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Geoelectrical logging for well screening in prolific aquifers in Ubima, Ikwerre Local Government Area, River State, Nigeria

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Geoelectrical logging was conducted in two well locations in Ubima community, Niger Delta, Nigeria. Self-Potential (SP) and Resistivity (Short Normal and Long Normal) logs were employed. Two points each in wells 1 and 2, respectively, were tested to determine the porosity (ϕ), permeability, *k* and the total dissolved solids (TDS) in the aquifer by derivation from electrical conductivity (EC). The results show that for test zones A and B in well 1, porosity and permeability had values of 20.6% and 49 *m*D, respectively, at depth range of 105 to 120 m and values of 19.4% and 34 *m*D, respectively, at depth range of 120 to 140 m. The total dissolved solid (TDS) derived from electrical conductivity range of 869.5 to 877 µmhoscm^{-1} is between 556 and 561 ppm for these zones. For well 2, test zones A and B, the porosity and permeability values observed were 23.7% and 108 *m*D at depth range of 80 to100 m and values of 22.0% and 71 *m*D at depth range of 100 to 120 m, respectively. A TDS value of 400 ppm was observed for both test zones in this well. This implies that screening and casing installations should be done between 90 and 110 m to ensure that a prolific and good water quality aquifer is delineated for borehole water project in this community.

Key words: Geoelectrical logging, well screening, prolific aquifer, Ubima, Niger Delta.

INTRODUCTION

Different kinds of aquifers systems exist within the subsurface of the Niger Delta (Oteri and Atolagbe, 2003; Etu-Efeotor and Akpokojde, 1990; Ekine and Osobonye, 1996; Amajor, 1991). Some contain mineralized water, saline water and fresh water. Post-drilling geoelectrical logging is a useful technique for hydrogeological characterization of these ground water aquifer systems when chemical analyses are not available. This should necessarily be conducted before screening and casing installations for water supply to wells to ensure that a

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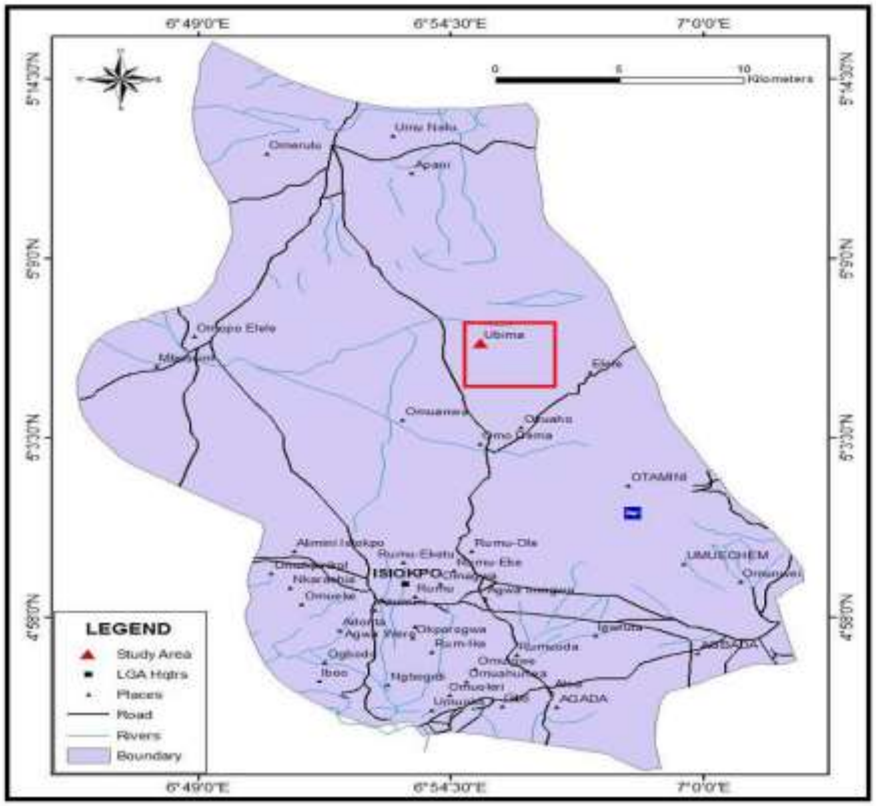


Figure 1. Map of Ikwerre L.G.A. showing the study area– Ubima.

prolific and good water quality aquifer is delineated for any borehole water project.

