; Mazac, *et al.*, 1987). This is because the resistivity measured can provide useful information about the fluid in the voids within the rock matrix of an aquifer. This is based on the existing relationship between resistivity of formation/formation water and the porosity of the formation. An aquifer with low resistivity would imply high TDS provided porosity is constant.

This study was carried out in western Niger Delta with the objective of comparing and validating the use of geoelectric techniques in absence of geochemical techniques to identify potentially useable aquifer based on total dissolved solids concentration.

Location and Geology

The study area Ughoton is located between latitudes 5° 36' and 5° 41' north of the equator and between longitude 5° 38' and 5° 41' east of the Greenwich meridian (fig. 1). The area lies within the Niger Delta basin whose formation began in early Paleocene. The Niger Delta covers a total of about 75,000 km² (Reijers, *et al.*, 1997). The sedimentary fill of the Niger Delta Basin are strongly diachronous and shows an overall upward and updip transition from marine pro-delta shales Akata Formation through an alternating sand/shale paralic interval of the Agbada Formation to continental sands of the Benin Formation (Merki, 1970; Ejedawe, *et al.*, 1984).

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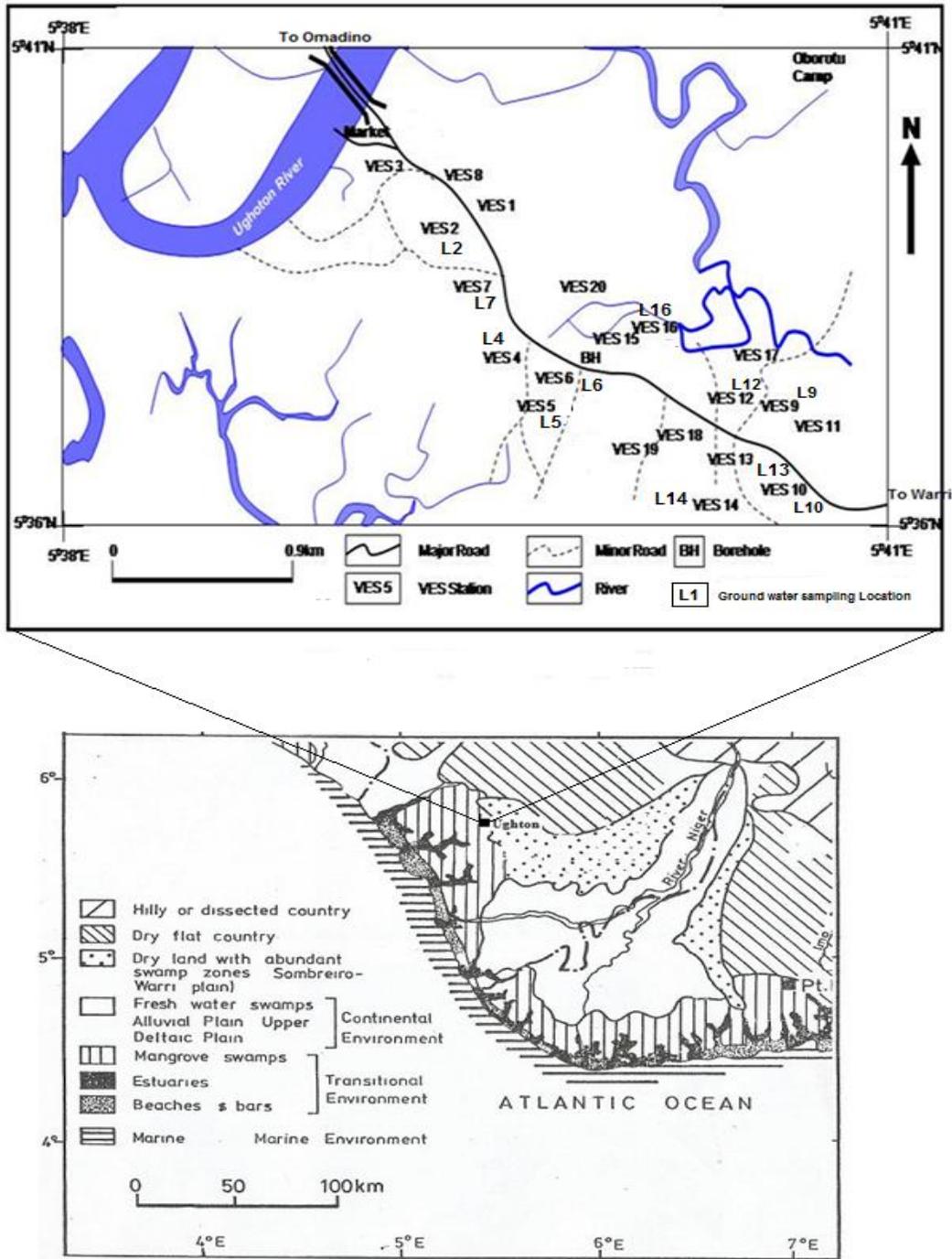


Fig. 1: Geologic map of Niger Delta showing study area (After Short and Stauble, 1967). Also showing location of resistivity measurements and groundwater sampling.

