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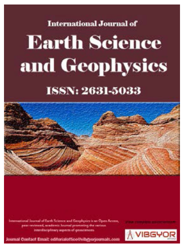
Delineation of Candidate Aquifers for Proper Borehole Screen Placements in Multi Aquifer Systems of Coastal Areas of the Niger Delta, Nigeria



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Abstract

Placement of screen pipes for boreholes drilled within the mainland and coastal plain sand areas of the Niger Delta is done with the greatest of ease. This is not usually the case for some aquifers of the coastal areas of the Niger Delta especially those of the saltwater swamps and coastal beaches and ridges geomorphic zones with multiple aquifer units of differing characteristics. Sixty-two (62) resistivity and gamma-ray logs of water wells in the area were acquired using Mount Sopris Instrument, Mgx II Logger automated geophysical logging instrument. Eighteen (18) of these wells drilled within the Salt Water Swamps and Coastal Beaches/Ridges geomorphological zones of the Niger Delta region encountered saline water/iron-contaminated aquifers at different horizons. The WellCAD interactive PC-based software package was used in the log data analysis. The area consists of multiple aquifer systems with three categories of aquifers delineated as Deep (410-600 m), Medium (135-409 m) and Shallow (5-134 m) aquifers. Based on the amount of Gamma Count, the aquifer systems are classified as Very Low Gamma Count (Highly Sandy), Low Gamma Count (Sandy) and Medium Gamma Count (Slightly Clayey) aquifers. On porosity of aquifer media, they are classified as high (> 65%), medium (36-65%), low (21-36%) and very low (< 21%) porosities. On aquifer resistivity values they are classified as Very Low Resistivity (Saline Water), Low Resistivity (High Ferrous Contamination), Medium Resistivity (Low Ferrous Contamination) and High Resistivity (Fresh Water with no Saline or Ferrous Contamination) aquifers. The saline-fresh water boundary was observed to be shallow within the Tunu flow station of Bayelsa State; NLNG Amadi Creek and Amadi Creek 2 of Rivers State; Erunallaje, Akpata Ijaw, Ayetoro and Adoloseimo areas of Ondo State. Deep saline-fresh water boundary occurs around Bonny, Fanima, Bille, Idama, Kula and Asaramatoru areas of Rivers State; Jinrinwo and Abealala Ilaje area of Ondo State as Well as Ogidigben area of Delta State. The saline water and iron contaminated horizons must be adequately blinded, the screen to be placed at the recommended depth and the right capacity submersible pump installed to enable effective production of fresh water from boreholes drilled within these localities.

Keywords

Borehole, Candidate aquifer, Multi aquifer, Saline water, Screen, WellCAD, Gamma counts, Resistivity

Introduction

The United Nations Children's Fund (UNICEF) has declared that about 43% amounting to about sixty-nine (69) million Nigerians lack access to potable water and a further nineteen (19) million Nigerians have to seek water from far distances from their

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places of domicile [1]. The peculiar nature of the coastal areas of the Niger Delta Nigeria rose sequel to the fact that they are crisscrossed by rivers and saltwater creeks. The groundwater is seriously contaminated by the presence of saline water and ferrous iron. Many of the water boreholes drilled in the coastal areas of the Niger Delta do provide the people with potable water. Most of the wells produce water that does not meet the [2] standard for potable water. Very little has been done in terms of detailed hydrogeophysical studies in coastal areas of the Niger Delta to properly characterize the underground water aquifers available in the area. As noted by [3], groundwater developments in several parts of the Niger Delta have been done randomly with little or no regard to water quality and aquifer yields. The only source of water supply for all purposes in the Niger Delta is groundwater and its demand has increased with the increase in population, improved standard of living and expansion and growth of the oil and gas industry ([4-7]). Although [3] and [8] identified saltwater intrusion in aquifers in the Niger Delta as a major problem, they did not identify the aquifers on a regional scale that are contaminated and the ones that are free from contamination and therefore contain potable water. Water supply in the Coastal areas of the Niger Delta is almost getting to a crisis point as access to potable water is diminishing very fast. The plausible approach to addressing the water supply issues in the area is to carry out detailed regional studies of the aquifer systems in a view to properly characterizing the aquifers and to determine aquifers with little or no contaminations to improve the groundwater supply needs of the people of the area. Over the years, the right placement of borehole screens to tap only fresh water from the best candidate aquifer within the coastal regions of the Niger Delta has been a herculean task. Hence, this research.

Location and geology of the study area

The study area falls within the Niger Delta, Nigeria. It lies between Latitude 4°23’N and 6°30'N and Longitudes 4°30’E and 8°31‘E. It comprises the Coastal areas of the Eastern and Western Niger Delta. The area was accessed by sea and land travelling through the creeks of the Niger Delta. Figure 1 shows the location map of the study area indicating the area extent of the study. The Niger Delta is predominantly low-lying. Most of the areas are almost at sea level or a maximum of 6 meters above sea level [9-11] adopted 3 geomorphic classifications for the Niger Delta viz: The Niger flood plain (foundation zone), the Vegetated tidal flat (Mangrove zone) and the Barrier Islands (Coastal zone). Many researchers and authors have explained the genesis and development of the Niger delta basin as well as their structural and stratigraphic frameworks. These include [11-17] described the thick succession of sediments in the Niger Delta as consisting of three lithostratigraphic units, namely: Akata, Agbada and Benin Formations. The thickness of the Quarternary deposits ranges between 40 m and 150 m [3] (Figure 2).

Materials and Methods

Gamma-ray and Electric logs as well as lithologic samples were acquired from nineteen (19) water wells, which encountered saline water aquifers at different horizons, drilled within the Salt Water Swamps and Coastal Beaches/Ridges geomorphological zones of the Niger Delta region and dutifully interpreted. These cover locations around Rivers, Bayelsa, Delta and Ondo States. Mount Sopris Instrument, Mgx II Logger which is a fully automated geophysical well logging instrument was used in the data acquisition. WellCAD software package was used in the log data analysis. Stratalogs were collected at 3m intervals from the drilled wells and were compared with the results of the gamma log to give an accurate subsurface soil stratification of the study area. The static water level in the wells was measured in some completed wells using an automated water level meter.

Results and Discussion

Borehole depths

The 2D plot of borehole depth is shown in Figure 3. The Total Drill Depth (TDD) of Boreholes within the study area ranges from 80 to 600 m. The deepest boreholes were encountered around the Ogidigben area of Delta State, the Bille area, Bonny and Finima areas of Rivers State. Depths to the different aquifer units mapped were plotted on a 2-D map. Three categories of aquifers were delineated as Deep, Medium and Shallow aquifers. Each of the aquifers was considered separately and depths to their tops and bottom were also plotted. The plot of the depth to the top of the deep aquifers within the study area is shown in Figure 4. Here it was observed that the deepest aquifer

