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Characterization of Groundwater Quality from Surface Geoelectrics: The Case of the Sombreiro – Warri Deltaic Plain Aquifer, Western Niger Delta, Nigeria

Aweto Kizito Ejiro* Akpoborie Irwin Anthony Ohwoghere-Asuma Oghenero
Department of Geology, Delta State University, Abraka
* E-mail of the corresponding author: kizaweto@yahoo.com

Abstract

The vertical and aerial distribution of total dissolved solids (TDS) in groundwater from the predominantly unconfined aquifer in the Sombreiro - Warri Deltaic Plain deposits at Orerokpe in the western Niger Delta have been inferred from geoelectric survey data. Results reveal a dominant trend of decreasing TDS with depth. Specifically, TDS values at 5 m are in the range of 11.2 ppm to 1914.9 ppm (mean value of 451.6 ppm) and thus indicative of the fact that the quality of water at this depth may have been compromised. However at 20m below ground level, TDS are in the range of 44.1 ppm to 151.7 ppm (mean value of 85.7 ppm) which is predominantly below 500 ppm and thus well within the range recommended by the Standards Organization of Nigeria and the USEPA for drinking water supply. The inferred TDS from geoelectric data are in agreement with results obtained from chemical analyses of groundwater samples obtained in previous studies in the area and thus confirm that geoelectric surveys can be helpful in evaluating total dissolved solids (TDS) in the absence of water samples.

Keywords: Resistivity, Total dissolved solids, Aquifer, Contaminants, Maximum contamination limit.

1.0 Introduction

The sedimentary formations underlying the Niger Delta are potential good aquifers and as a result there is abundance of groundwater resources. However, pollution of groundwater has gradually been on the increase in the Niger Delta as a result of population growth and poor method of wastes disposal such as domestic garbage on land, in shallow excavation and rivers. These activities pose a serious threat to water quality. A major constraint for the use of groundwater is its quality. Most of the water used by inhabitants in the Niger Delta comes from shallow aquifer exploited by the use of hand dug wells and boreholes. The quality of water in these shallow aquifers may have been compromised by contaminants (Ejechi *et al.,* 2007; Akpoborie *et al.,* 2000; Abimbola, 2002; Olobaniyi *et al.,* 2007).

Groundwater is less contaminated as compared to surface water due to natural filtration process nevertheless; groundwater contains a variety of chemical constituents at different concentrations. The greater part of the soluble constituents in groundwater comes from soluble minerals in soils and sedimentary rocks (Waterwatch, 2005). These chemical constituents are calcium, potassium, sodium, chlorides, nitrates, carbonates, iron e.t.c. These ionic species when added together accounts for most of the salinity that is commonly referred to as total mineralization or total dissolved solids. Soluble salts are present in groundwater and their concentrations usually determine the potability. The distribution and evaluation of the values of pore water total dissolved solids (TDS) within a groundwater reservoir is one of the basic data in hydrogeological survey. Without water samples, analyses, an idea about the groundwater quality can be derived from electrical resistivity surveys (Kelly, 1976; Koefoed, 1979; Urish, 1983; Benson, 1991). Successful exploitation of groundwater in this region requires a proper understanding of its quality.

The objective of this paper is the use the empirical relationship between pore water resistivity and TDS values to characterize the TDS level of groundwater in aquiferous layers of Sombeiro-Warri Deltaic Plain deposits.

2.0 Location and Geology

Orerokpe community as shown in figure 1 lie within longitudes $5^0 41^1$E and $5^0 57^1$E and longitudes $5^0 31^1$N $5^0 40^1$N and located in the Niger Delta basin. The geology of the Niger Delta has been described by Allen, 1965; Burke *et al.,* 1972; Short and Stauble, 1972; Murat, 1972.