MATERIALS AND METHOD

A total twenty (20) vertical electrical soundings including ten (10) soundings from (Akpoborie and Aweto, 2012) were ran employing Schlumberger configuration with an ABEM SAS 1000 Terrameter. The apparent resistivities measured were plotted on a bi-logarithm graph against half current electrode spacing. These were later converted to layer/formation thicknesses and resistivities by partial curve matching

and computer iteration (Orellana and Mooney, 1966; Vander, 2004).

In this study, TDS level was derived from connate water resistivity, this is because of an existing proportional relationship between TDS level in groundwater and water resistivity. Archie (1942) has shown that groundwater resistivity R_w is related to formation resistivity R_b of sandy aquifers by the following expression:

$$F = \frac{R_b}{R_w} \dots\dots\dots (1)$$

F is the formation factor dependent on porosity, (Winsauer *et al.*, 1952) as shown below.

$$F = \frac{a}{\phi^m} \dots\dots\dots (2)$$

Using F = 5.4 (Aweto, 2013) in equation 1, R_w can be determined from measured formation resistivity R_b . TDS in mg/L was calculated using equation 3 below.

$$TDS = \frac{10000 \times 0.64}{R_w} \dots\dots\dots (3)$$

TDS values from geochemical analyses of ten (10) groundwater samples taken from boreholes near sounding locations reported by Akpoborie and Aweto

(2012) also constitute part of this study in order to validate the results.

DISCUSSION

The quantitative interpretation of the sounding curves (Fig. 2 and Table 1) indicates four (4) to six (6) geoelectric layers. Because of ambiguities inextricably linked with modelling and interpretation of sounding curves, borehole lithologic log from the area was used as an independent geological control to discriminate between valid and alternative interpretation of the VES data (Kearey and Brooks, 1991). As a result four – layered earth model was deduced comprising of top soil, clay/clayey sand/sand and sand (Fig. 3). The resistivity of the top soil; range between 50.1 and 1022.4 ohm-m with thickness of between 0.9 and 5.5m. The second layer is made up of clay/sandy clay/clayey sand and sand, their resistivity values range between 61.1 and 1402.2 ohm-m with thickness of 5.8 and 72.2m. The third and fourth layer characterized by resistivity values of between 92.0 and 976.3 ohm-m. This is interpreted as sand of over 50 m thick; it extends all over the investigated sites and corresponds to the aquifer.