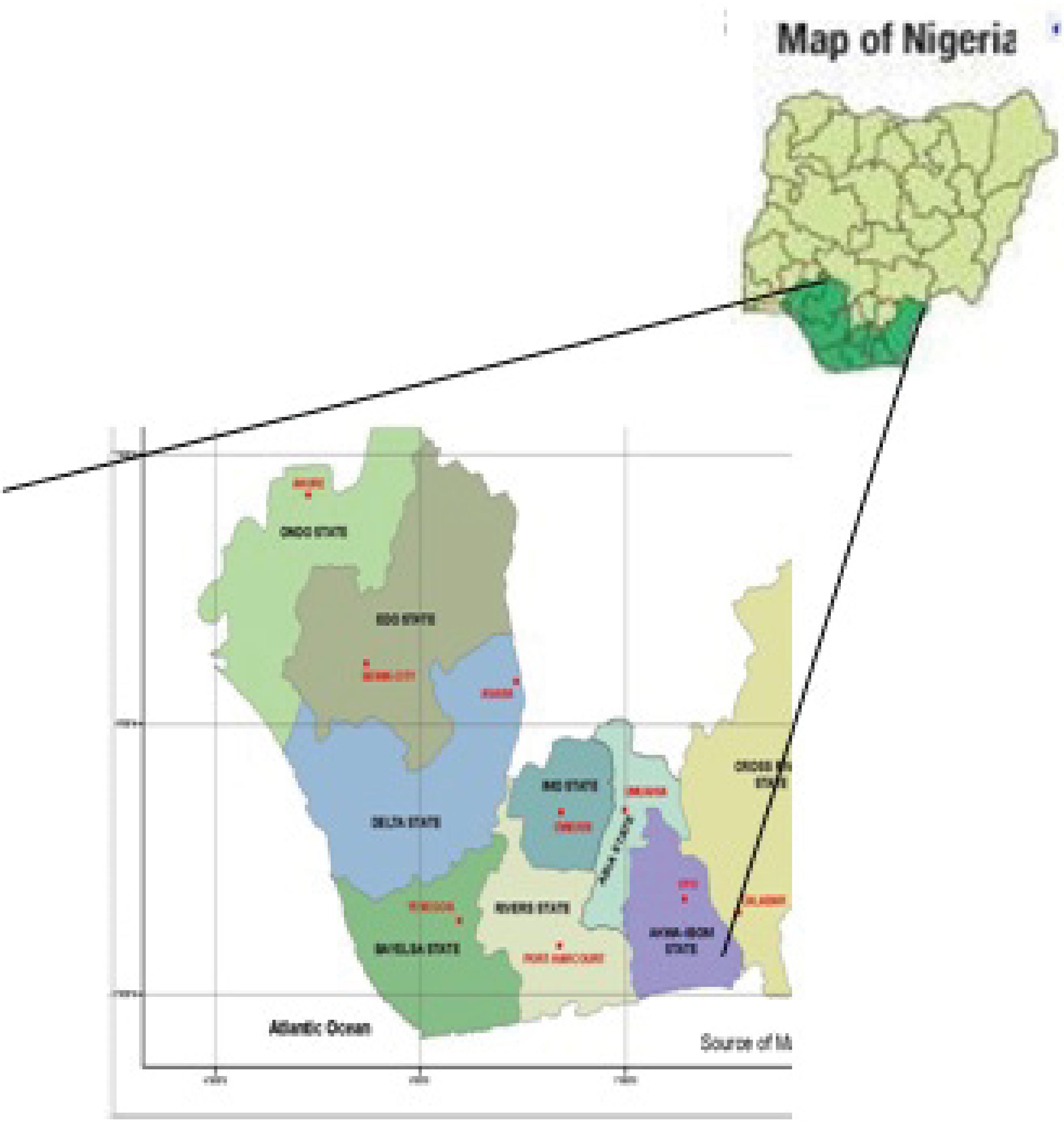

Figure 1: Location map of the study area.

within the study area was delineated around the western part of the area with a depth exceeding 410 m. Similarly, the same location recorded the highest depth to the bottom of the aquifer mapped in the area as the base of the aquifer was observed to occur far beneath 580 m (Figure 5). An average deep aquifer thickness of more than 150 m (Figure 6) was recorded in the study area.

The plot of the depth to the top of the medium aquifers in the area is shown in Figure 7. The highest depth to the top of the medium aquifers occurred within the Northwestern part of the study area with values greater than 165m corresponding to locations within Erunallaje area of Ondo State. The depth to bottom of medium aquifer in the area ranges from 135 to above 260 m with the deepest located within Okpai area of Delta State and the QIT Ibeno location of AkwaIbom State (Figure 8). The average medium aquifer thickness in the study area ranges from 1 m to more than 190 m with the Owaza area of Abia State recording the thickest medium aquifer in the study area (Figure 9). Figure

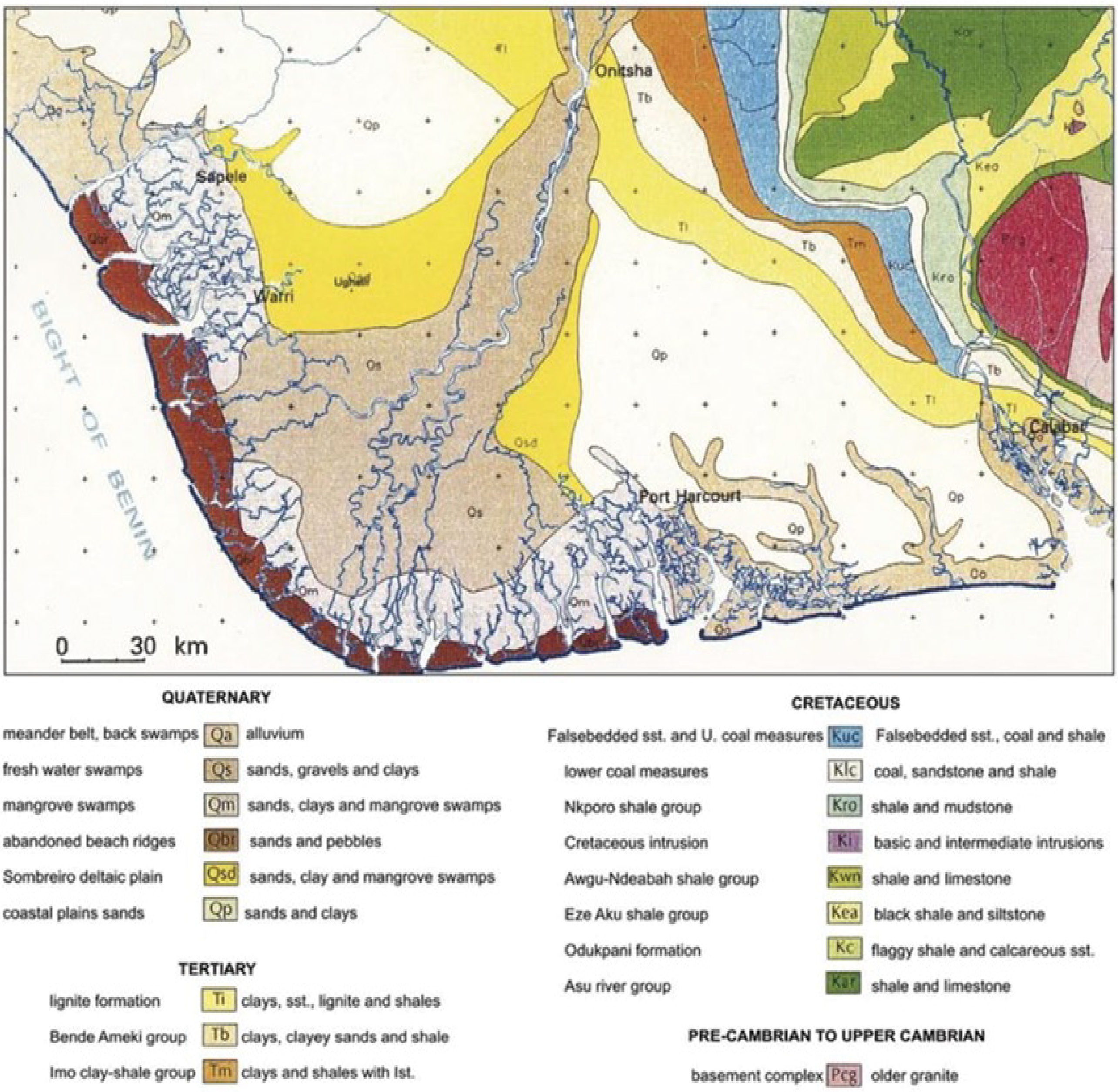

Figure 2: Geologic map of the study area.