The formation of the Niger Delta began in early Paleocene times and was as a result of the build-up of sediments eroded and transported by the Niger River and show a transition from marine prodelta shales through an alternating sand/shale parallic interval to continental sands. The basin consists basically of three subsurface diachronous lithostratigraphic units: Akata, Agbada and Benin Formations. The basal Akata Formation (Paleocene - Recent) was deposited in marine environment. It consists of high pressure marine shales, clays/silts with occasional turbidite sand lenses. The formation is rich in organic matter and is the source rock of oil in the

Niger Delta. The formation has a relative thickness of 5882m. The overlying Agbada Formation (Eocene - Recent) consists of an upper predominantly sandy unit with minor shale intercalations and lower shale unit. The Benin Formation (Miocene - Recent) is the topmost layer. The formation is composed of 90% massive, porous sands with localized clay/shale interbeds. It is about 2000m thick. Overlying the Benin Formation are the Quaternary deposits of the Sombreiro-Warri Deltaic Plain which are 40-150m thick comprising of rapidly alternating sequences of sand and silt/clay (Etu-Efeotor and Akpokodje, 1990) with the later becoming increasingly more prominent seawards

3.0 Methods

Geoelectric survey was conducted utilizing ABEM Terrameter SAS 1000. A total of Twenty (20) VES stations were occupied employing Schlumberger configuration with maximum electrode separation of 300m. The apparent resistivities measurements at each station were plotted against half electrode spacing (AB/2) on bi-logarithmic graphs. Interpretation of the curves was carried out using partial curve matching technique. The results of the curve matching (layer resistivities and thickness) were used as a starting model in an iterative modeling technique using winRESIST software version 1.0 (Vander, 2004). The interpretated results (layer resistivities and thicknesses) were used to characterize the subsurface layers.

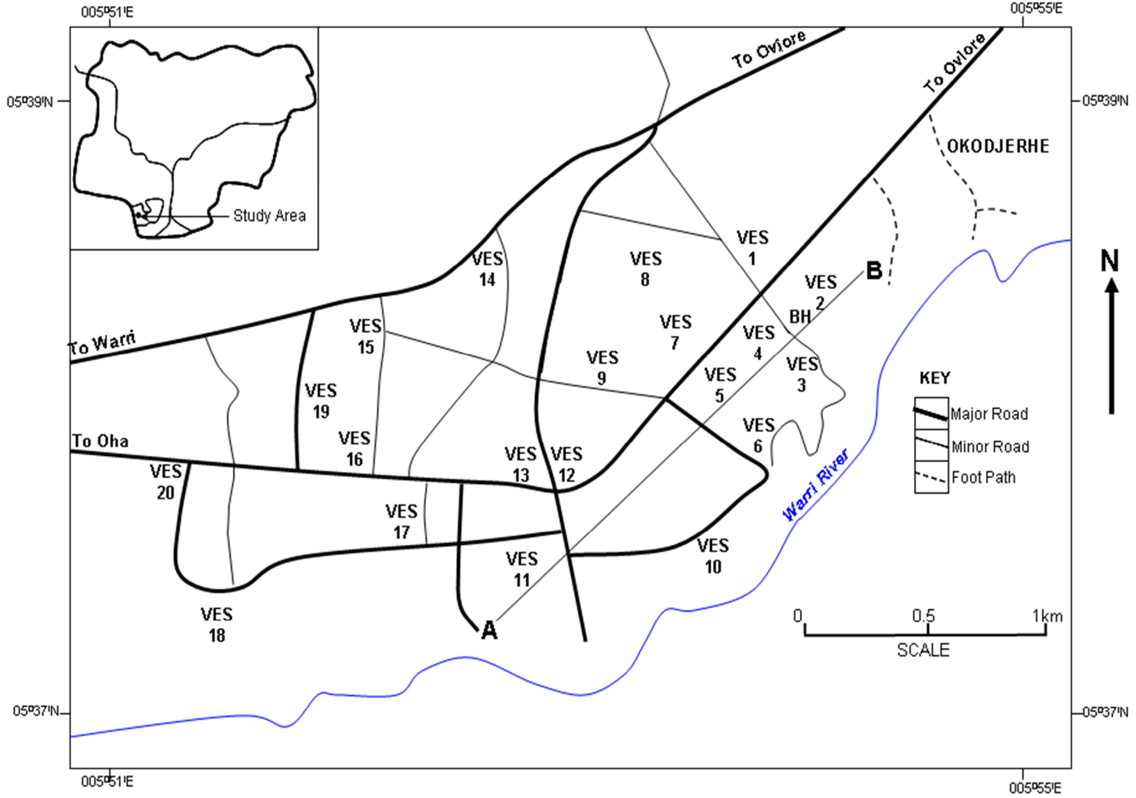


Figure 1. Map of study Area showing VES locations (Source: Aweto and Akpoborie, 2015)