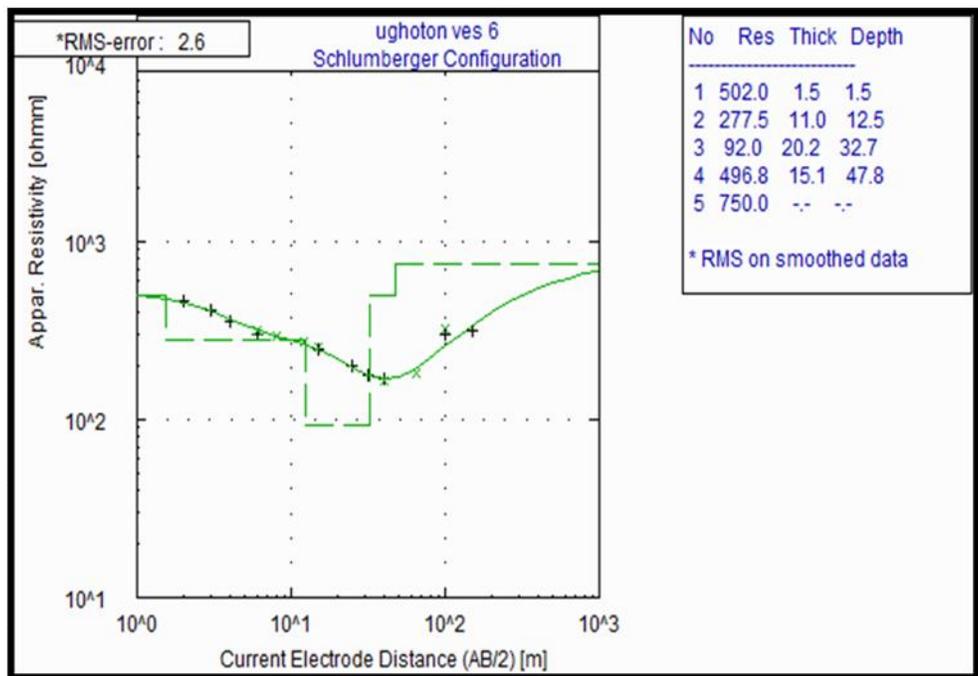


Fig. 2: Computer generated model data curve for Ughoton VES 6

Table 1: Results of quantitative interpretation of resistivity data

Location	Formation Resistivity (m)	Thickness (m)
1	230.0/536.7/930.0/433.3/853.3/375.0	1.2/2.3/16.4/15.0/14.3
2	602/933.3/700.2/503.3/350.1	1.0/1.9/5.6/18.0
3	421.3/280.1/1698.5/323.1/590.0/321.4	1.1/3.3/3.1/12.0/30.0
4	32.1/181.3/31.2/111.4/361.0/93.3	1.0/0.2/1.6/6.3/15.4
5	50.0/61.1/151.7/700.0/469.8	1.0/2.8/10.3/8.5
6	502.0/277.5/92.0/496.8/750.0	1.5/11.0/20.2/15.1
7	189.4/1693.0/525.3/405.7/370.5/183.5	1.4/2.9/4.1/17.6/37.1
8	975.5/613.9/418.2/638.1/561.0	1.2/3.8/5.7/29.1
9	178.4/781.7/719.4/967.4/370.1/217.9	1.1/0.6/3.7/11.3/32.7
10	466.5/195.0/1402.4/428.1/237.8	1.3/3.8/5.8/37.1
11	762.2/1296.7/212.9/461.5/364.1	1.1/0.9/6.0/18.7
12	999.8/1533.7/529.6/632/455.4	1.2/1.5/9.2/19.2
13	681.7/1066.6/275.6/350.9/255.6	1.0/1.3/8.1/51.4
14	804.0/1518.6/444.3/461.3/702.7	1.0/2.6/12.0/46.0
15	146.3/52.0/323.7/976.3	0.9/3.5/43.3
16	28.1/77.9/210.6/536.2	1.9/4.0/32.0
17	1022.4/1072.6/802.0/543.1	2.3/10.4/13.4
18	554.3/1355.1/714.4/542.0	1.2/5.0/60.5
19	762.4/1536.7/842.0/658.0/196.7/198.9	1.1/2.0/8.8/24.2/31.6
20	986.8/1138.5/557.0/487.2	1.8/7.3/10.5

Table 2: Estimates of TDS in Groundwater from Sounding and Geochemical Method

Location	Formation Resistivity (m)	Water Resistivity (m)	TDS _(Sounding) mg/L	TDS _(Geochemical) mg/L
1.	433.3	80.2	79.8	
2.	*503.3	93.2	68.7	*60
3.	*590	109.3	58.6	
4.	*361.0	66.9	95.7	*64
5.	*700	129.6	49.4	*17
6.	*92	17	376.5	*494
7.	405.7	75.1	85.2	*64
8.	*638.1	118.2	54.1	
9.	370.1	68.5	93.4	*61.9
10.	*428.1	80.7	64	*59
11.	461.5	85.5	74.9	
12.	632	117	54.7	*63
13.	350.9	65	98.5	*160
14.	461.3	85.4	74.9	*61
15.	323.7	59.9	106.8	*285
16.	*210.6	39	164.1	*167
17.	*802	93	68.8	
18.	*714.4	132.3	48.4	
19.	658.0	121.9	52.5	
20.	487.2	90.2	71.0	

*Data from Akpoborie and Aweto (2012)

