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Aquifer delineation in parts of Akwa-Ibom State, Southern Nigeria using Resistivity Survey

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Abstract

In line with Sustainable Development Goals (SDG 6.6), aquifer delineation in parts of Akwa-Ibom State, Southern Nigeria was carried out using resistivity survey. The areas covered in the study included Uyo, Itu and Ibiono Ibom. Electrical resistivity technique was applied to obtain data from the subsurface layers. The study utilized a Signal Averaging System (SAS) 1000 Terrameter, four stainless steel electrodes, four reels of cable, geologic hammer, a measuring tape and a Global Positioning System (GPS). A SAS 1000 Terrameter was used in measuring the resistivity of the materials within the subsurface. Electric current was transmitted into the ground from the Terrameter using current electrodes while the potential difference between the current electrodes was measured. A total of four (4) stainless steel electrodes were used: two (2) current electrodes which transmitted electric current into the ground and two (2) potential electrodes from which the potential difference was measured between the current electrodes. Four reels of cable were used to link the electrodes and the Terrameter. The cable served as conductor of electric current into the ground. A total of four geologic hammers were used in sending the electrodes into the ground and in making them to be firmly fixed. A 100-m measuring tape was used to determine the intervals between the current electrode and potential electrode. A total of nine (9) ERT data points were obtained, processed and interpreted. The data obtained from the field were processed and also interpreted from curve matching techniques together with computer-aided software called Interplex 1-D. Deeper aquifers free from surface contamination and suitable for groundwater development are encountered at depth ranges of 90 m to 120 m, 70 m to 130 m, 80m to 160m and 70 m at Uyo, Itu, Ibiono Ibom and Ibesikpo respectively. The depths to aquifer, thicknesses and resistivity values were 1.086-445m, 1.086-248m and 0.114-8,132 Ωm, and 1.45-378m, 1.45-348m and 203-5,229Ωm, and 1.345-863.8m, 1.345-422.5m and 202.5-445.3Ωm, and 1.464-66.61m, 1.464-41.99m and 90.85-695.4Ωm in Uyo, Itu, Ibiono Ibom and Ibesikpo Asutan respectively. Borehole drilling within the locations where survey was carried out should target the depths of the delineated aquifers is recommended.

Keywords: Aquifer Delineation; 2-D Model; Subsurface Layer; Resistivity Values; Aquifer Depth and Thickness

1. Introduction

Water is an indispensable natural resource and life will cease to exist without it. It seems to be the most defining factor for life, its quality and existence. According to Okere *et al.,* (2021), the survival of man and other living things has been hinged on this importance resource. Udom *et al.,* (2018) posited that good quality drinking water remains a necessity for life. To ensure that people have access to clean, potable drinking water, Goal 6 of the Sustainable Development Goals (SDGs) focuses on access to clean water (UN, 2018). Groundwater is water stored, preserved and locked-up beneath the earth's surface and it constitutes over one-third of the water used either for domestic, agricultural or industrial purposes (Wu *et al.,* 2020). As one of the most refined forms of potable water that is available in nature, groundwater is useful for domestic use and other purposes. Many cities and towns in Nigeria make use of groundwater for domestic, industrial and agricultural purposes (Udom *et al.,* 2018). It seems that many people in the developing countries of the

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world have shown preference to groundwater as a reliable source of drinking water owing to its high quality and less vulnerability to pollution compared to surface water.

Water-yielding bodies or rocks are referred to as aquifers. These are saturated permeable geologic units that can transmit significant quantities of water under ordinary hydraulic gradients. Identifying the depth to these geologic units alongside the determination of their thicknesses helps in drilling productive and effective boreholes as well as efficient groundwater management. This can be done by delineating through geophysical survey a suitable zone with large thickness and situated at depth that is free or less vulnerable to surface contamination. In most parts of Akwa Ibom State, it is very common to see unproductive boreholes and wells which could be attributed to unavailability of hydrogeological data or failure to utilize existing data for drilling boreholes. Such factors once caused a high rate of failed boreholes quantified to be about 70% of boreholes sunk within Akwa-Ibom State (Udom *et al.,* 1999). Unavailability of non-consideration of existing hydrogeological data regarding the depth to aquifer could lead to diminishing yield or drying up of boreholes and drilling of unproductive wells (Beka *et al.,* 2015).