3.1 Aquifer Resistivity – TDS Relationship

The resistivity of groundwater (pore-water) ρ_{water} can be related to aquifer resistivity $\rho_{aquifer}$ by Archie's law for sandy material (Archie, 1942).

$$\rho_{aquifer} = \rho_{water} \times F \text{ ....} \quad (1)$$

Where F is called the formation factor and can be expressed as

$$F = \frac{a}{\phi^{m}} \text{ ....} \quad (2)$$

Where ϕ is the porosity; a, is a constant taken as 0.62 and m, a cementation index taken as 2.15 for soft deposits (Repsold, 1989).

It is now established that an empirical relationship between aquifer resistivity and TDS exists (Lebbe and Pede, 1986) as shown below

$$TDS = \frac{10,000 \times F}{P_{aquifer}} \text{ ....} \quad (3)$$

Where $\rho_{aquifer}$ is the resistivity measured by the terrameter in ohm-meter and TDS is in ppm

Using a porosity of 0.34 (Aweto, 2013) in equation (2), a formation factor of 5.4 was derived which was used in equation 3 to evaluate TDS.

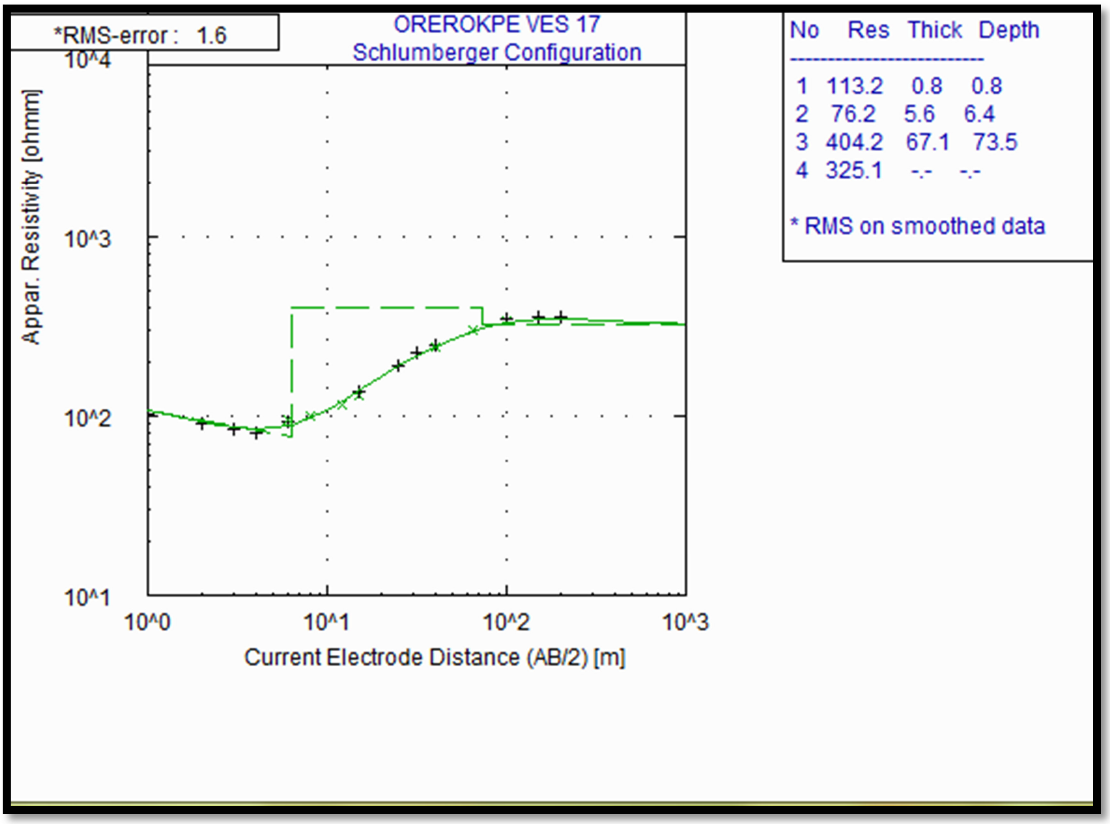
4.0 Results and Discussion

The existing electric resistivity contrasts between lithological sequences in the subsurface were used in delineating geoelectric layers and identifying aquiferous units (Dodds and Ivic, 1988; Deming, 2002).

The result of the geoelectric investigation revealed that the prevailing lithostratigraphic units within the study area consist of top soil (with variable composition), clay and sand. Groundwater occurs in an aquifer comprising of rapidly alternating sequence of sand and clay. The aquifer type is predominantly unconfined intercalated with lenses of saturated clays at some locality. The depth to the aquifer varied between 8.3 m to 28.1 m while thickness ranged from 15.1 m to 57.1 m (Figure 3).

4.1 Evaluation of TDS from Geoelectric data

The shallow layers are exploited in Orerokpe and indeed everywhere in the Sombreiro Warri Deltaic Plain with hand-dug wells while shallow boreholes penetrate and tap water from the deeper layers (Aweto and Akpoborie, 2011). The interpreted geoeletric data were used to evaluate TDS values at depths of 5 m and 20 m below ground level (Table 1 and Table 2).



No	Res	Thick	Depth
1	113.2	0.8	0.8
2	76.2	5.6	6.4
3	404.2	67.1	73.5
4	325.1	-.-	-.-