10 shows the plot of the depth to the top of the shallow aquifer units encountered in the study area with a range between 5 to 100 m. The shallowest top of 5 to 10 m was observed as pockets of closures within the central and southern fringes of the study area. These areas corresponded to the Kwale area of Delta State; Oguede Bonny, Ndoni Rivers and Agbada Flow station areas of Rivers State, Otakeme and Brass areas of Bayelsa State, as well as Owaza well 4 location in Abia State (Figure 10). The depth to the bottom of the shallow aquifer in the area ranges from 25 to over 125 m within the Northern fringe of the area corresponding to the zone occupied by the coastal plain sands (Benin Formation) showing the deepest shallow aquifers greater than 125 m (Figure 11). Pockets of the very shallow aquifer were seen disseminated around the Okapi IPP area of Delta state, within Bille and Eagle Island locations of Rivers State. The average thickness of the shallow aquifers in the area ranges from 5 to over 105 m within the Okpai IPP location showing the thickest (Figure 12).

Resistivity profile of the aquifers in the study area

To establish the subsurface resistivity profile of the aquifers of the area as inferred from the open-hole geophysical logging, the resistivity values of

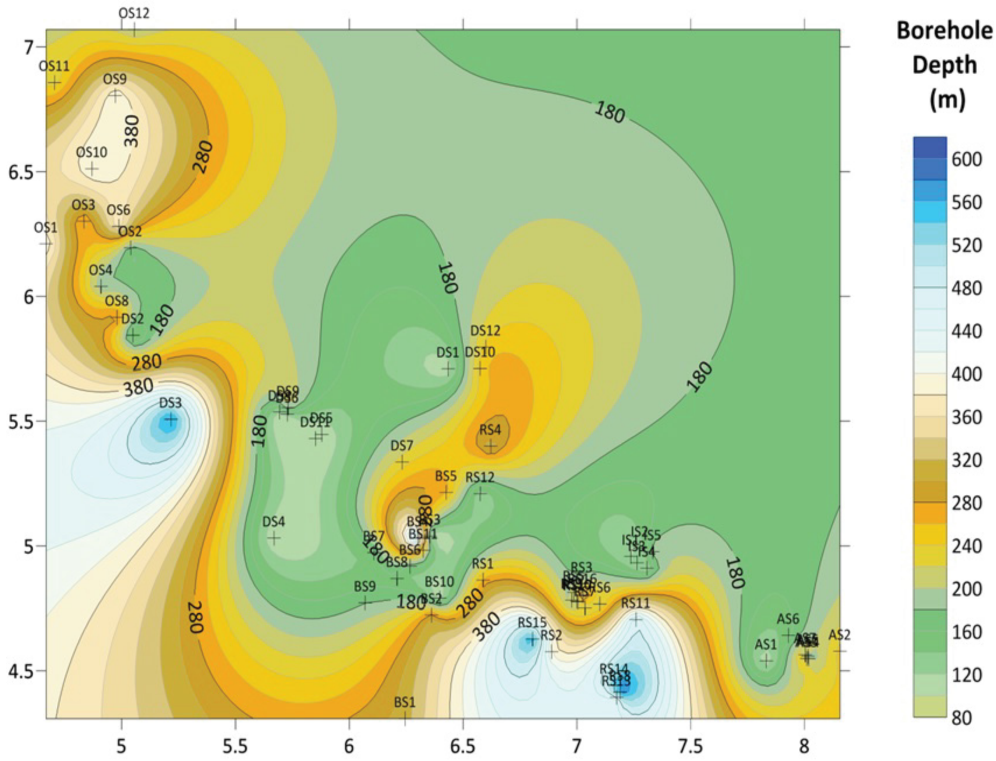

Figure 3: Plot of borehole depths in the area.

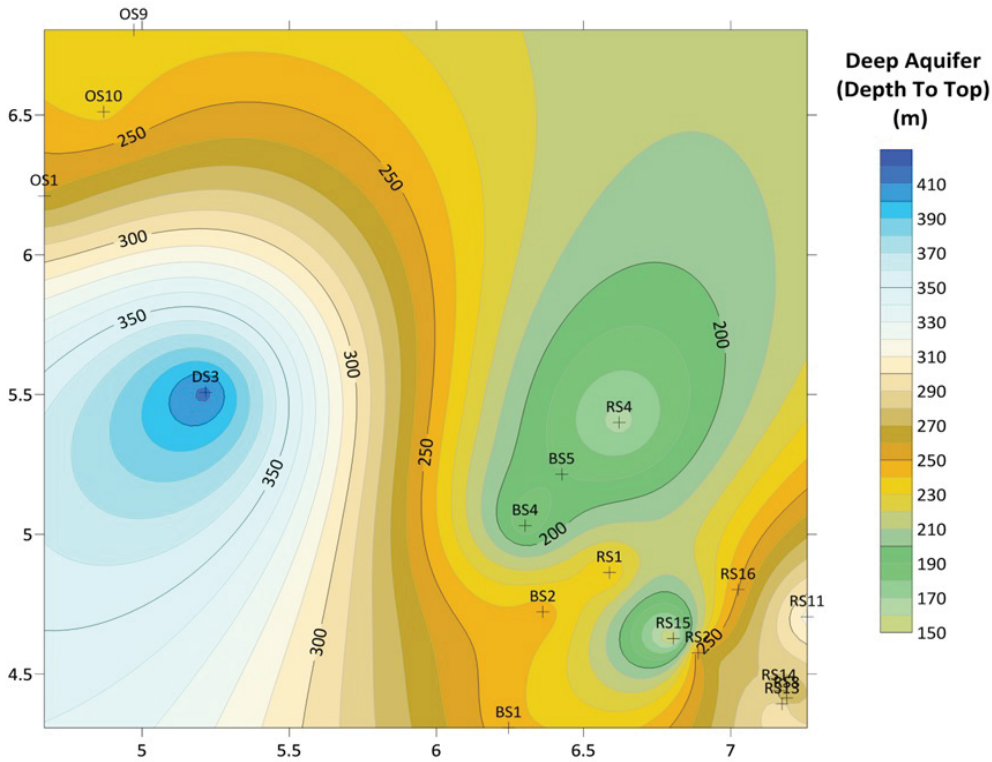

Figure 4: Depth to top of deep aquifers.