Due to incessant oil spills which have led to the pollution of surface water in the Niger Delta region of Nigeria and rendering the abundant surface water unsafe and unfit for consumption, increasing pressure has been seen in the use of and dependency on groundwater as the available source of potable water within the area (Okonkwo *et al.,* 2021; Akantali *et al.,* 2022). According to Udom *et al.,* (2018), Niger Delta region of Nigeria is a sensitive ecological area where the overexploitation of its groundwater has adverse effect. There is need for aquifer delineation especially in locations that are prone to groundwater pollution. This is in line with SDGs 6.6 which is concerned with the protection of aquifers. This shall be useful in groundwater management. Although aquifer delineation has been carried out in regional level using borehole data (Udom 2004; Udom *et al.,* 2018), there is need to apply resistivity survey method to delineate aquifer at local level.

1.1. Study Area

This study was carried out within Uyo, Itu, Ibiono Ibom and Ibesikpo Asutan Local Government Areas in Akwa-Ibom State (Figure 1). Uyo main town and its adjoining areas are generally low-lying plains having ground elevations generally being below 66m above mean sea level (Akpokodje, 1989). Akwa-Ibom State as a whole has a total land-mass of 6,900 km^2 and is drained by three major rivers namely the Cross River, the Imo River and the Qua Iboe River to the east, south west and south central part respectively.