* RMS on smoothed data

Figure 2: Typical computer iterated curve for Orerokpe

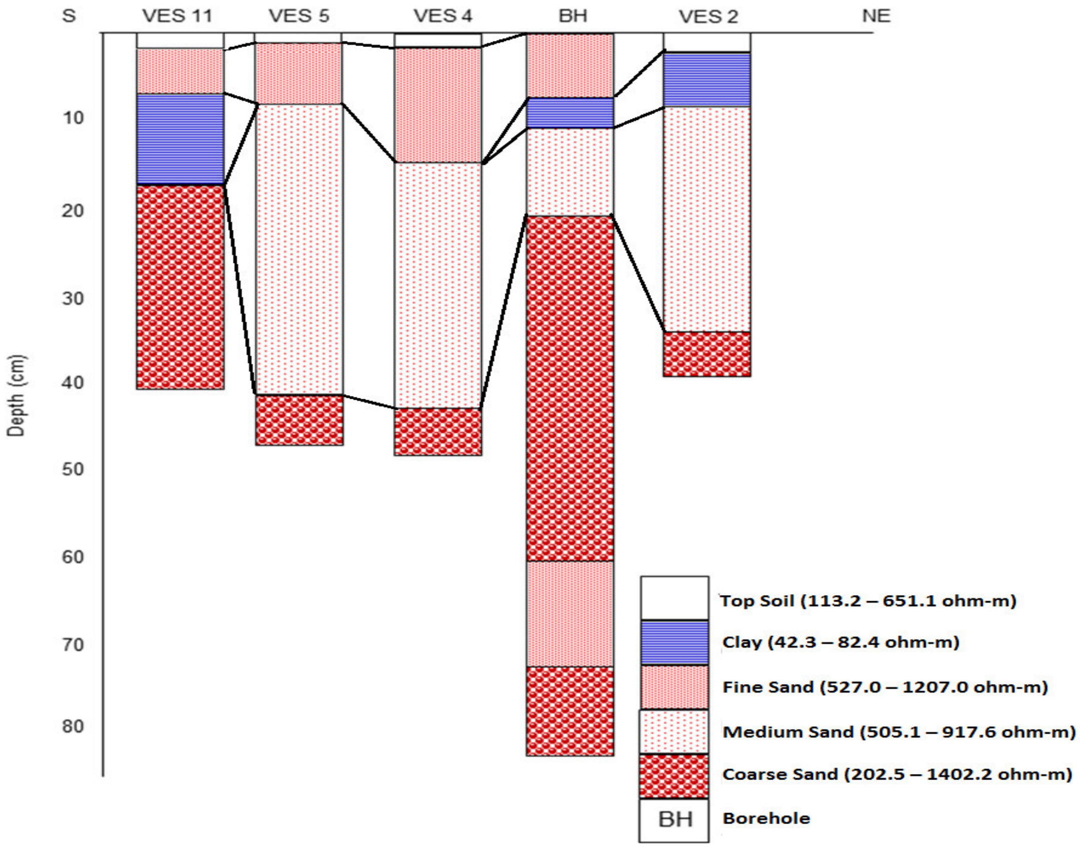


Figure 3: Geoelectric section at Orerokpe along profile AB in Figure 1. (Source: Aweto and Akpoborie, 2015)

Table 1: Results of evaluated TDS values at 5 m below ground level

VES Station	Resistivity of Layer (ohm-m)	Calculated TDS (ppm)
1	180.8	298.7
2	42.3	1276.6
3	68.2	791.8
4	120.3	448.9
5	1418.8	38.1
6	355.1	152.1
7	89.4	604.0
8	137.1	393.9
9	264.6	204.1
10	396.6	136.2
11	77.4	687.7
12	399.0	135.3
13	687.0	78.6
14	28.2	1914.9
15	78.6	687.0
16	298.6	180.8
17	76.2	708.7
18	449.0	120.3
19	591.5	91.3
20	648.2	83.3

Table 2: Results of evaluated TDS values at 20 m below ground level

VES Station	Resistivity of Layer (ohm-m)	Calculated TDS (ppm)
1	429.9	125.6
2	928.7	58.1
3	1084.2	49.8
4	917.6	58.8
5	583.3	92.6
6	1047.9	51.5
7	771.0	70.0
8	530.0	101.9
9	355.9	151.7
10	604.0	89.4
11	402.2	134.3
12	938.7	57.5
13	384.2	140.6
14	368.0	55.8
15	621.8	86.8
16	550.6	98.1
17	404.2	133.6
18	483.0	111.8
19	1165.0	46.4
20	1225.0	44.1

The data in Table 1 and 2 were used to produce maps showing variations of TDS in the aquifer at depths of 5 m and 20 m below ground level (Figures 4 and 5) using SURFER software. The area with light orange indicates where TDS is less than 500 ppm and the areas with brick red indicate where TDS is greater than 500 ppm. At 5 m below ground level (Figure 4) TDS values ranged from 11.2 ppm to 1914.9 ppm. The levels of TDS in groundwater at 5 m in Orerokpe when compared with the maximum contamination limits (MCL's) of 500 ppm set by USEPA (2011) for potable water indicates that 65% of the