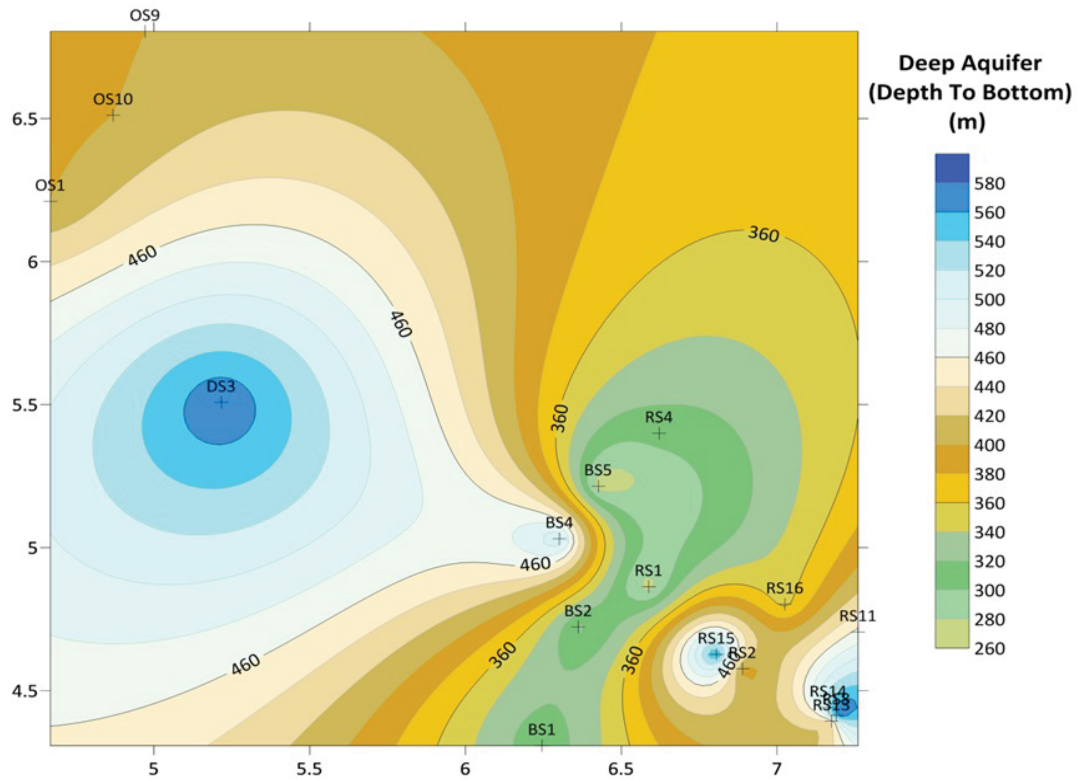

Figure 5: Depth to bottom of deep aquifers.

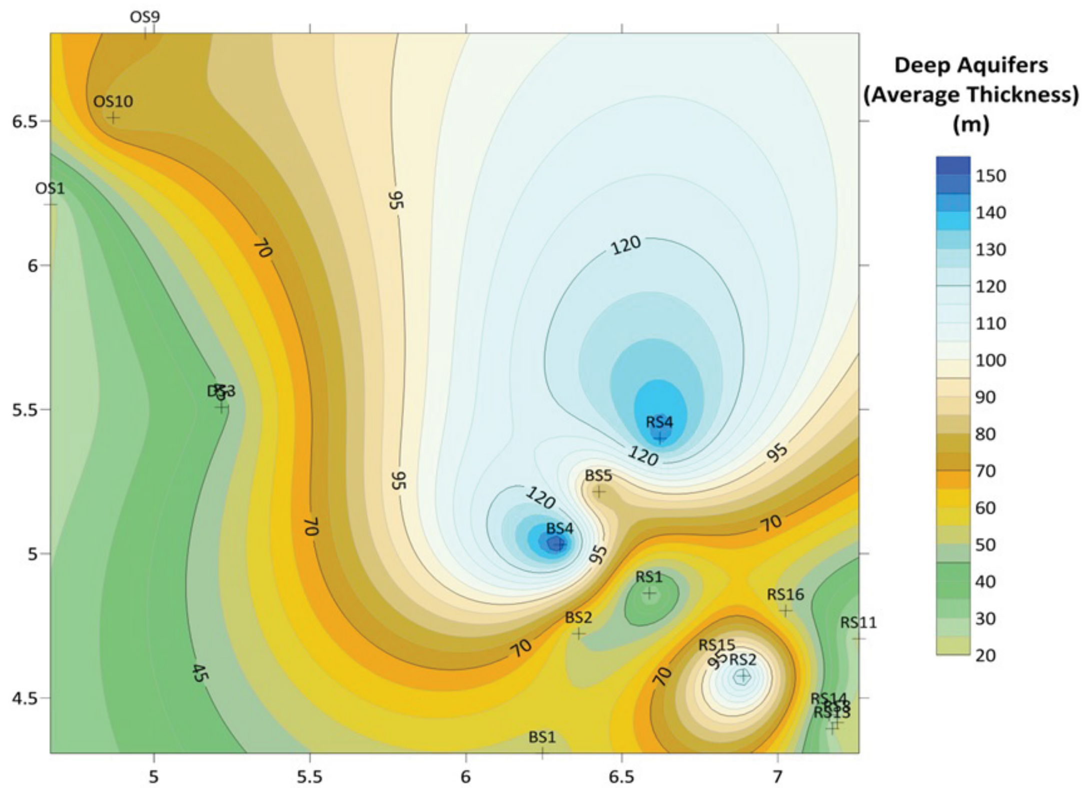

Figure 6: Average thickness of deep aquifers.

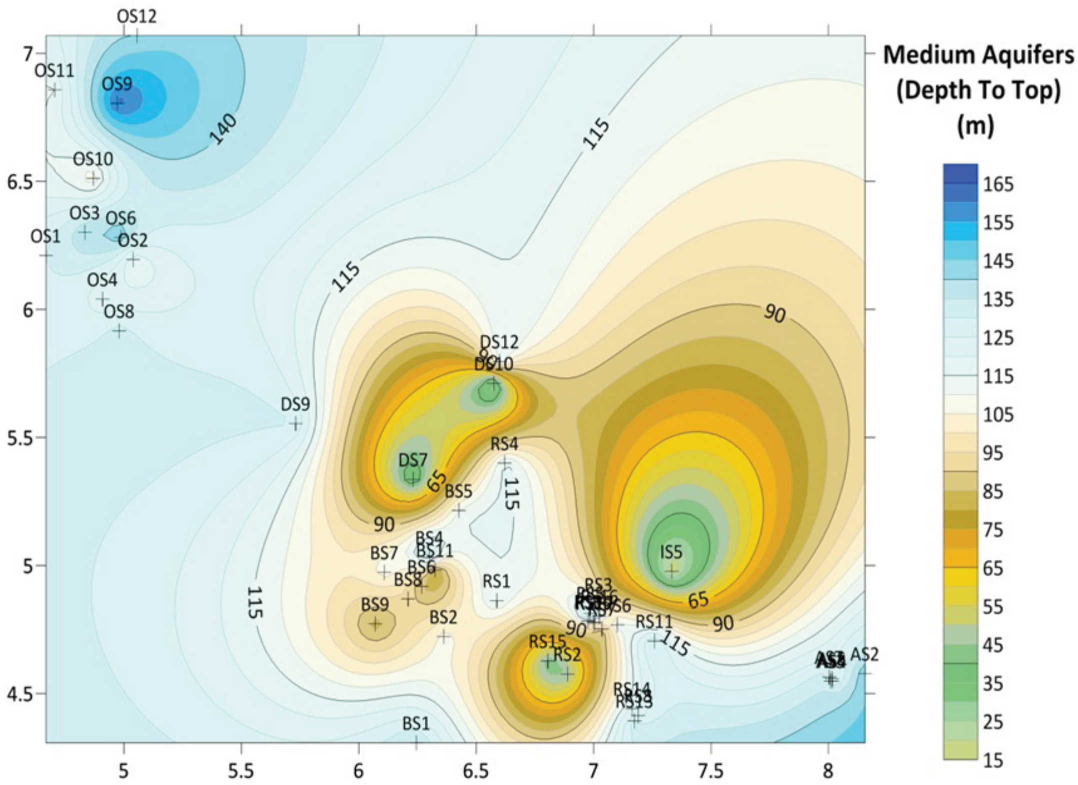

Figure 7: Depth to top of medium aquifers.