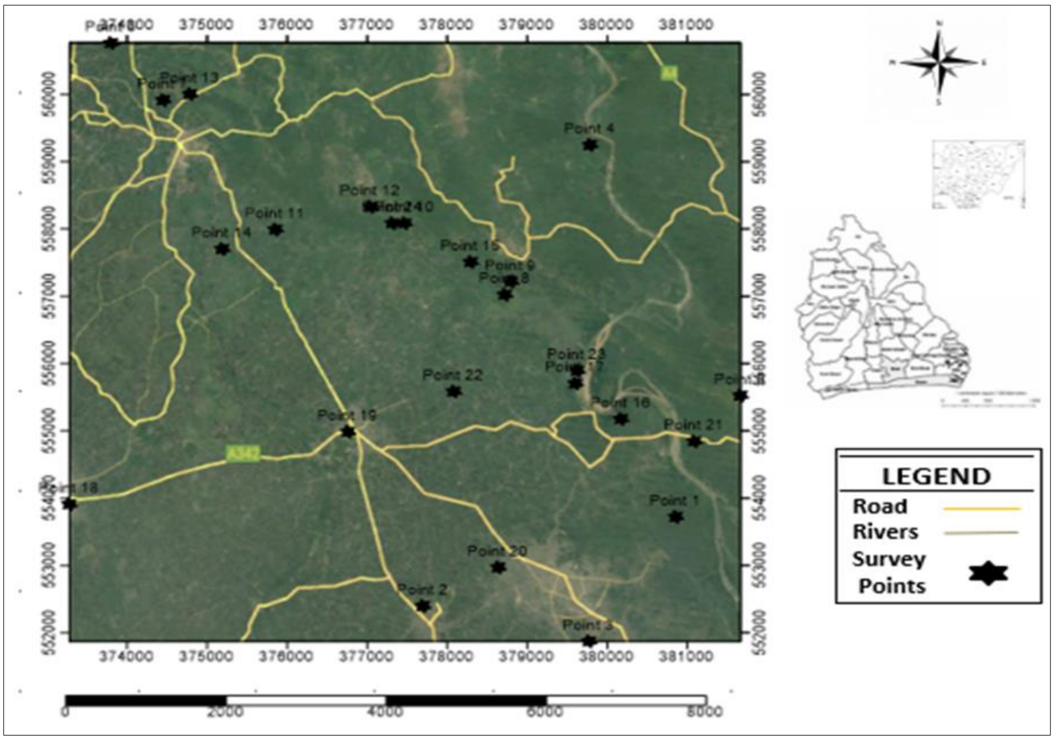

Figure 1 Location Map of the Study Area

Akwa-Ibom State is situated within the Eastern Niger Delta. Along the estuaries and coasts, mangrove swamps are well developed (Wilcox, 1955). Rain falls almost in all the months of the year with mean annual rainfall ranging from 3000 mm in the inland cities to 4000 mm in the coastal areas. The Niger Delta has a tropical monsoon climate with two seasons: the dry season which starts from November and ends in January and the wet season which starts in February and ends in October. A break in rainfall amount commonly referred to as "August break" occurs around August.

The Niger Delta has the monthly mean temperature ranges between 25 °C and 29 °C and mean annual rainfall ranging from 2000 mm (inland) to over 4000 mm at the coast, and about 85 % of this occurs in the wet season. The high humidity (which decreases slightly in the dry season) alongside the long-wet season of about 6-10 months ensure adequate supply of water and moisture which promote the growth of perennial trees and shrubs (Abam & Nwankwoala, 2020). The water table depths in the area increase seawards, varying from about 5 m (inland) to 0.5 m at the coast. The high-water table in the Delta resulting from the high rainfall, swampy and flat topography of the area accounts for the high-water content of soil in the region.

1.2. Hydrogeology of the Area

Hydrogeological studies have been carried out in the Niger Delta. For instance, Etu-Efeotor & Odigi (1983) and Etu-Efeotor & Akpokodje (1990) found that there are several irregular, lenticular and laterally discontinuous layers of clay aquitards which in most areas partially sub-divided the regular aquifers into units. The depths to water table in Akwa-Ibom State decrease in seaward direction (varying from inland to the coast).

The main aquifer system within the Niger Delta of Nigeria is the Benin Formation with sands and sandstones constituting about 90 % of the lithology (Offodile, 2002). The freshwater aquifer dominant in the formation consists of sands with clayey and silty materials which are believed to have been deposited within the mixed environment of continental fluviatile to deltaic environment of deposition (Amajor, 1989). Although the clay unit varies in thickness from 1 m to 15 m, the intercalations of sands and clays gave the Niger Delta its characteristic multi-layer system of aquifer (Etu-Efeotor and Odigi 1983; Amajor, 1989). The Niger Delta region has numerous perched aquifers besides unconfined and confined aquifers. Although Etu-Efeotor & Odigi (1983) subdivided the Niger Delta into three main hydrologic zones namely coastal zone of deep aquifer consisting of sand beaches, transition zone of marine and continental deposits, and northern zone of shallow aquifer (which consists of continental deposits in aquifers of about 60 m deep), Etu-Efeotor (2009) mapped out three (3) major aquiferous zones within the Niger Delta grouped into the lower, middle and upper water-bearing zones.

2. Material and methods

2.1. Field Instrumentation and Data Processing

A Signal Averaging System (SAS) 1000 Terrameter, four (4) stainless steel electrodes, four (4) reels of cable, geologic hammer, a measuring tape and a Global Positioning System (GPS) were used for the geophysical survey. A SAS 1000 Terrameter was used in measuring the resistivity of the materials within the subsurface. A total of four (4) stainless steel electrodes were used: two (2) current electrodes which transmitted electric current into the ground and two (2) potential electrodes from which the potential difference was measured between the current electrodes. Four reels of cable were used to link the electrodes and the Terrameter. The cable served as conductor of electric current into the ground. A total of four geologic hammers were used in sending the electrodes into the ground and in making them to be firmly fixed. A 100-m measuring tape was used to determine the intervals between the current electrode and potential electrode.