Etu-Efeotor and Akpokodje (1990) noted that groundwater development and abstraction have been undertaken indiscriminately without regard to the safe yield of aquifers and possibly deterioration of water quality. Most ground water wells are not geoelectrically logged by some drilling outfits before completion and production probably due to the cost implications or lack of expertise. In such cases, the hydrologists rely only on core samples collected at depth intervals while drilling to draw conclusion on the location for screening in the wells. This certainly does not allow for proper delineation of a prolific and good quality aquifer. The result in this case is sometimes, polluted ground water systems with mineralized water, saltwater intrusions and or dry wells after some period of abstraction.

Sequel to the above, geoelectrical logging was conducted in two well locations with drilled depths of about 140 and 120 m, respectively, at Ubima community, Niger Delta, Nigeria. Self-Potential (SP) and Resistivity (Short Normal and Long Normal) Logs were employed. The total dissolved solids (TDS) were determined by the derivation of the electrical conductivity (EC) and ultimately the porosity (ϕ) and permeability and k of the aquifers.

Location of the study area

The study area is Ubima Community located in Ikwerre Local Government Area of Rivers State delimited by Latitude 6°49′0′E and 7°0′0′E and Longitude 4°58′0′N and 5°14′30′N in the Niger Delta (Figure 1).

Geology of the study area

Generally, the Benin Formation constitutes the major aquiferous formation in the study area. It is about 2100 m thick at the basin centre and consists of coarse-medium grained sandstones, thick shales and gravels. The upper section of the Benin Formation is the quaternary deposits which are about 40-150 m thick and comprise sand and silt/clay with the later becoming increasingly more prominent seawards (Etu-Efeotor and Akpokodje, 1990). The Formation consists of predominantly freshwater continental friable sands and gravel that have excellent aquifer properties with occasional intercalations of claystone/shales (Olobaniyi and Oweyemi, 2006).

According to Etu-Efeotor (1981), Etu-Efeotor and Akpokodje (1990), Offodile (2002), Udom et al. (2002), the Benin Formation is highly permeable, prolific and productive and is the most extensively tapped aquifer in the Niger Delta. All the boreholes in the study area are drilled into the Benin Formation.

According to Nwankwoala and Warmate (2014), Ubima is underlain by the Coastal Plain sands, which in this area is overlain by soft-firm silty clay sediments belonging to the Pleistocenic Formation. The general geology of the area essentially reflects the influence of movements of rivers, in the Niger Delta and their search for lines of flow to the sea with consequent deposition of transported sediments. In broad terms, the area may be considered flat. The surface deposits in the area comprise silty-clays. The near surface silty clays are subjected to mild desiccation during the dry season. Substantial seasonal variations in moisture are expected in the area. This could result in some false enhancement of strength in the dry season. The sandy layers underlying the top clay are predominantly medium-to-coarse in grain sizes, fairly well graded and found to exist in various states of compaction (Nwankwoala and Warmate, 2014).

Theory of geoelectrical logging

Spontaneous (self) potential log

Static SP values relate to the chemical activity of the formation water (Ushie, 2001), which also correlates the true resistivity of the formation and the formation of water resistivity. They are used to distinguish lithology such as shaly from sandy formation (Raghumath, 2008). Moore and Rust (1944) stated that electrochemical potential is the primary parameter for the SP log. Electrochemical potential relates to the chemical activities of the formation water by (Schlumberger, 1989):

$$EC = -KLog\frac{a_w}{a_{mf}} \quad (1)$$

Where: EC = electrical conductivity; a_w, = chemical activity of the interstitial water; a_{mf} = chemical activity of the mud filtrate; K = coefficient proportional to the absolute temperature of formation.

Since the chemical activity of the formation water is related to NaCl content and hence the resistivity, Wyllie (1948) proposed that the SP due to the electrochemical activity may also be written as:

$$SP = KLog\frac{R_{mf}}{R_w} \quad (2)$$

Where: K= 0.133T_f + 61; T_f = formation temperature in degrees Fahrenheit; R_{mf} = resistivity of the mud fluid = 16 Ωm (for NaCl-based mud); R_w = resistivity of the formation water.

