INDUCED POLARIZATION SIGNAL AS A TOOL FOR PREDICTING Fe ENRICHMENT OF UNDERGROUND WATER IN YENAGOA, SOUTH-SOUTH, NIGERIA.

Oboshenure Kingsley Karo [1], ***Ogobiri Godwin*** [2], ***Francis Omonefe*** [3]

Department of Physics, Niger Delta University, Amassoma.

Abstract

1D Resistivity and chargeability survey were conducted at a Fe enriched groundwater area and Fe free groundwater area in Yenagoa metropolis, Bayelsa state to investigate chargeability responses within the groundwater table enriched with Fe as well as a Fe free groundwater. Eight (8) survey profiles were conducted in two areas (Ekeki and Tombia). Shallow boreholes were dug. Water samples where collect from new and existing boreholes for water analysis. For location 1 (Ekeki axis), water quality analysis from new and existing dug wells in the areas showed high iron concentrations of 0.58 – 9.30 mg/L exceeding the permissible limits which are 0.3mg/L according to W.H.O. Interpreted resistivity/chargeability models showed a spike increase in its chargeability graph (>10ms) as we move through the groundwater table. For location 2 (Tombia axis), water quality analysis from new and existing dug wells in the area showed very minimal iron concentrations (0.04 – 0.15 mg/L) which is within the permissible limits. Interpreted resistivity/ chargeability models from surveyed profiles in this study area showed no spike increase in its chargeability trend as it moves through the groundwater table.

Keyword: Resistivity, IP, Groundwater, Geochemical, Fe.

1.INTRODUCTION

Several investigations have been carried out in Yenagoa and environs to characterize the source, regulating processes and distribution of Fe in the aquifers (Amajor, 1991; Okiongbo and Douglas, 2013; Okiongbo and Douglas, 2015). These studies reported the occurrence of high dissolved iron (Fe) in the groundwater collected from the shallow aquifers in many areas. The issue of high iron concentration (> 0.3mg/L) in groundwater is a common problem since over 90% of residents in and around yenagoa city depend on water collected from shallow private boreholes. Presently, we remain remarkably ignorant of the cause of the high Fe enrichment and heterogeneity in the groundwater.

From previous work done around the study area using VES and Boreholes (Oki & Oboshenure, (2017); Okiongbo & Douglas (2013), the stratigraphic section reveals that the area is characterized by mainly three geological layers which are the Topsoil, the clay or sandyclay and the sand. The topsoil has a relatively thin surface layer which consists of loamy soil mixed with organic matter (Amajor, 1991). The second layer is sandyclay or clay. Clay is a low permeable argillaceous material, thus areas with clayey layers are of low permeability and hence play a significant role in the development of redox conditions in the aquifer that drives iron (Fe) release into the groundwater (Okiongbo and Gede, 2017). This clay layer is extensive within Yenagoa and environs. Its lateral extend explains in part why the occurrence of high groundwater Fe is pervasive in one part of the study area. The third layer is dominantly sand which contains the groundwater.

Chargeability is the ability of the Earth to store electric charges over time. chargeability measures the voltage drop after turning off the injected current. The higher the chargeability, the longer the charge is held. chargeability decreases over time, usually a few seconds, sometimes up to minutes, and eventually disappear. Chargeability is very useful for applications in mineral exploration. In essence, resistivity answers the question "What is the resistance to the flow of electric current?"

while chargeability answers the question "How long does the earth hold an electric charge?".

The normalized chargeability and clay composition extend to studies of 1-D and 2-D to IP fields. (Okay et al., 2009). 2-dimensional studies use clear conductivity and normalized charge data to segment images into areas that are relatively free of clay and rich in clay. Similarly, such an approach can eventually be used to predict relative changes in clay content, salinity, and possible concentration of pollutants. The strong chargeability effect is usually observed in clay sediments. Therefore, rocky sand/silt and rocky sandstone usually show great chargeability effects. In contrast, compact clay is usually associated with high chargeability effects, because conductivity in ohm dominates the flow of current. The small but measurable chargeability effect is related to pure sand and gravel (Alabi et al., 2010).