Electrical resistivity technique was applied to obtain data from the subsurface layers. Both Schlumberger and Wenner configurations were employed to determine vertical and horizontal differences in the subsurface resistivity. In the former, the two sets of electrodes (current and potential electrodes) have a common midpoint and were aligned symmetrically along a straight line. Current electrodes were positioned outside while potential electrodes were positioned inside. In order to change the depth range of the electrodes, the current electrodes were displaced outside while the potential electrodes remained stationary. In Wenner configuration (Plate 3.1), the four electrodes were equally spaced out. This helped in separating the different layers of the subsurface according to their resistivity values in a vertical pattern from the sounding point. The depth of penetration was increased by increasing the common distance of separation between the electrodes and maintaining the location of the centre of the configuration.

The data obtained from the field were processed and also interpreted from curve matching techniques together with computer-aided software called Interplex 1-D. From the interpretation of data, the resistivity values at different soil layers were obtained alongside their corresponding depths and thicknesses. The apparent resistivity values described as a function of the spacing between the electrodes were then changed to true resistivity values using computer-aided software to provide the sounding curves.

Figure 2 Instrumentation and Data Acquisition

3. Results and Discussions

3.1. Aquifer Delineation, Aquifer Depth and Thickness

The study delineated aquifers at different depths with different thicknesses across the study area. The minimum and maximum values of aquifer depth, thickness and resistivity are presented in Table 2. The values of depth to aquifer varied significantly from place to place. The values at Uyo, Itu, Ibiono Ibom and Ibesikpo Asutan varied between 1.086 m and 445 m, 1.45 m and 378 m, 1.345 m and 863.8 m, and, 1.464 m and 66.61 m respectively. The values of aquifer thickness for Uyo, Itu, Ibiono Ibom and Ibesikpo Asutan ranged from 1.086m to 248 m, 1.45 m to 348 m, 1.345 m to 422.5m and 1.464 m to 41.99 m respectively. The resistivity values of subsurface layers ranged from 0.114 Ωm to 8,132 Ωm, 203 Ωm to 5,229 Ωm, 202.5 Ωm to 445.3 Ωm and 90.85 Ωm to 695.4 Ωm in Uyo, Itu, Ibiono Ibom and Ibesikpo Asutan respectively. The resistivity data revealed four different layers of the subsurface including clay, fine sand, sand (aquifer unit) and silty clay. The lithologies delineated in this study are the same with the lithologies reported by Beka *et al.,* (2014) and Laouini *et al.,* (2017) who delineated aquifers in parts of Akwa Ibom State. These independent researchers showed sands and clays are major subsurface layers with the sand serving as aquifer unit. Different aquiferous formations were delineated at varying depths across the study area. Deeper aquifers free from surface contamination and suitable for groundwater development are encountered at depth ranges of 90 m to 120 m, 70 m to 130 m, 80m to 160m and 70 m at Uyo, Itu, Ibiono Ibom and Ibesikpo respectively. According to Beka *et al.,* (2014), second aquifer units (by depth) were delineated at depth range of 30m to 138m while the third or deeper aquifers are encountered in depth beyond 138m.

Table 2 Minimum (Min) and Maximum (Max) Values of Aquifer Properties

Locality		Depth to Aquifer (m)	Aquifer Thickness (m)	Resistivity Values (Ωm)	Deeper Aquifers (m)
Uyo	Min	1.086	1.086	0.114	90
	Max	445	248	8,132	120
Itu	Min	1.45	1.45	203	70
	Max	378	348	5,229	130
Ibiono	Min	1.345	1.345	202.5	80
	Max	863.8	422.5	445.3	160
Ibesikpo	Min	1.464	1.464	90.85	70
	Max	66.61	41.99	695.4	