Electrical resistivity logs

The resistivity logs used contain both short normal and the long normal. The short normal has a distance of 16" between the potential electrodes, MN, while the long normal has a distance of 64" between the potential electrodes, MN. The apparent resistivity of a medium can be calculated by the formula:

Resistivity, ρ = Resistance, R x Geometry Factor (3)

Where: Resistance, $R = \frac{V}{I}$ (Ohms)

Geometry factor is simplified as follows:

Short Normal Resistivity (16") = 4πMN = 12.56 x 16 = 5.02 m

Long Normal Resistivity (64") = 4πMN = 12.56 x 64 =20.0 0m

MN = Separation between the potential electrodes in meters

Archie's (1942) formula relates formation factor, porosity, the resistivity of the rock, and the resistivity of the formation water for clean water-bearing zone as follows:

$$F = \frac{R_o}{R_w} = \frac{R_t}{R_w} = \frac{a}{\phi^m} \quad (4)$$

Where F = formation factor; R_o = resistivity of rock saturated with conducting fluid; R_w = resistivity of formation water; R_t = true resistivity of the formation; *m* = 3 (cementation factor for a high yielding water productive aquifer); *a* = 1 (for unconsolidated sands); ϕ = porosity.

Electrical conductivity (EC) of water estimates the total amount of solids dissolved in water, that is, total dissolved solids (TDS). TDS is measured in ppm (parts per million) or in mg/l. The aquifer quality can be determined by the total dissolved solid (TDS), which is derived from the electrical conductivity values (EC) using Equation 5 (Raghumath, 2008):

$$TDS = 0.64xEC \quad (5)$$

The permeability of the identified aquifers can be estimated using the Jorgensen (1988) equation:

$$k = 84105\left(\frac{\phi^{m+2}}{(1-\phi)^2}\right) \text{ (milliDarcies, mD)} \quad (6)$$