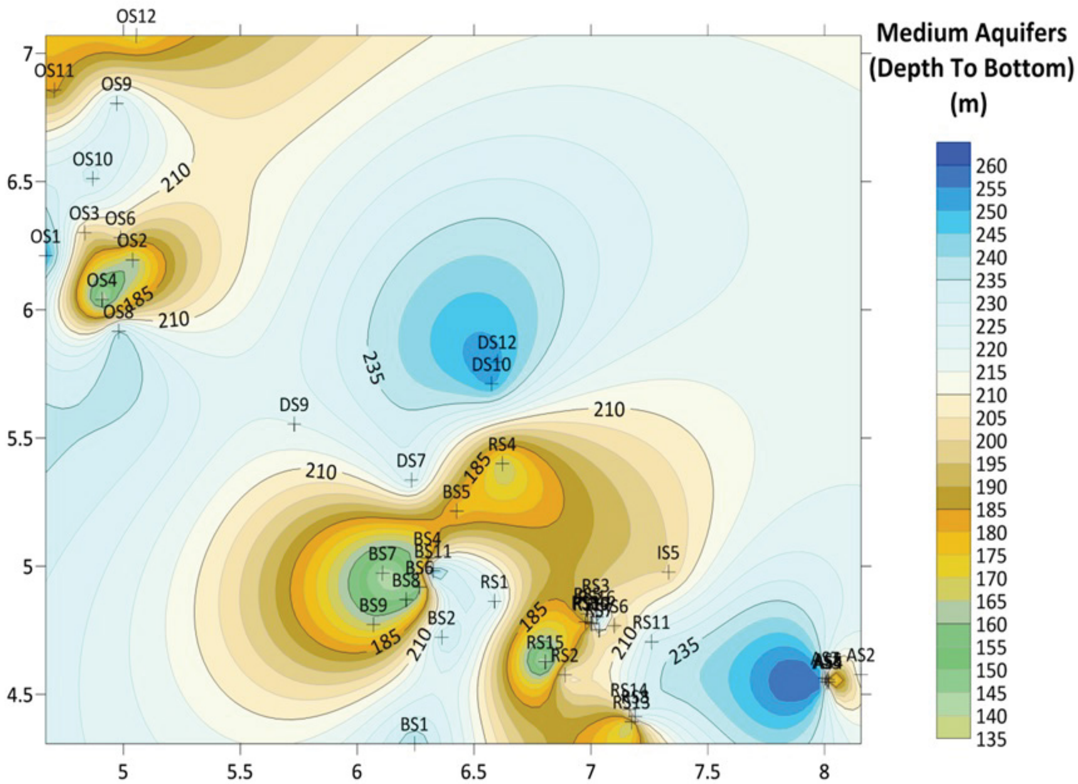

Figure 8: Depth to bottom of medium aquifers.

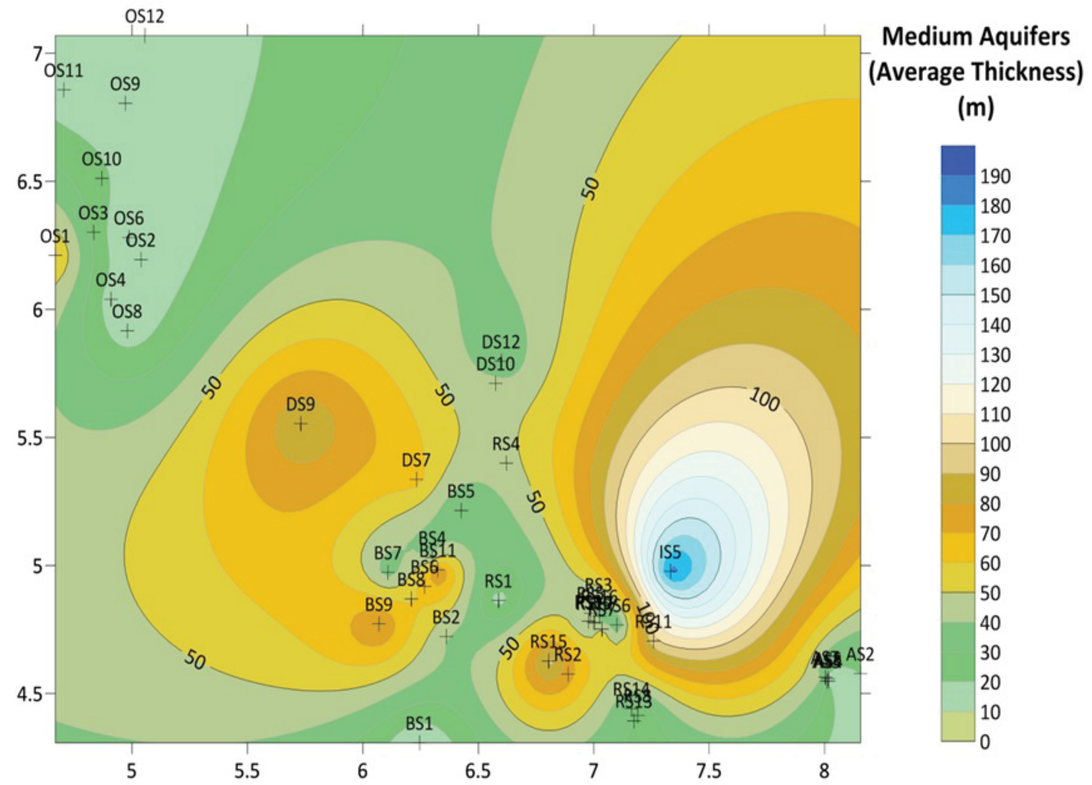

Figure 9: Average thickness of medium aquifers.

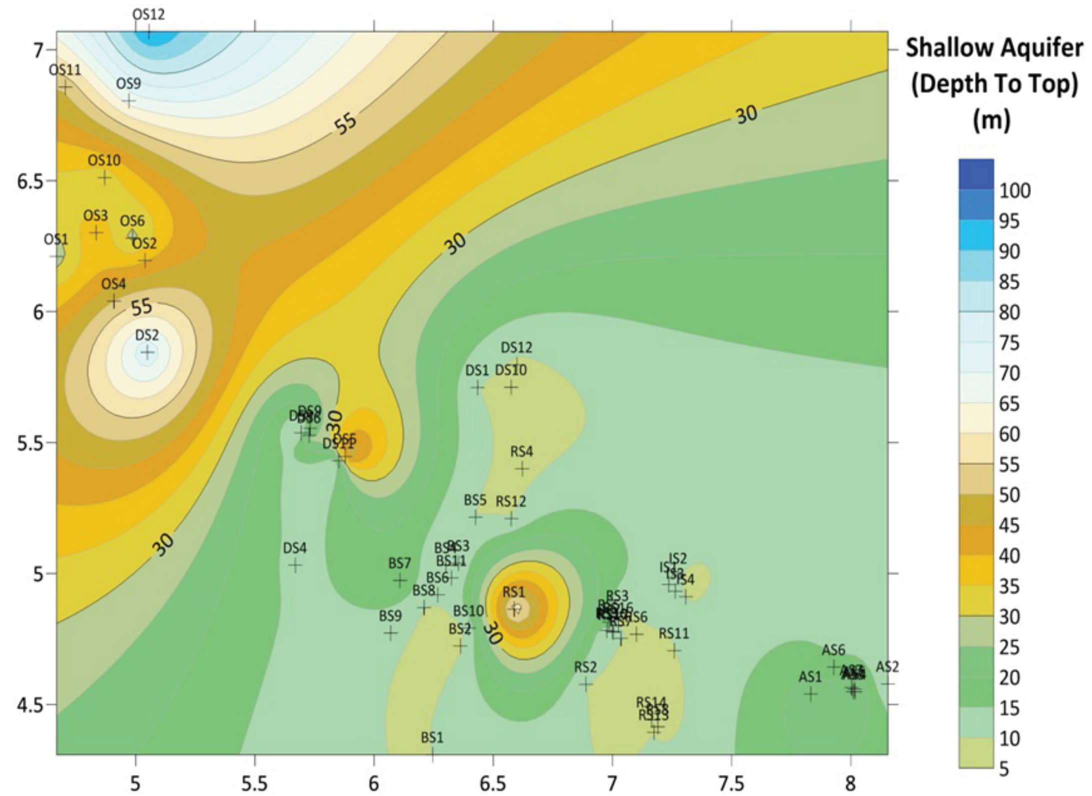

Figure 10: Depth to top of shallow aquifers.

various lithologic units as recorded by the logging system were obtained. Table 1 shows the location of the wells and the resistivity values of the aquifers as obtained from the open-hole resistivity log. The log from where the values were obtained is the N64 resistivity log which obtains data 64" from the well bore beyond the mud cake zone.