3.2. Interpretation of 2-D Contour Map

At a site along Clement Isong Avenue behind St. Patrick Primary School Iboko Offot, Uyo, there is presence of an aquifer at the depth of 90m with a narrow contour closure and a horizontal spread and broad contour occurring at the depth of 10-20m (Figure 3). The blue colouration is a sand layer with a resistive fluid and it depicts the aquifer zone. Aquifers were delineated at depth ranges of 90m to 160m with a horizontal spread at 10-20m (Figure 5). The red colouration visible in the map at depth range of 20-60m marks out a clay layer with conductive fluids. This is an indication of contaminant plumes. The aquifer can be easily contaminated because of the migration of contaminant plumes in both downward and lateral direction. Within the Discovery Park, Udo Umana Street, Uyo, there are zones with blue colouration consisting of an aquifer formation with highly resistive fluids. The black circle depicts prospect zones at a depth of 120m-170m (Figure 3). This is the best depth to drill a borehole and it should be within the horizontal spread of 30m-40m. Although there a zone with blue colouration at 0- 40m (top soil), it indicates the presence of rainwater.

In a mechanic workshop opposite Federal Science and Technical College, Ukana Offot Street, Uyo, the subsurface layers have different intensities of resistivity. The blue colourations on the map which are suggestive of sand layers indicate the presence of resistive fluids found at the subsurface of the earth. There is an indication of percolation of run-off water within the top soil. The aquifer depth is at depth 120m and 180m with a horizontal spread of 10-20m (Figure 4). At this depth, the resistivity is high with a broader spreading and thereby the level of contamination is minimal. Also, at a mechanic workshop beside Arm of the Lord Church, No. 5, Library Avenue, Uyo, the presence of aquifer was observed at the depth range of 70-130m (Figure 4).

At a site opposite the United Evangelical Church, off Udo Udom Avenue, Uyo, there is silty clay layer and sandy layer (aquifer unit). The best zone to drill a borehole is within the depth range of 70m-130m and horizontal spread of 50m-60m (Figure 5). The zone is highly resistive and as a result might contain good quality of groundwater. At the Mechanic Village Uyo, aquifer was delineated at different depths of the subsurface which ranged from 60m, 90m and 160m (Figure 4).

Aquifer delineation was carried out at two sites within Itu namely Government Primary School, Afara Ube, Itam and by the wall of Qua Ibo Church. At the former, aquiferous sand unit was delineated at depth range of 40-70m (Figure 6). The blue colours show resistive fluids and are the perfect zones for borehole drilling. At the latter site (Qua Ibo Church), the best zone (or the best blue coloured zone) to drill a borehole is within the aquifer depth of 130m-158m and with a horizontal spread of 20m-40m. This aquifer has the highest resistivity according to the blue colouration. At a site along Adak Ukana Road, Ikot Ada Idem, in Ibiono L.G.A., aquifer was delineated at the depths of 80m, 120m and 160m respectively with the last depth having a horizontal spread of 40-50m (Figure 7).