The resistivity of the formation water, R_w can be estimated

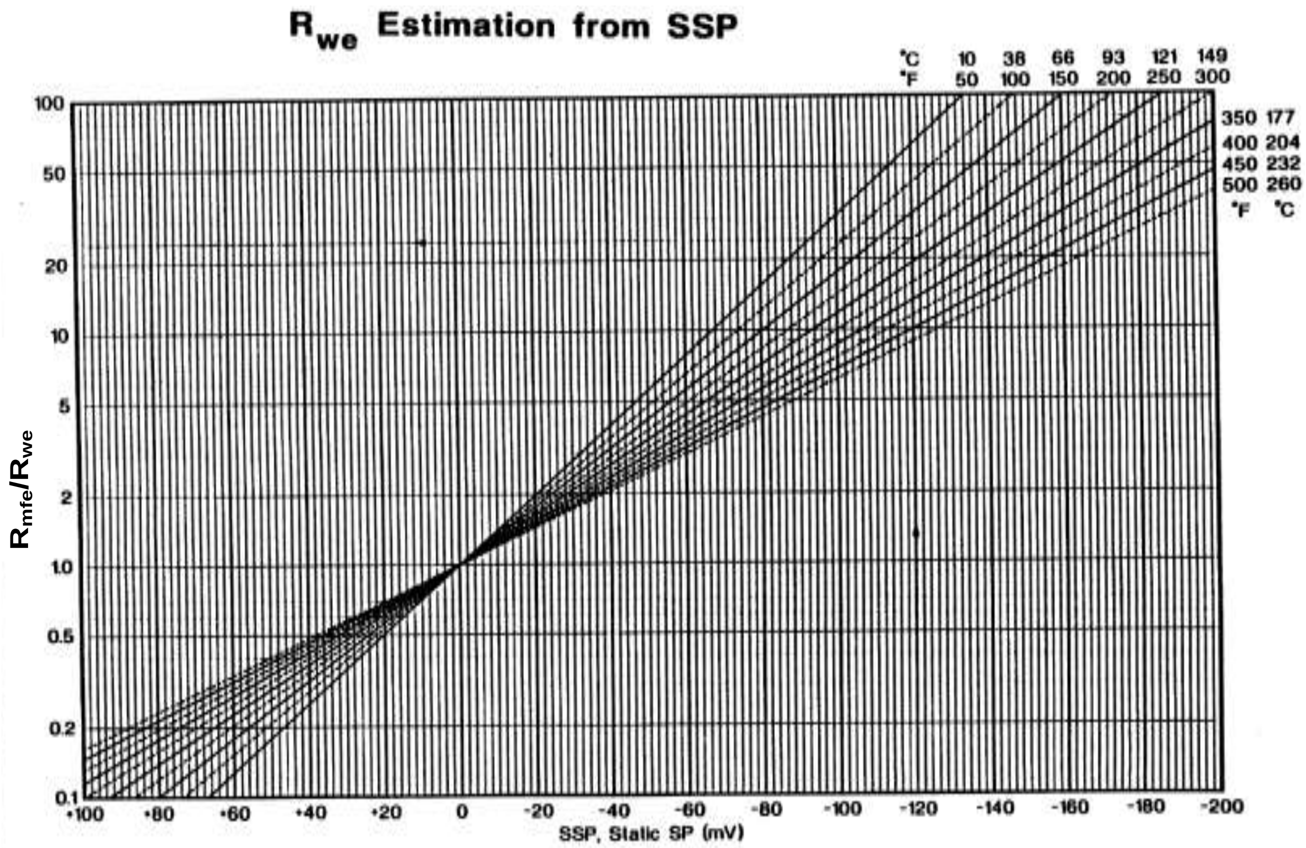


Figure 2. Typical R_{mf}/R_w versus static SP chart (Schlumberger, 1986).

from the Static Spontaneous Potential (SSP) Chart (Figure 2). The wells in this study were at a temperature of 38°C.

METHODOLOGY

Set-up

The Terrameter system used for the logging exercise consist of a basic unit called the SSR-MP-ATS measuring unit with a liquid crystal digital read-out and automatic signal averaging microprocessor, a current control box, and multi electrode probe. The unit has capabilities of measuring spontaneous potential (SP) and resistivity (Short Normal 16" Normal 64" long lateral 18").

Logging

The operations involve the logging of two boreholes, about 10 km apart and drilled to total depths of 140 and 120 m, respectively. Self-potential (SP) resistivity logs (Short Normal 16" and Long Normal 64") were run. The sonde was first lowered step by step towards bottom of the hole. Thereafter, the resistivity and SP measurements were taken when the sonde was being pulled out of the hole. This allowed for a steady sonde and unperturbed logging of electrical resistivity and spontaneous potential in the wellbore.

Digitization of logs

Electrical resistivity (Ωm) and spontaneous potentials (*mV))* were digitized from the logs only at depth intervals (zones) that are likely to depict good aquifers. These zones indicated by 'two 'sharp kicks' (deviation from a smooth trend) were observed in both wells respectively and indicate two aquiferous layers of different hydrogeological properties.

RESULTS

Figures 3 and 4 show the electrical resistivity and spontaneous potential loggings for both wells, respectively. These show that the depth investigated is made of permeable sandy layer down to the logged depths. Zones A and B were tested in wells 1 and well 2, respectively. The logs show that the electrokinectic streaming potential within regions of 100-120 m for test zone A in well 1 and 80-100 m for test zone A in well 2 are higher than other regions. The digitized values are shown in Table 1.

From Table 2, it can be observed that for test zones A and B in well 1, porosity and permeability have values of 20.6% and 49 *m*D, respectively, at depth range of 105 to