In this study, we pay close attention to the chargeability signature on two distinctive areas, one with high iron (Fe) enriched groundwater and the other with no/low iron (Fe) enriched groundwater in the time domain as we move through the groundwater table within Yenagoa.

2. DESCRIPTION OF THE STUDY AREA

The study areas are Ekeki and Tombia all in the Yenagoa City of Bayelsa State. Generally, the study areas lie between Longitudes 006o 15´ and 00 6o 025´ East of the prime meridian and Latitudes 04o 55´ and 05o 00´ North of the equator and is within the coastal area of the recent Niger Delta (Fig. 1.). The study area has an area extent of about 18 km. Bayelsa State is located in the southern part of Nigeria and is within the Niger Delta basin.

The Niger Delta stratigraphy is divided into three known as Akata, Agbada, and the Benin Formation in the age of descending order (Short & Stauble, 1967). Details of the sequence of the Niger Delta stratigraphy are documented by several scientists, including Short and Stauble (1967); Uko, et al, (2002); Amajor, (1991) and Table 1.1 shows the stratigraphic sequence of the Niger Delta. The major aquiferous formation in this study area is the Benin Formation.

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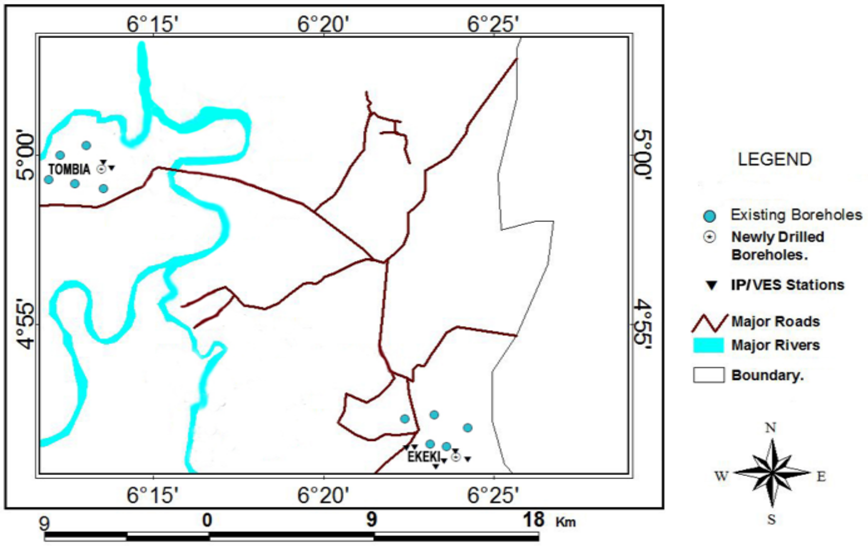

Fig.1: Map of the study area.

The Benin cluster is very permeable, has good reservoir quality, and productive and is the most commonly explored aquifer in the Niger Delta. It is about 2100 m thick at the basin center (Short & Stauble, 1967), its upper section is the Quaternary deposit which is about 40 – 120 m thick and comprises of sand and silt with the later becoming increasingly more prominent seaward. The Formation consists of fluvial and lacustrine deposits whose thicknesses are variable. Clay deposits in the Benin formation have led to the multi-aquifer system in the region (Etu-Efeotor & Akpokodje, 1990).

Table 1: Stratigraphy of the Niger Delta (after Allen, 1965)

Geologic Unit	Lithology	Age
Alluvium (General)	Gravel, sand, clay, silt	Quaternary
Freshwater Backswamp, Meander Belt	Sand, clay, some silt gravel	
Mangrove and Salt Water/Backswamps	Medium-fine sands, clay and some silt	
Active/Abandoned Beach Ridges	Sand, clay, and some silt	
Sombreiro-Warri Deltaic Plain	Sand, clay, and some silt	
Benin Formation (Coastal Plain Sand)	Coarse to medium sand with subordinate silt and and clay lenses	Miocene
Agbada Formation	Mixture of sand, clay and silt	Eocene
Akata Formation	Clay	Paleocene

The main source of recharge is through direct precipitation where annual rainfall is as high as 3000 mm. The aquifers in the delta are recharged by the water that infiltrates through the highly permeable sands of the Benin Formation (Amajor & Ofoegbu, 1988).