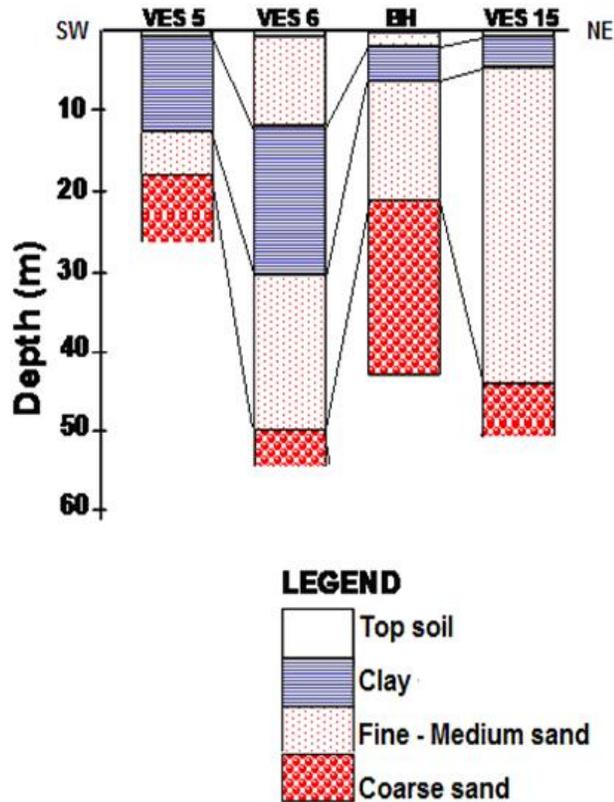


Fig. 3: Geologic section for Ughoton along SW-NE traverse

The amount of TDS in groundwater estimated from electrical resistivity sounding is presented in Table 2. The results showed that TDS level varied between 49.4 and 376.5 mg/L; the estimated TDS values were below the maximum contamination level of 500 mg/L prescribed by USEPA (2002) and SON (2007). This suggests that the groundwater in the study area may be suitable for drinking purpose. The presence of highly conductive clays in the geologic section at location 6 as seen in fig. 3 may increase the likelihood that the clays are the source of the fairly high TDS (376.5 mg/L). Total dissolved solids levels may also be influenced by groundwater pollution by heavy metals; Akpoborie and Aweto (2012) reported iron, cadmium and lead content of 1.42 mg/L, 0.07 mg/L and 0.09 mg/L respectively at

location 6. The occurrence of these heavy metals in groundwater are in order of magnitude higher than the maximum prescribed level of 0.3 mg/L; 0.003 mg/L and 0.01 mg/L for iron, cadmium and lead respectively (SON, 2007). This imply that groundwater source in this location may not be potable despite having TDS level below stipulated standards. Occurrence of these heavy metals in the Mangrove Swamps was also reported by (SPDC, 1998). Though the study area lies within the Mangrove Swamps the groundwater is fresh; according to Drever (1988), fresh water is defined as water containing TDS of less than 1000 mg/L. Akpoborie and Aweto (2012) reported mean chloride value of 25.24 mg/L in groundwater which also supports the facts that groundwater in the study area is fresh.

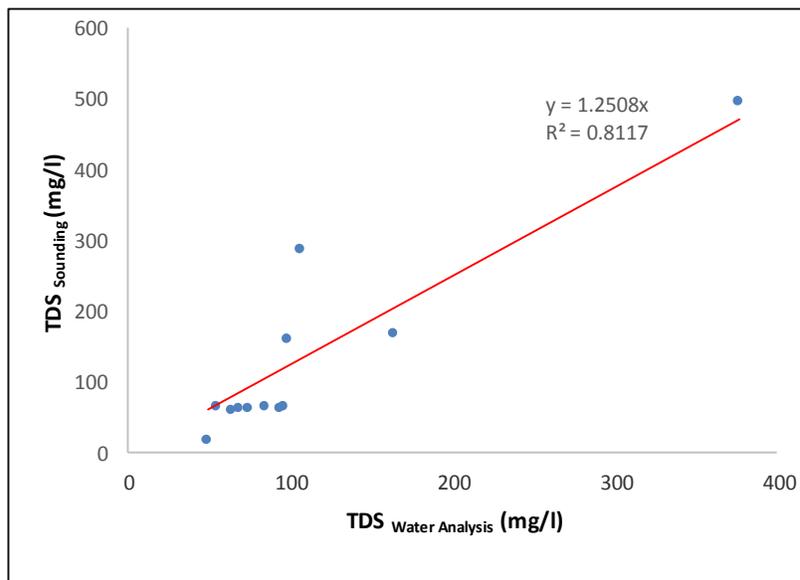


Fig. 4: Correlation of TDS estimates from sounding with water analyses

For comparison, results of TDS deduced from water analyses of ten (10) groundwater samples from Akpoborie and Aweto (2012) is also presented in Table 2. TDS determined by water analysis varied between 17 and 494 mg/L. In order to address the main objective of this paper; the TDS values determined by electrical resistivity sounding were correlated with those obtained from geochemical analyses as shown in fig 4. The amount of TDS in groundwater derived from the two techniques shows strong positive correlation ($R^2 > 0.8$); the slope of the line is approximately 1 indicating that TDS determined by the two methods give similar values. This finding is in agreement with that of Aweto *et al.* (2015) who showed that mean TDS of 269.77 mg/L derived from resistivity sounding correlated with mean TDS of 211.1 mg/L deduced from previous geochemical study by Aweto and Akpoborie (2011). Salufu, *et al.* (2015) also reported a close agreement between previous results of TDS from geochemical analyses and those predicted from electrical sounding ($R^2 = 0.9922$).

CONCLUSION

The results of this study shows that TDS level in groundwater estimated from geoelectric soundings were found to be well within permissible limits of 500 mg/L and as a result may be suitable for drinking purpose. There is a strong positive correlation between results of TDS estimated from geoelectric sounding and those derived from geochemical analyses. TDS inferred from soundings were validated and found to be in agreement with TDS values derived by geochemical method. Thus electrical resistivity sounding show good promise for application in determination of water quality based on TDS in the absence of results of water analyses.

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