groundwater at this depth is of good quality while the remaining 35% indicates that there is indeed cause for concern at locations (VES 2, VES 3, VES 7, VES 11, VES 14 VES 15 and VES 17). Changes in the concentrations of certain dissolved substances in groundwater of an aquifer system could be natural or anthropogenic; these may affect the suitability of the aquifer system as a source of water. Aweto and Akpoborie (2011) identified the importance of water – rock interactions in determining the chemistry of shallow groundwater in the Sombreiro-Warri Plain deposits of the Niger Delta. According to Aweto and Akpoborie (2011) the sequence of abundance of the cations is Na > K > Ca> Mg. This trend differs significantly from the natural order in pristine groundwater which is Ca > Mg > K > Na and this variation could be indicative of geochemical processes that would be altering and possibly resulting in water quality deterioration (Akujieze and Oteze, 2002; Karanth, 2006). The elevated TDS at these locations may be due to clays (Aweto, 2013). Increase TDS can result from cation-exchange processes in clays because, for clays to maintain electrical charge balance, two monovalent sodium or potassium ions must enter solution for each divalent ion absorbed. Clay minerals can have high cation-exchange capacities and may exert a considerable influence on the proportionate concentration of the different cations in water associated with them (Hem, 1985). The exchange of calcium for sodium results in high sodium levels, and total dissolved solids increase in ground water when calcium ions are exchanged for sodium ions (Freeze and Cherry, 1979).