3. THEORETICAL REVIEW

Investigation of decreasing potential differences as a function of the current time is referred to as induced polarization (IP) in the time domain (figure 2). The origin of induced polarization is very complex and it is not very well understood. This is mainly because certain phenomena and physical-chemical conditions are responsible for their occurrence. Seigel (1970) states that by immersing metal electrodes in ionic solutions with certain concentrations and valences, there is a potential difference between the metal and the solution interface. This potential difference is a clear function of ion concentration, valence, etc. An external voltage interface is applied so that the current flows and the potential drop interface changes from its original value. The interface changes voltages called "waves" or "polarization" electrodes. To overhaul the surge due to the accumulation of ions on the electrolyte side of the interface. The accumulation of

time and constant attenuation is usually very small, probably a few tenths of a second.

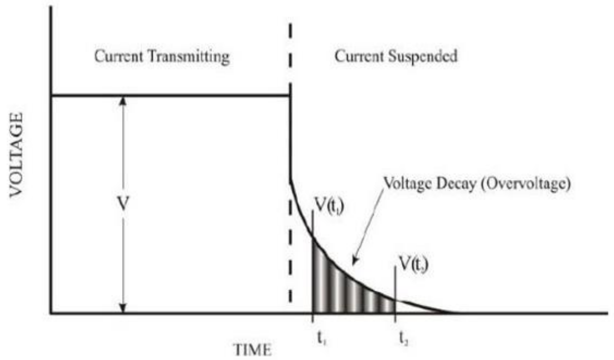

Figure 2. Voltage Decay in Time domain (Glaser 2007)

The time-domain IP uses several indices to determine the polarizability of the medium. Seigel (1959) defines "IP/Chargeability" as an area under the decay curve (in millivolt-seconds mV-s) in ratio to the potential difference (in mV) measured before the current is cut or switched off.

Komarov et al. (1968) define "polarization" as the ratio of potential differences after a certain period by turning off the current to a potential difference before turning off the current. Polarization is expressed in percentage. Considering Archie's law, 1942, aquifer resistivity is proportional to the electrical resistivity of its content. The porous sand formation is electrically resistive but the ionic solutes are conductive. The electrical effect of ionic pollutants is so obvious on aquifer electrical properties, the ionic solute decreases the aquifer electrical resistivity value.

$$\rho_a = \rho_w a \Phi^{-m} S^{-n} \qquad (1)$$

Where ρ_a = adenotes electrical resistivity of fluid saturated rock in (Ωm),

ρ_w = electrical resistivity of the formation in (Ωm),

Φ = the porosity,

S = Formation saturation,

m = cementation exponents of rock,

n = the saturation exponents and

a = tortuosity factor.

Based on the induced polarization properties, ions presented in aquifer change successively its petrophysical properties and its water ionic content. Its chargeability value increase, according to reference zone chargeability value. Note that the induced polarization is characterized by the chargeability parameter. It presents the relaxation time of rock after cutting the current injection.

$$m = \frac{1}{V_p}\int_a^b V_t(t)dt \qquad (2)$$

Where , m = chargeability in (ms or mV/V),

V_p = current potential just before its cutting of,

$V_t(t)$ = potential in t time.

As the measurement of the V_t (t) is physically impossible. Seigel (1959) shows that the diverse in content of the media of n different materials, apparent chargeability ηa is roughly related to apparent resistivity by

$$\eta_a = \sum_{i=1}^{n} \eta_i \frac{\partial \log \rho_a}{\partial \log \rho_i} \qquad (3)$$

Where η_i = chargeability of the ith material,

ρ_i = resistivity of the ith material.

Seigel 1959 showed that

$$\sum_{i=1}^{n} \eta_i \frac{\partial \log \rho_a}{\partial \log \rho_i} = 1 \qquad (4)$$

Therefore, by combining equation 3 and 4, a very useful formula for η_a/η_1 was obtained as

$$\frac{\eta_a}{\eta_1} = 1 + \sum_{i=2}^{n} \frac{\partial \log \rho_a}{\partial \log \rho_i}\left[\frac{\eta_i}{\eta_1} - 1\right] \qquad (5)$$

If the theoretical expression for apparent resistance ρ_a is known, then an equivalent expression for a clearly reduced apparent chargeability η_a/η_i can be obtain.