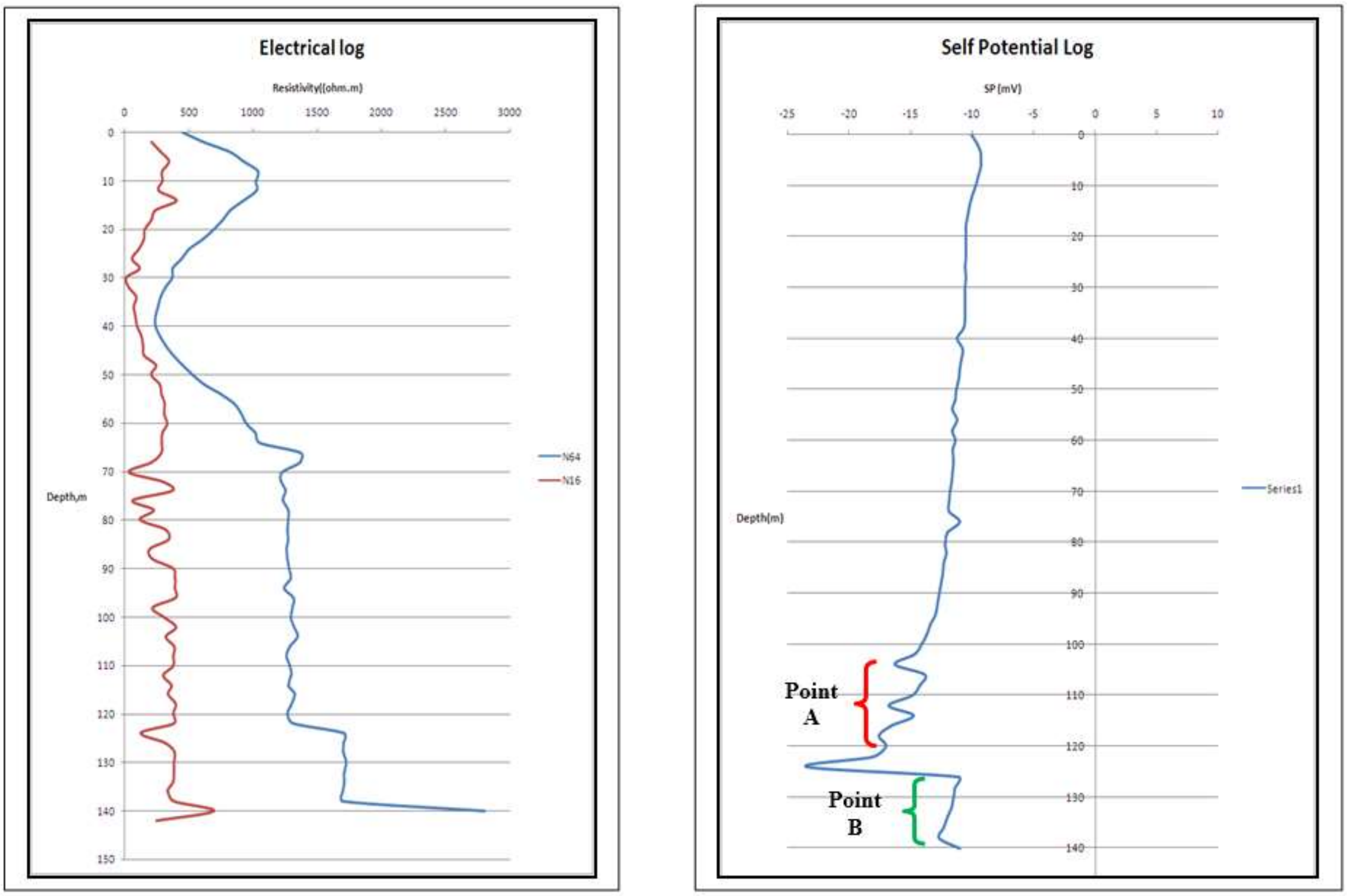


Figure 3. Resistivity and SP logs for Well 1.

120 m and values of 19.4% and 34 *m*D, respectively at depth range of 120 to 140 m. The total dissolved solid (TDS) derived from electrical conductivity range of 869.5 to 877 µmhoscm^{-1} is between 556 and 561 ppm for these zones.

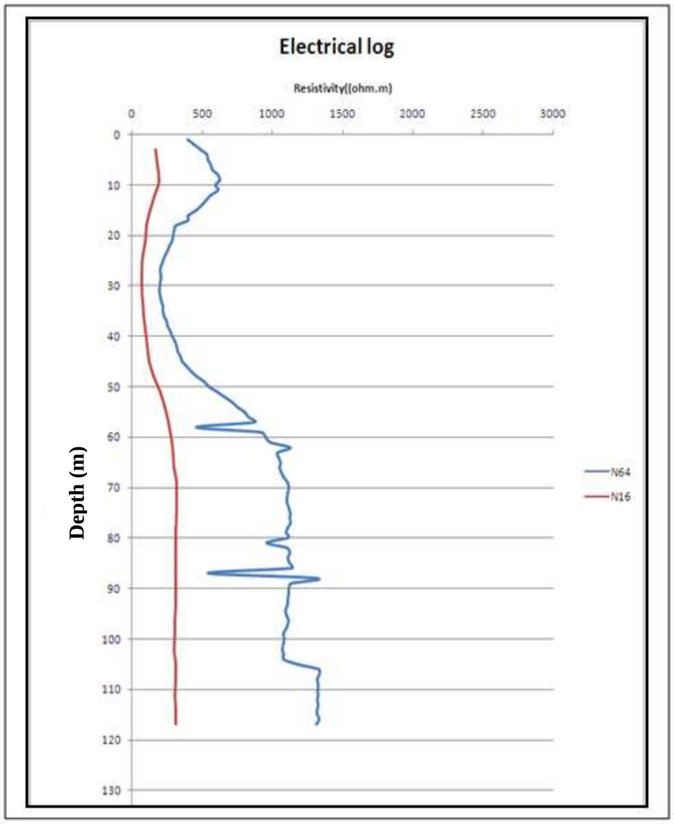
For well 2, test zones A and B, the porosity and permeability values observed were 23.7% and 108 *m*D at depth range of 80 to100 m and values of 22.0% and 71 *m*D at depth range of 100 to 120 m, respectively. A TDS derived from EC value of 625 µmhoscm^{-1} was observed to be 400 ppm for both test zones in this well.