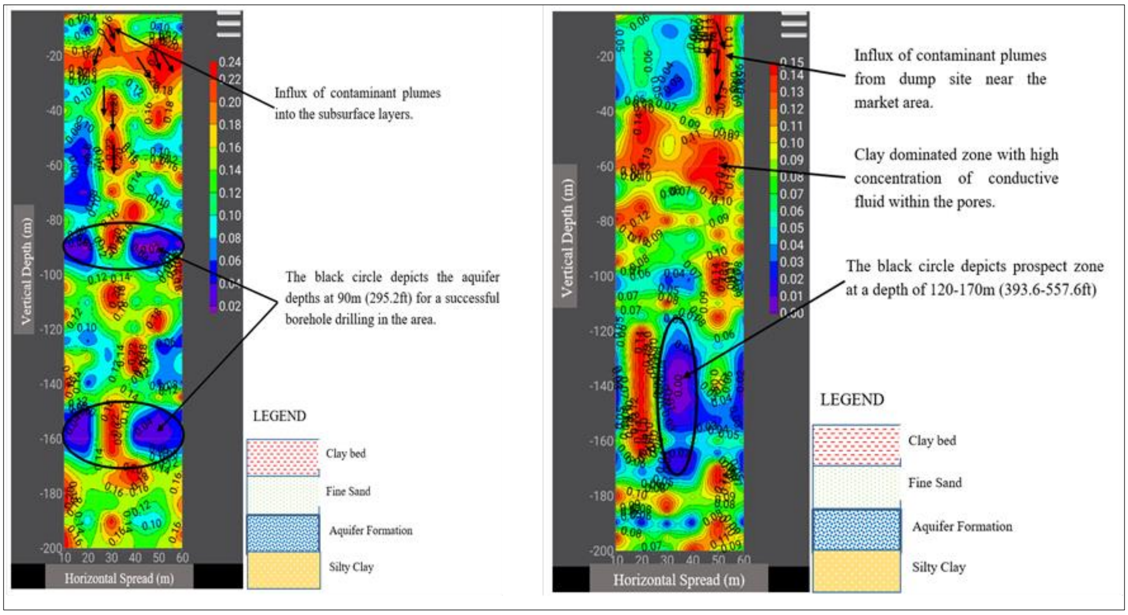

Figure 3 A 2-D contour map of Uyo (Left = Clement Isong Avenue behind St. Patrick Primary School Iboko, Right = Discovery Park)

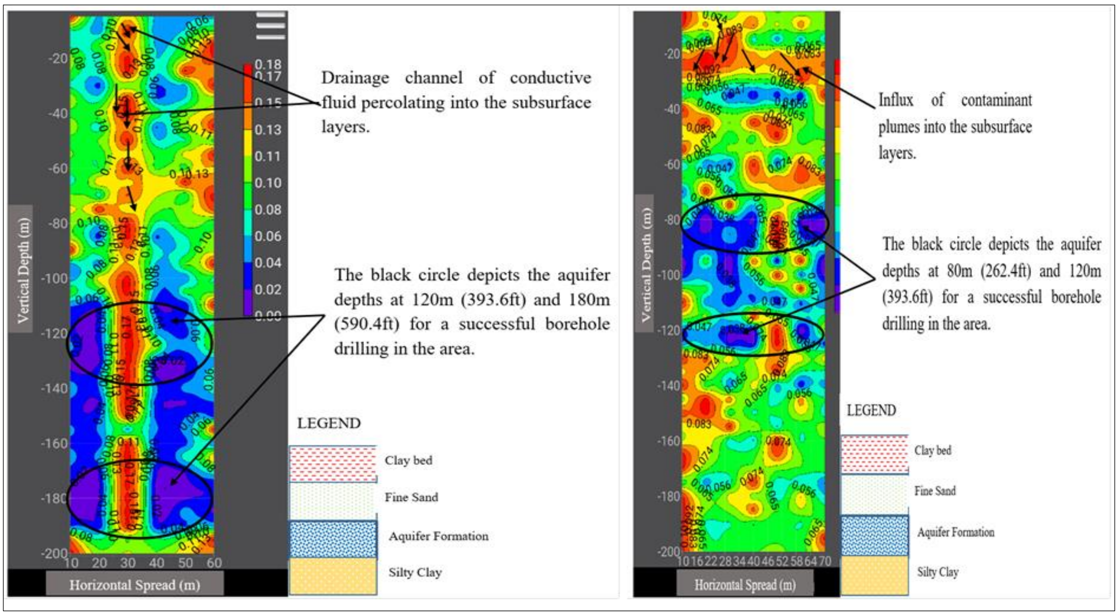

Figure 4 A 2-D Contour Map of Uyo (Left = Mechanic Workshop Opposite Federal Science and Technical College, Ukana Offot Street, Right = Arm of the Lord Church, No. 5, Library Avenue)