4. METHODOLOGY

In this study, Vertical Electrical Sounding (VES) technique using the Schlumberger configuration was used in the data acquisition. The Schlumberger array was chosen because 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). Eight Resistivity and chargeability measurements were collected in two different locations. Six (6) Resistivity and chargeability measurements were collected in location 1 and two (2) Resistivity and chargeability measurements were collected in location 2. A multi-channel ABEM Field equipment was used. Survey depth is determined by electrode spacing. The software used for this interpretation is zond.

one new borehole was drilled in each study area within the shallow depth (≤30 m) using the rotary drilling method. The boreholes were lithologically logged and sampled at 3.0 m or more often when characteristics of the sediment changed based on their grain size and colour.

Groundwater samples were also collected from five (5) pre-existing boreholes in both locations. In these groundwater samples, situ measurements of temperature, redox potential (Eh), and pH were carried out using pre-calibrated portable pH/ORP meter at the time of groundwater sampling.

5. RESULTS AND DISCUSSIONS

Eight (8) survey profiles were conducted in two areas (Ekeki and Tombia). The Resistivity and chargeability model were analyzed and interpreted using Zond software. Zond is a flexible geophysical software developed for near-surface geophysics. This Software is effective for processing and interpretation of geophysical data such as Resistivity imaging and seismic tomography. The study result is as follows:

5.1. Location 1 (Ekeki Axis).

Six (6) 1D VES profiles of both resistivity and chargeability measurements were taken in this site. The total length for each profile is 80 m, thus allowing the depth of investigation down to 19.5 m. This depth covered up to the water table. The resistivity model from the 1D VES profiles correlated with the newly drilled borehole log indicates that there are three (3) main layers within the depth of investigation. The resistivity curves alone all profiles show that the Ekeki site is predominately H-Curve where $\rho1 > \rho2 < \rho3$. The result of the model shows that layer 1 consists of clayey sand (topsoil) which has resistance values ranging from 21 – 56 ohm-m and at a depth ranging from 0.8 – 1.3 m. The underlying layer is clay with resistance values ranging from 8 – 30 ohm-m and a depth ranging from 2.2 – 6.7 m. The Aquifer is a light grey coloured sandy formation with resistance values ranging from 87 – 130 ohm-m and a depth ranging from 11.4 m – 19.5 m. Table 2 shows a summary of the resistivity and the chargeability model across the six profiles in the Ekeki site.

Fig. 3a-f represents Resistivity and chargeability model from location 1 (Ekeki axis). The ruler on the X-axis represents the coordinates of the sounding point. The left-hand y-axis shows the apparent resistance values of the sounding in ohm-m and the right-hand y-axis shows the chargeability values of the sounding in ms. The red curve represents the resistivity while the blue curve represents chargeability.

Table 2: Geoelectrical layer parameters (Resistivity and depth) obtained from the interpretation of the Geoelectrical Soundings

VES Profile No	Depth of Layers (m)			Resistivity of Layers (Ohm-m)			Chargability of Layers (msec)			RMS Curve
	d_1	d_2	d_3	$\rho 1$	$\rho 2$	$\rho 3$	$\eta 1$	$\eta 2$	$\eta 3$	(%)
1	1.2	4.5	15.7	31	8	89	1.4	4.3	13.2	2.4354
2	1.3	2.2	11.4	30	12	105	1.3	4.3	0.66	1.3441
3	1.3	2.7	18.6	27	15	87	0	9.5	0.52	1.9559
4	1	5.6	16.3	21	20	96	0	3.4	27.0	2.4581
5	0.8	6.2	19.5	46	30	130	2.3	1.0	0.018	2.9936
6	1	4.6	16.0	56	12	99	1.1	2.5	99	4.3442