DISCUSSION

The SP logs display a fining upward sequence which depicts a fluvial environment. Two zones (A and B) in each of the two wells were observed to be of hydrogeological interest in this study. The log records indicate the fact that the zones of low SP values (105 to 120 m for well 1 and 80 to 100 m for well 2) are of high porosity and permeability than the other zones. The core samples collected around the two zones (A and B) during the drilling of the two wells consist of friable sands and gravels indicative of good aquifer ‘pay zones’. The zones have porosities between 20 and 30% respectively which are consistent with established standards for good aquiferous geological materials (Freeze and Cherry, 1979; Todd, 1980; Driscoll, 1986).

Conclusion and recommendation

The logging details of the borehole as shown identified aquifer ‘pay zone’ at depth range of about 90 – 125 m. The lithology here comprises sandy and gravely subsurface material. Ultimately, the borehole materials exhibit a productive aquifer thickness greater than 20 m. Screen installation and proper gravel packing of the well annulus, to improve on the efficiency of the well production system should be done at the extensive aquifer zone between 90 and 110 m for a productive



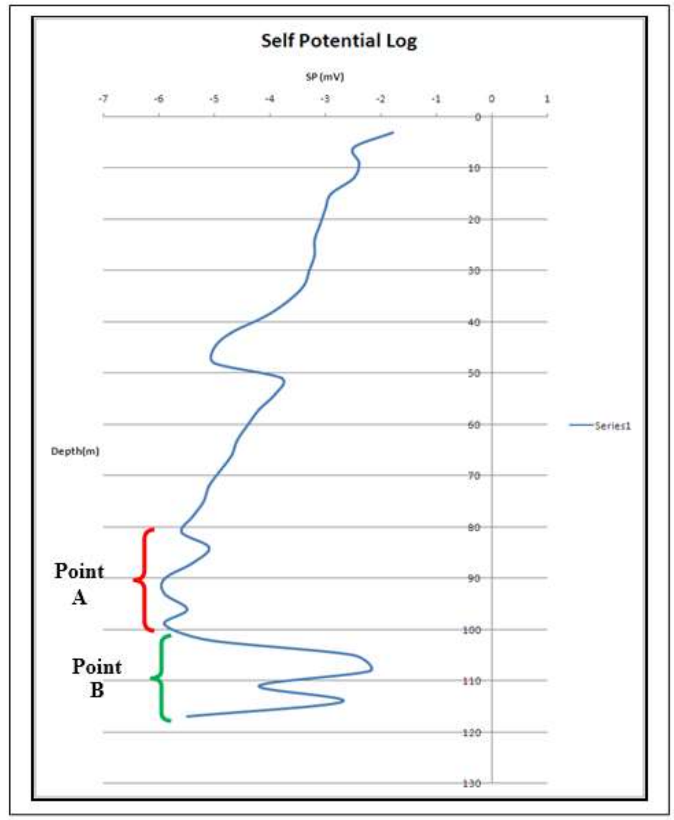


Figure 4. Resistivity and SP logs for Well 2.

Table 1. Summary of the test zones, digitized SP values and formation resistivity, mud weight resistivity and formation water resistivity.

Well	Test zones (m)	Depth (m)	Sp value (mv)	R_o=r_t (Ωm)	R_{mf}/r_w Versus static sp	R_{mf} (Ωm)	R_w (Ωm)
1 (Figure 3)	A	105 -120	-15	1300	1.4	16.0	11.4
	B	125 -140	-8.0	2000	1.1	16.0	14.5
2 (Figure 4)	A	80 - 100	-6	1200	1.0	16.0	16
	B	100 -120	-3	1500	1.0	16.0	16

Table 2. Summary of the computation of porosity, permeability, electrical conductivity and total dissolved solid.

Well	Test zones (m)	Depth (m)	Porosity Φ (%)	Permeability *K* (mD)	EC (µmhoscm^{-1})	TDS (ppm)
1 (Figure 3)	A	105 - 120	20.6	49	877	561
	B	125 - 140	19.3	34	869.5	556.5
2 (Figure 4)	A	80 - 100	23.7	108	625	400
	B	100 - 120	22	71	625	400

groundwater well system in Ubima Community.

The TDS observed for the test zones in both wells are all within acceptable World Health Organization palatability for drinking water.

CONFLICT OF INTERESTS

The author has not declared any conflict of interests.

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