Table 1 shows eighteen (18) locations with multi-aquifer systems and the preferred candidate aquifer(s) for proper screen placement. Placing this table side by side with the borehole logs acquired at these localities shows that it is easier to get water free from saltwater and iron water contamination around PortHar court axis than around Bonny, Finima and Bille areas where the wells are much deeper to be free from salt water and lower ferrous contamination. The resistivity values of the aquifers are higher within the Onne, Amadi Creek, Amadi Flats and Kidney Island locations which are within the Port Harcourt area. There is general decrease in aquifer resistivity as one traverses from the Port Harcourt area towards the Bonny area. The resistivity values around the Onne, Amadi Creek, Kidney Island and the Amadi flats are above 600 Ohmmeters and the water produced from these aquifers is potable and therefore free from saline

Table 1: Selected candidate aquifers for screen placements in some boreholes within the study area.

S/N	Lat	Long	Borehole ID	Location	No of Aquifers	Candidate Aquifer Depth (m)	Resistivity of the Candidate Aquifer (Ohm-m)	Screen Placement	Remarks
1	4.8138	6.9866	RS5	Onne Federal Ocean Terminal	3	150-205	623.0	3rd Aquifer	Screened
2	4.7788	7.0001	RS10	Kidney Island, Abonema Warf PHC	3	98-152	889.0	3rd Aquifer	Screened
3	4.7518	7.0357	RS7	Amadi Creek (Eastern By Pass) BH 1	3	156-210	660.0	3rd Aquifer	screened
4	4.802	7.025	RS16	Amadi Creek BH2	8	250-312	950.0	7th Aquifer	screened
5	4.6269	6.8051	RS15	Idama	5	415-570	450.0	5th Aquifer	Screened
6	4.5763	6.8888	RS12	Bille	4	260-390	150.0	4th Aquifer	Screened
7	5.8444	5.0495	DS2	Ogheye	2	75-110	67	2nd Aquifer	Screened
8	6.5116	4.8694	OS10	Idogun Ayadi	8	237-320	12.15	7th Aquifers	Screened
9	4.4409	7.1643	RS14	Oguede Bonny	13	430-457	659.5	13th Aquifer	Screened
10	6.0399	4.9092	OS4	Akpata Ijaw	5	95-114	100.8	4th Aquifer	Screened
11	4.7053	6.8572	OS11	Jiririnwo	6	170-183	53.32	6th Aquifer	Screened
12	4.3933	7.1744	RS13	Finima	7	410-426	317.0	7th Aquifer	Screened
13	4.4142	7.1898	RS8	Bonny	17	528-574	246.0	16th Aquifer	Screened
14	6.1946	5.0392	OS2	Adoloseimo Ondo	7	140-160	224.0	7th Aquifer	Screened
15	4.8632	6.5880	RS1	Asaramatoru	7	242-270	187.3	7th Aquifer	Screened
16	4.7049	7.2597	RS11	Kula	6	132-230	220.0	4th Aquifer	Screened
17	5.5075	5.2162	DS3	Ogidigben	4	537-580	171.0	4th Aquifer	Screened
18	4.3078	6.2456	BS1	Brass	12	222-240 243-306	154.0 152.0	11th and 12th Aquifers	Screened

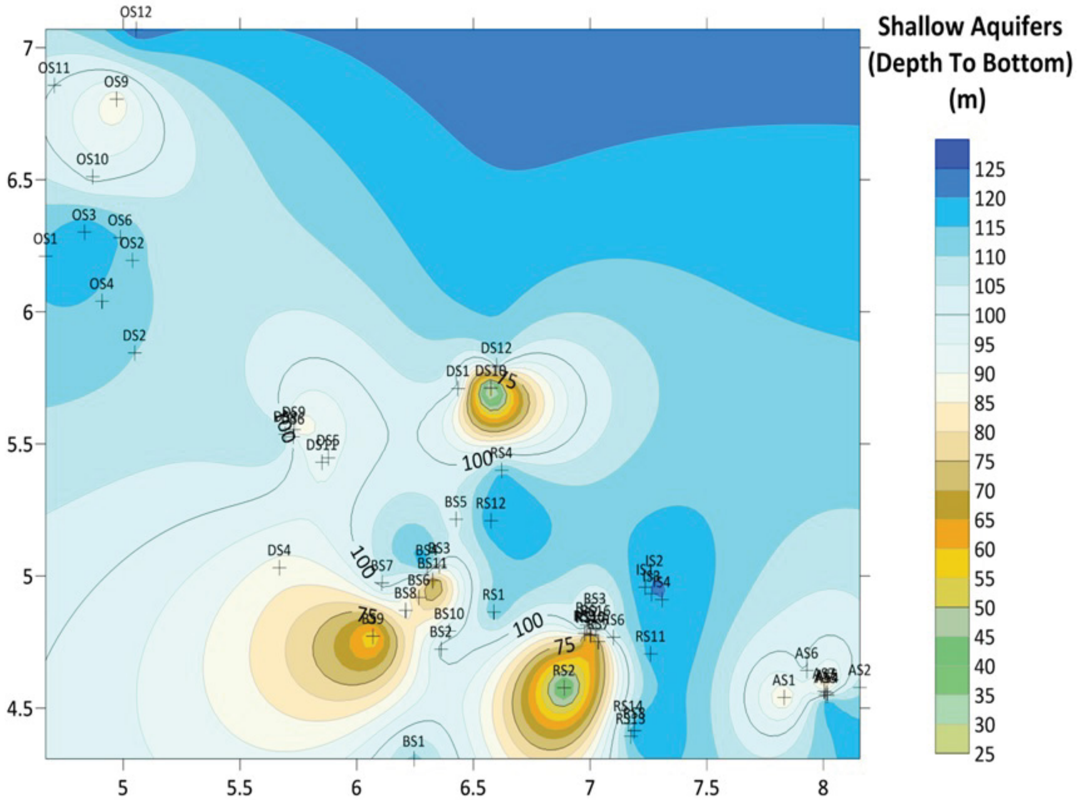

Figure 11: Depth to bottom of shallow aquifers.