Other sources of TDS are anthropogenic related which include urbanization and associated wastes generated (Akpoborie *et al.*, 2015). The effects of human activities on quality of water resources are felt over a wide range of scales ranging from "local scale" which implies distances from a few feet to a few thousand feet and areas as large as a few square miles to "subregional and regional scales" which range from tens to thousands of square miles. Groundwater in the vicinity of indiscriminately disposed wastes may be contaminated by leachates from the disposed wastes (Hensel and Dalton, 1995; Bernstone and Dahlin, 1996). The leachates become part of the groundwater flow system immediately they reach the water table. In arid environments, the leachates may take a longer time to penetrate the surrounding soil or rock due to lack of rainfall but may still contaminate the groundwater (Aljaradin and Persson, 2010), the extent of pollution is however greater in tropical environments (Al-Yaqout and Hamoda, 2003). VES 14 and VES 15 are located in a fast growing area in Orerokpe with no concern for proper waste management; the elevated TDS levels in these part of the study area may be due to domestic wastes deposited in open dumps and shallow excavation. Around VES 11 in the southern part are several abattoirs where cows are slaughtered on a daily basis. These abattoirs operate under poor hygienic conditions with no proper means of disposing the wastes generated. In most cases, these wastes are buried in pits. These pits have become point-source of pollutants through which the decomposing wastes in the pits percolates and infiltrates into the groundwater. This most likely is responsible for the high concentration of TDS within this area. A high concentration of TDS will make water unpalatable and might have an adverse effect on people who are not used to drinking such water; hence, people should be discouraged from drinking water from hand-dug wells in this area.

At 20 m below ground level (Figure 5), the TDS values ranged from 44.1 ppm to 151.7ppm. TDS in water is related to the resistivity of water. In a saturated zone, higher resistivity implies higher quality. As TDS decrease, water quality increases (Turcan, 1966). The reduced TDS values at this depth show that there is of good quality. The result indicates that 25% of groundwater in shallow aquifer in the study area has been contaminated as TDS level exceeded maximum contamination limits (MCL's). The TDS values inferred from geoelectric measurements (mean value of 269.77 ppm) shows good correlation with those obtained from water samples (mean value of 211.1 ppm) of previous study (Aweto and Akpoborie, 2011).