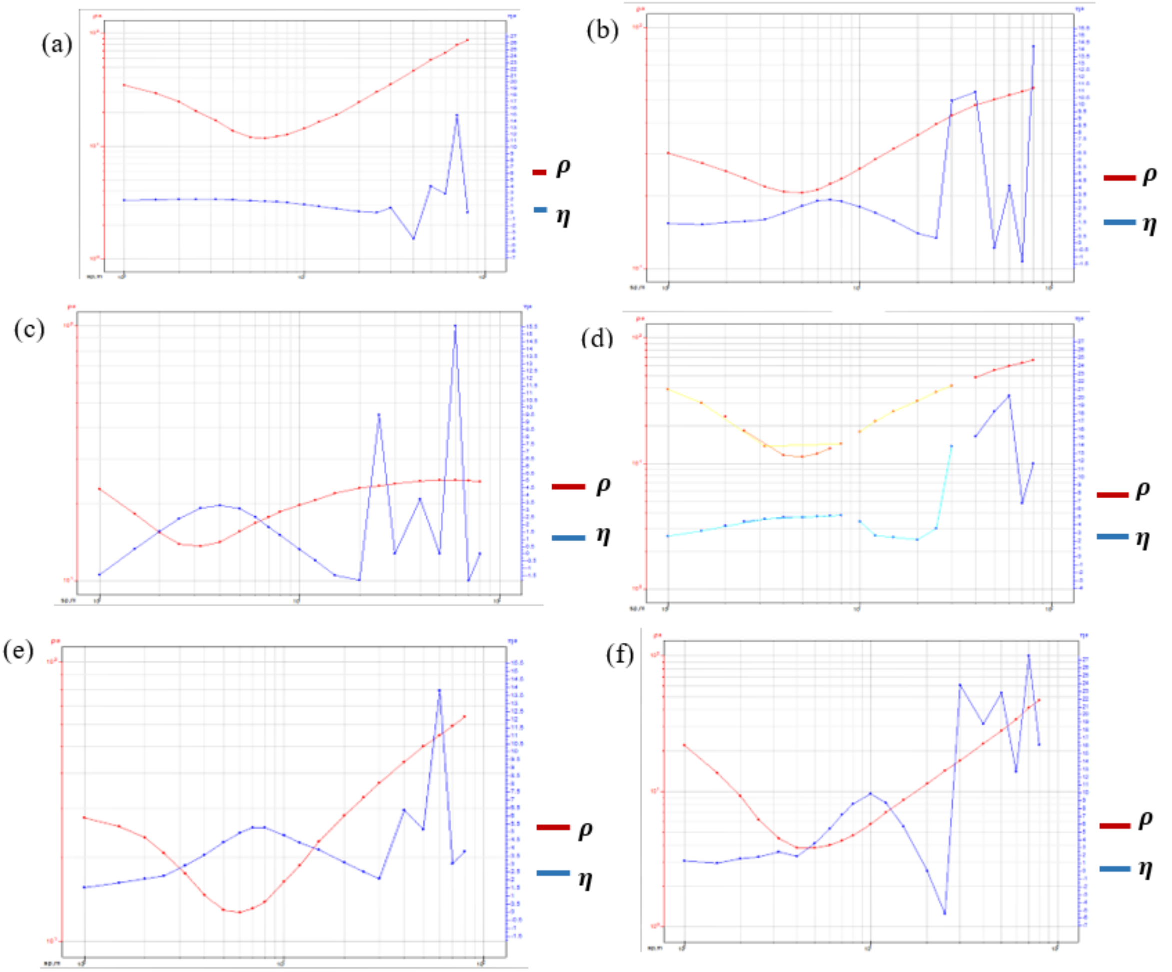

Figure. 3: Resistivity and its corresponding Chargeability curve. (a) Profile 1. (b) Profile 2. (c) Profile 3. (d) Profile 4. (e) Profile 5. (f) Profile 6.

The purpose of this investigation is to study the behavior of the chargeability curve as it moves close to the aquifer containing high dissolved Fe water (Fig. 4a-f) (blue curve). The corresponding chargeability model shows an increased chargeability anomaly that corresponds with low resistivities at an approximate depth of 1.0 m down to 6.7 m.

According to Barker (1990), chargeability will increase as the salinity of the groundwater increases up to 500mg/l. It is seen that as we move towards the groundwater table, a spike increased chargeability values were observed towards the Aquifer indicating Fe concentration from around depth 10 – 20 m. The high chargeability anomaly spikes (> 10 msec) is believed to be due to dissolved organic Fe and not clay which according to Aristedemou et al. (2001) has a chargeability value of < 10msec.