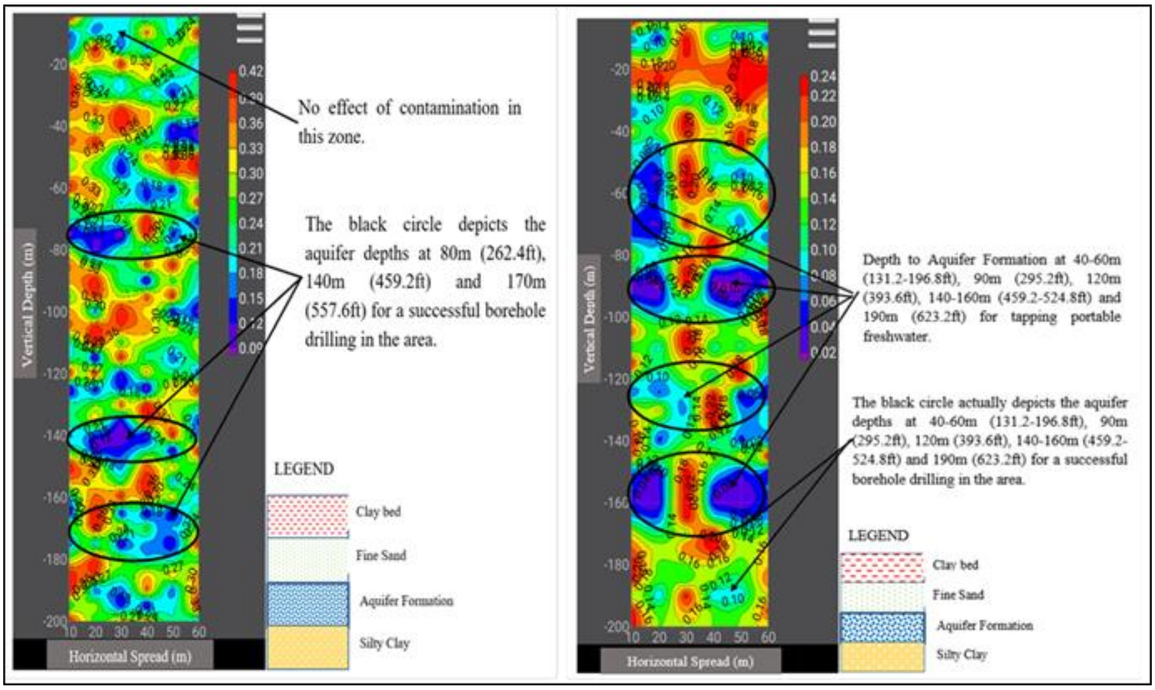

Figure 5 A 2-D Contour Map of Uyo (Left = United Evangelical Church, Off Udo Udom Avenue, Right = Mechanic Village)