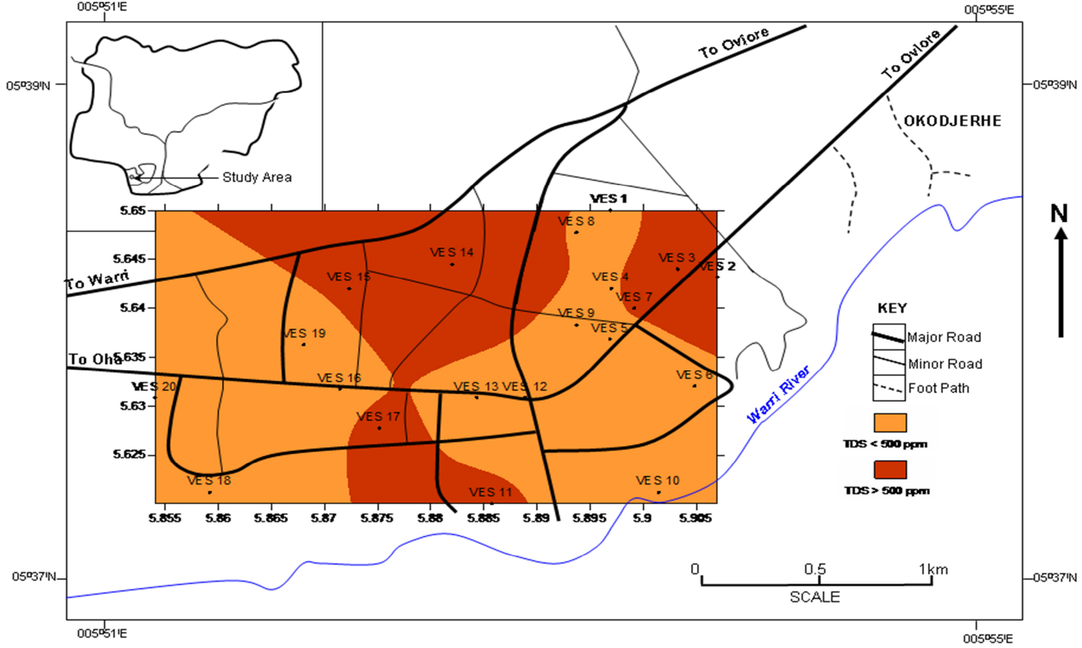


Figure 4: TDS levels at 5m below ground level

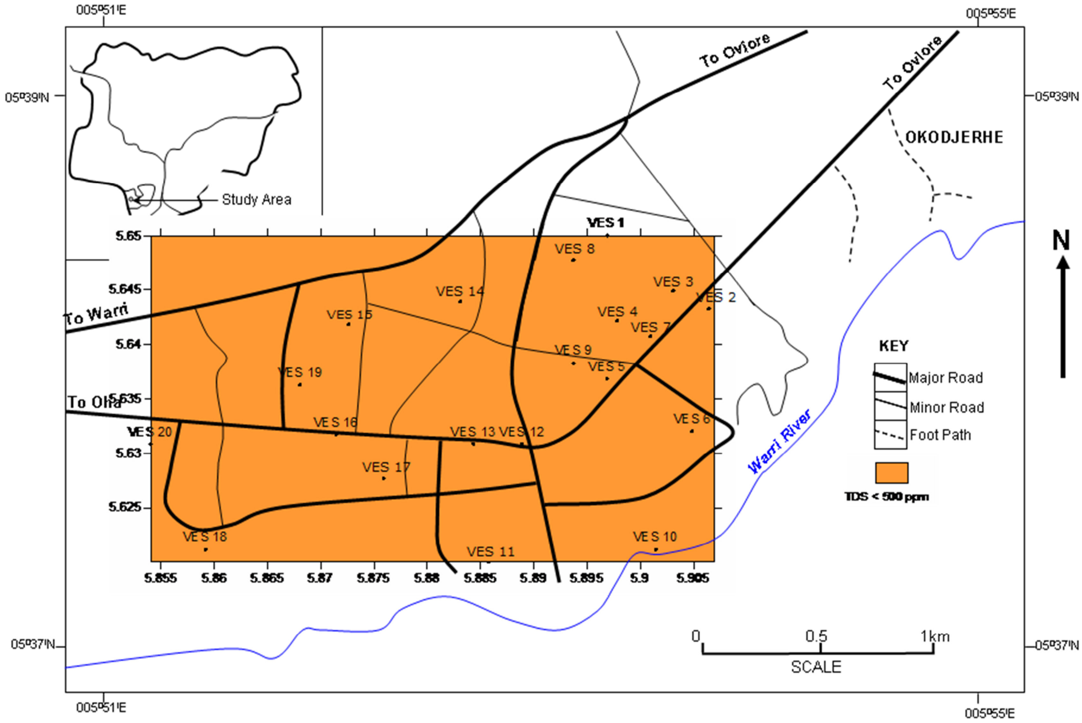


Figure 5: TDS levels at 20 m below ground level

5.0 Conclusion

A surface geoelectric investigation was conducted at Orerokpe, Western Niger Delta, with the aim of providing information on water quality of shallow aquifer based on TDS. The result reveal a dominant trend of improve in water quality with depth. In general, the presence of 2 distinct aquifer zones was delineated viz: very shallow zones (5 m) exploited by hand-dug wells and shallow boreholes penetrating relatively deeper layers (20 m below ground level). The quality of groundwater based on TDS values at 5 m below ground level has deteriorated in about 35% the study area. However, as depth increased water quality improved as TDS values fell below the 500 ppm the lower limit stipulated by USEPA (2011). Good prospect for groundwater development exist in the study area of depths greater than 20 m where TDS values ranged from 44.1 ppm to 151.7 ppm. The geoelectric data has successfully estimated TDS values which are in good agreement with TDS values obtained from water samples in the study area from previous study.

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