A new borehole was drilled and logged 3 m away from profile 3. Water samples were collected from the new and 5 pre-existing boreholes for hydrochemical analysis (Table 4).

Table 2: Variation of Fe concentration in borehole sediment and groundwater samples in Ekeki axis (area of high groundwater Fe concentration). The screened aquifer Horizons are marked in green

Borehole	Depth	Sediments Samples			Groundwater Samples			
	(m)	Borehole Lithology	Fe (mg/L)	Colour	Temp (ºC)	pH	Eh (mV)	Fe (mg/L)
	New Borehole							
	3.7	Clayey sand	0.50	Dark Grey	-	-	-	-
	9.1	Clay	2.40	Grey	-	-	-	-
BH1	15.2	Fine Sand	0.75	Light Grey	26.8	6.78	125	3.40
	Existing Boreholes							
BH2	-	-	-	-	26.6	6.27	128	0.58
BH3	-	-	-	-	27.3	6.59	107	5.73
BH4	-	-	-	-	26.5	6.82	120	6.30
BH5	-	-	-	-	26.5	6.91	118	9.30
BH6	-	-	-	-	26.5	6.91	118	7.10

The results show that the pH in the groundwater obtained from both new and existing boreholes ranges from 6.27 - 6.91. The pH values show that the groundwater is slightly acidic. The mild acidity can be attributed to organic acids resulting from the decomposition of swampy environments (Davidson, 1995). Dissolved Iron (Fe) concentration from the groundwater samples from both new and existing boreholes in this location ranges from 0.58– 9.30 mg/L. This range of values is highly more than the permissible limit (0.3mg/L). The Eh (redox potential) values vary from 107 – 128mV. Table 2 summarizes the results from the hydrogeochemical analysis of the groundwater samples.

5.2. Location 2 (Tombia Village).

Two (2) profiles of both 1D resistivity and chargeability measurements were taken on this site. The total length for each profile is 80 m, thus allowing the depth of investigation down to 16 m. This depth covered up to the water table. Table 3 shows a summary of the resistivity and the chargeability model across the two (2) profiles in this study area. The resistivity/chargeability model graph is displayed in Fig.4a-b respectively.

Table 3: Geoelectrical layer parameters (Resistivity and depth) obtained from the interpretation of the Geoelectrical Soundings

VES Profile No	Depth of Layers (m)			Resistivity of Layers (Ohm-m)			Chargability of Layers (msec)			RMS Curve	VES Curve
	d_1	d_2	d_3	$\rho 1$	$\rho 2$	$\rho 3$	$\eta 1$	$\eta 2$	$\eta 3$	(%)	Type
1	1.2	3	15.3	112	1113	1683	1.4	0.31	4.91	0.4354	K
2	0.8	4.2	12.0	87	189	801	1.3	0.66	3.42	1.0122	K