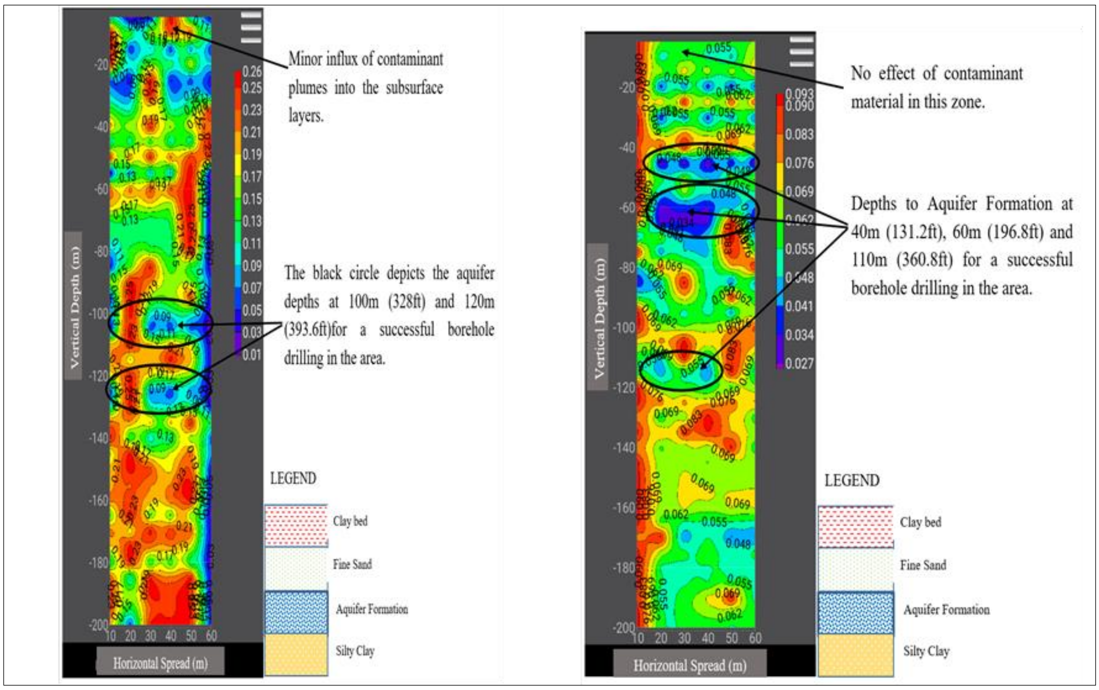

Figure 6 A 2-D Contour Map of Itu (Left = Government Primary School, Afara Ube, Itam, Right = Qua Ibo Church)

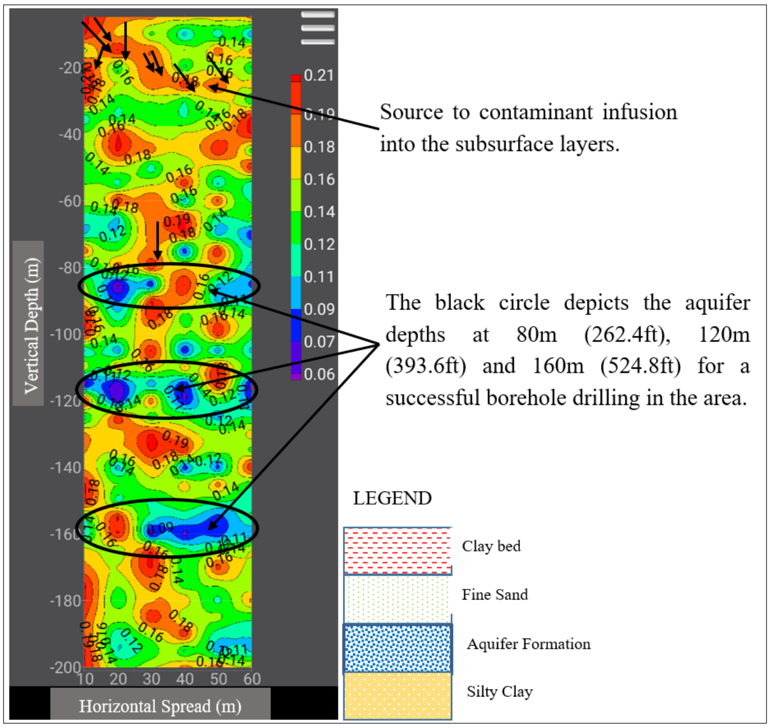

Figure 7 A 2-D contour map of Adak Ukana Road, Ikot Ada Idem Ibiono LGA

4. Conclusions

Deeper aquifers free from surface contamination and suitable for groundwater development are encountered at depth ranges of 90 m to 120 m, 70 m to 130 m, 80m to 160m and 70 m at Uyo, Itu, Ibiono Ibom and Ibesikpo respectively. The depths to aquifer, thicknesses and resistivity values were 1.086-445m, 1.086-248m and 0.114-8,132 Ωm, and 1.45-378m, 1.45-348m and 203-5,229Ωm, and 1.345-863.8m, 1.345-422.5m and 202.5-445.3Ωm, and 1.464-66.61m, 1.464-41.99m and 90.85-695.4Ωm in Uyo, Itu, Ibiono Ibom and Ibesikpo Asutan respectively.

Recommendations

The study recommends that borehole drilling within the locations where survey was carried out should target the depths of the delineated aquifers.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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