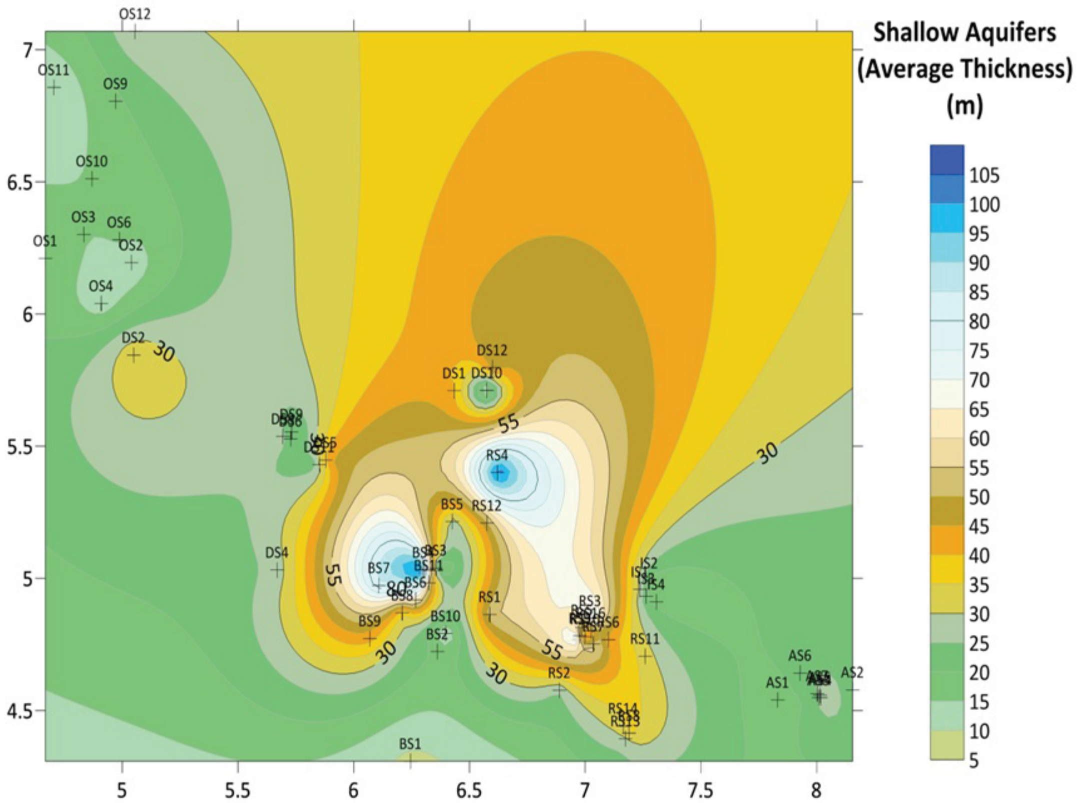

Figure 12: Average thickness of shallow aquifers.

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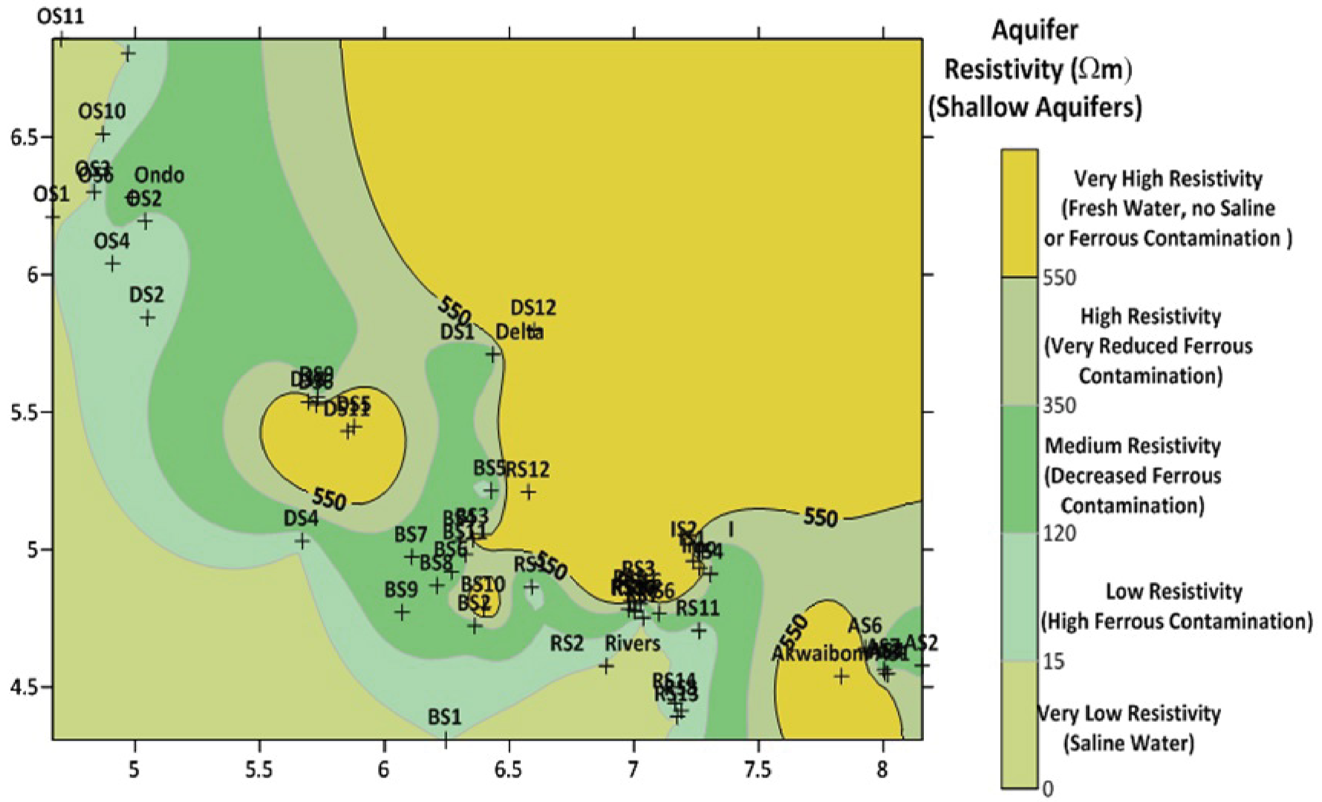

Figure 13: Resistivity plot for shallow aquifers.

water and ferrous contaminations. The water from the Aquifers around Finima, Shell Bonny, Bonny water board, and Oguede had resistivity values below 600 ohms. Water produced from the aquifers contained ferrous iron contamination in treatable quantities but had no salt content. Based on the distribution of aquifer resistivity values at different depths where aquifers were mapped out, the entire study area was adjudged to have the following aquifer systems viz: Very Low Resistivity Aquifers (Saline Water), Low Resistivity Aquifers (High Ferrous Contamination), Medium Resistivity Aquifers (Low Ferrous Contamination) and High Resistivity Aquifers (Fresh Water with no Saline or Ferrous Contamination). From the shallow aquifer resistivity plot (Figure 13), the northeastern part of the study area was seen to contain fresh water without the presence of saline water and ferrous contamination. This water type also occurs in pockets within the Otorogu gas plant of Delta state; around Otakeme and Kolo areas of Bayelsa State as well as QITIbeno Land 3 locations of Akwa Ibom State. Very reduce ferrous contamination, decreased ferrous contamination, as well as high ferrous contamination aquifers, were seen aligned in a linear form from the Northeastern part to the Southern part of the study area. Saline water aquifers were quite predominant within the Southern fringe of the study area (Figure 13). A similar trend was observed in the medium aquifers plot (Figure 14). The only observed difference is that at this depth the occurrence of freshwater tends to extend to the Uzere area of Delta State and the Otakeme area of Bayelsa State (Figure 14). From the resistivity plot of the deep aquifers, freshwater aquifer units and those with very low to decreased ferrous contamination was encountered within the Southern part of the study area (Figure 15). Thus, within the coastal area of the Niger Delta, the effect of ferrous contamination may not be eliminated through the drilling of deep wells.