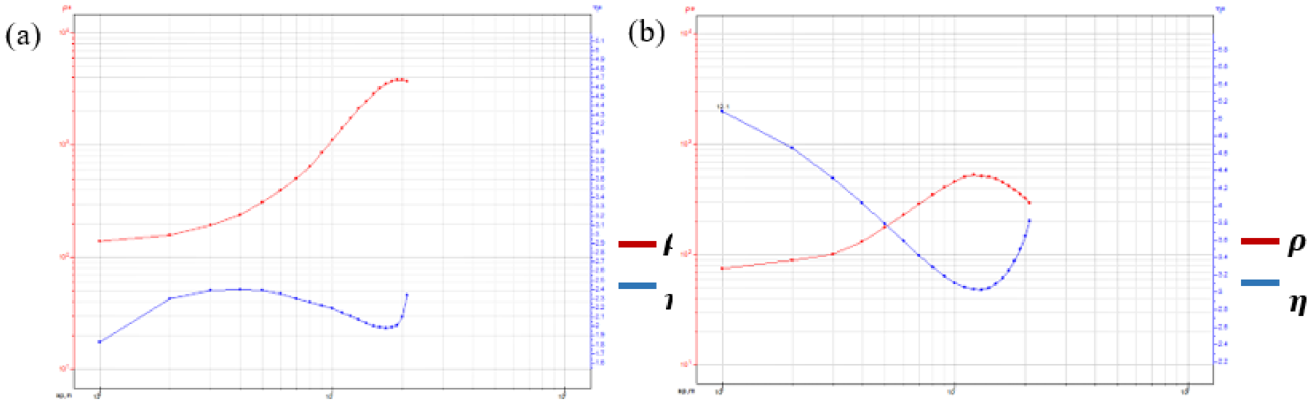

Fig. 4: Resistivity and its corresponding Chargeability curve. (a) Profile 1 (b) Profile 2.

The resistivity and chargeability model of the 1D VES profiles correlated with the newly drilled borehole log indicates that there are 3 main layers within the depth of investigation. The resistivity curves alone the two profiles show that the study area is predominately K-Curve where ρ1< ρ2<ρ3. The result of the model shows that layer 1 which consists of sand (topsoil) which has resistance values ranging from 87 – 112 ohm-m and at a depth ranging from 0.8 – 1.2 m. The underlying layer is fine sand with resistance values ranging from 189 – 1113 ohm-m and a depth ranging from 3.0 – 4.2 m. The Aquifer is a Brown coloured fine sand formation with resistance values ranging from 801 – 1683 ohm-m and a depth ranging from 12.0 – 15.3 m.

The corresponding chargeability model shows a decrease in near-surface chargeability response that corresponds with an increase in resistivities at an approximate depth of 1.0 m down to 4.2 m. No anomalous spike increased chargeability values were observed as we move towards the groundwater table. The chargeability response for this study area follows the normal trend where an increase in resistivity value gives rise to a decrease in chargeability reasons and vise-visa.

A new borehole was drilled and logged 6 m away from profile 1. Water samples were collected from the new and additional 5 pre-existing boreholes for hydrochemical analysis (Table 4). Fe concentration in borehole sediments and groundwater samples in this study area is tabulated in table 4 where the screened aquifer horizons are marked in blue.

The results from the hydrogeochemical analysis of the groundwater samples show that the pH in the groundwater obtained from both new exiting boreholes range from 6.33 - 6.89. The pH range shows that the groundwater is slightly acidic. A contributing factor for this acidity is attributed to gas flaring which releases carbon-dioxide and reacts with atmospheric precipitation to form carbonic acid, which infiltrates into the groundwater system to reduce the pH of the water thus increasing acidity (Okiongbo and Douglas, 2013). Dissolved Iron (Fe) concentration from the groundwater samples from both new and existing boreholes in this location ranges from 0.04 – 0.15 mg/L and the Eh (redox potential) values vary from 138 – 164 mV.

Table 4: Variation of Fe concentration in borehole sediment and groundwater samples in Tombia Village (area of low groundwater Fe concentration). The screened aquifer horizons are marked in green.

Borehole	Depth	Borehole Sediments Samples			Groundwater Samples			
	(m)	Lithology	Fe (mg/L)	Colour	Temp (^{o}C)	pH	Eh (mV)	Fe (mg/L)
New borehole								
BH1	1.2	Top Soil	0.72	Dark Grey	-	-	-	-
	3.0	Fine Sand	0.50	Brown	-	-	-	-
	12.0	Fine Sand	0.50	Brown/Red	28.7	6.52	164	0.08
Existing borehole								
BH2	-	-	-	-	26.9	6.89	138	0.04
BH3	-	-	-	-	27.6	6.84	157	0.06
BH4	-	-	-	-	28.9	6.33	148	0.15
BH5	-	-	-	-	27.5	6.46	162	0.12
BH6	-	-	-	-				

6. CONCLUSION

Geophysical techniques have made, and continue to make, a major contribution to subsurface investigations. The data collected in an area where there is little or no iron (Fe) content in its aquifer water is used as a comparison to study the change in chargeability signal as a result of the water composition. This study provides a qualitative assessment of the utility of the chargeability signal. It was found that with careful interpretation, chargeability imaging can improve understanding of the properties and material of the subsurface.

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