Gamma count

Based on the amount of gamma Count per Second (CPS), the aquifer system in the area can be classified into Very Low Gamma Count (Highly Sandy Aquifers), Low Gamma Count (Sandy Aquifers) and Medium Gamma Count (Slightly Clayey Aquifers). The very low gamma count aquifers indicating high sandy aquifers have counts ranging from 9.9 to over 12.9 CPS. Bonny waters aquifer has the least gamma count (Figure 16). The low gamma count aquifers

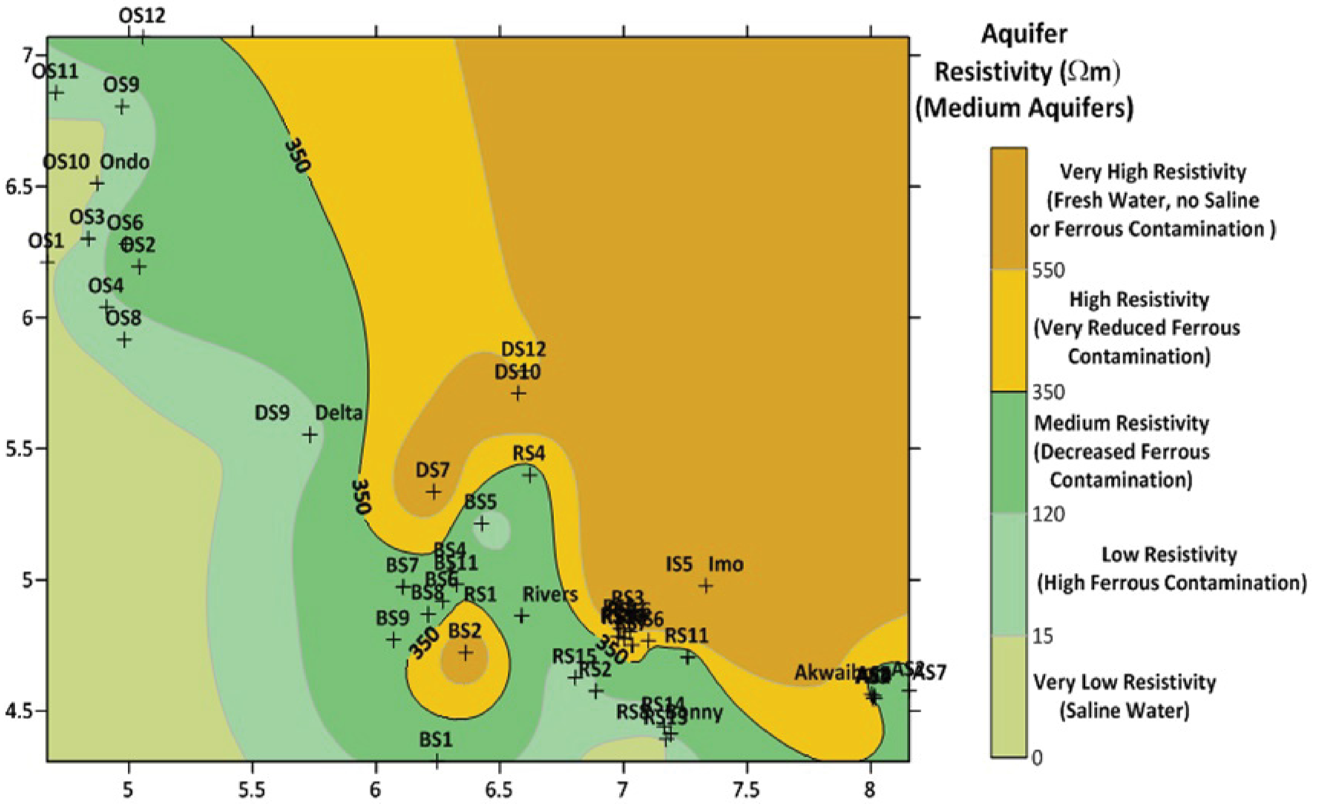

Figure 14: Resistivity plot for medium aquifers.

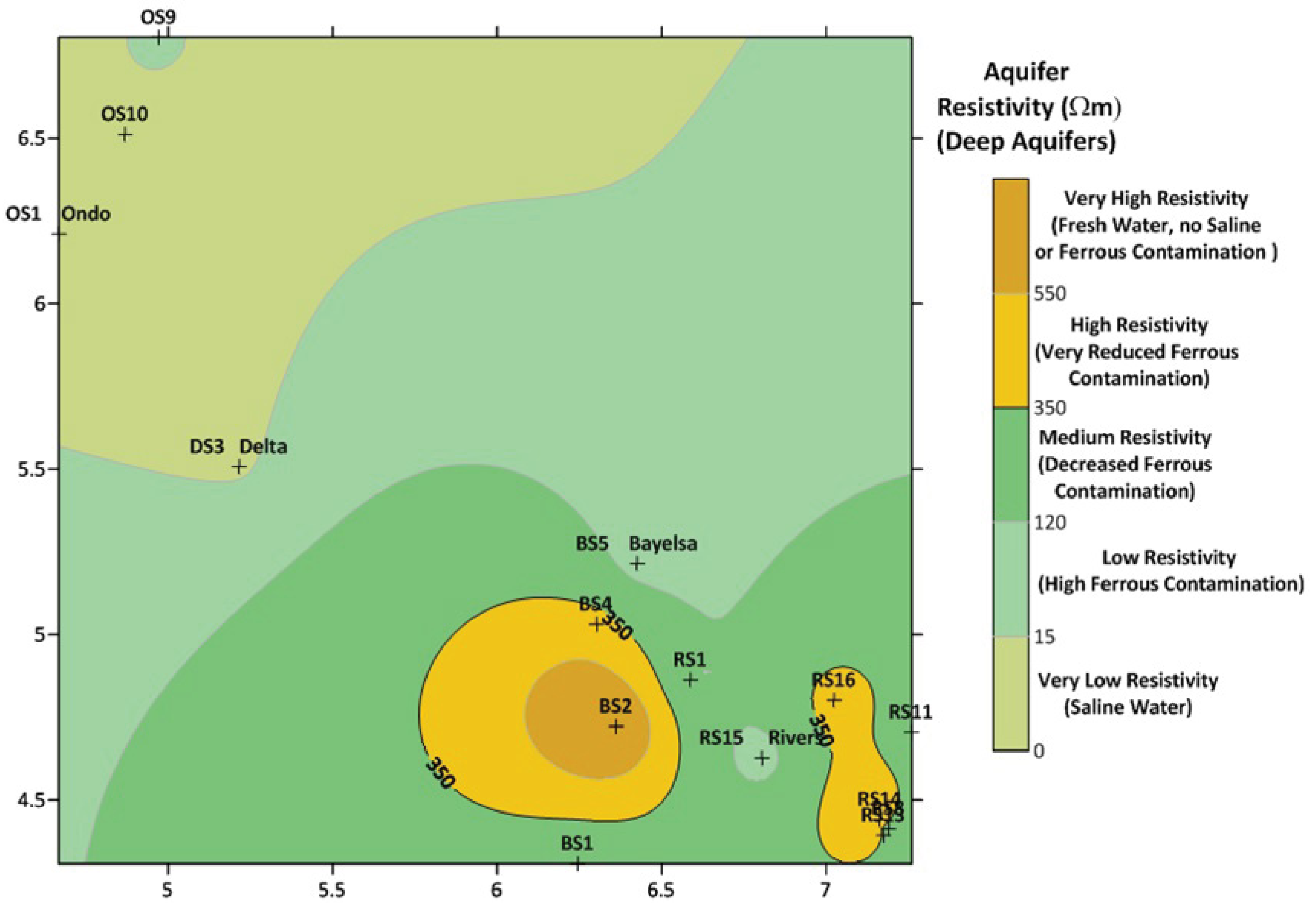

Figure 15: Resistivity plot for deep aquifers.

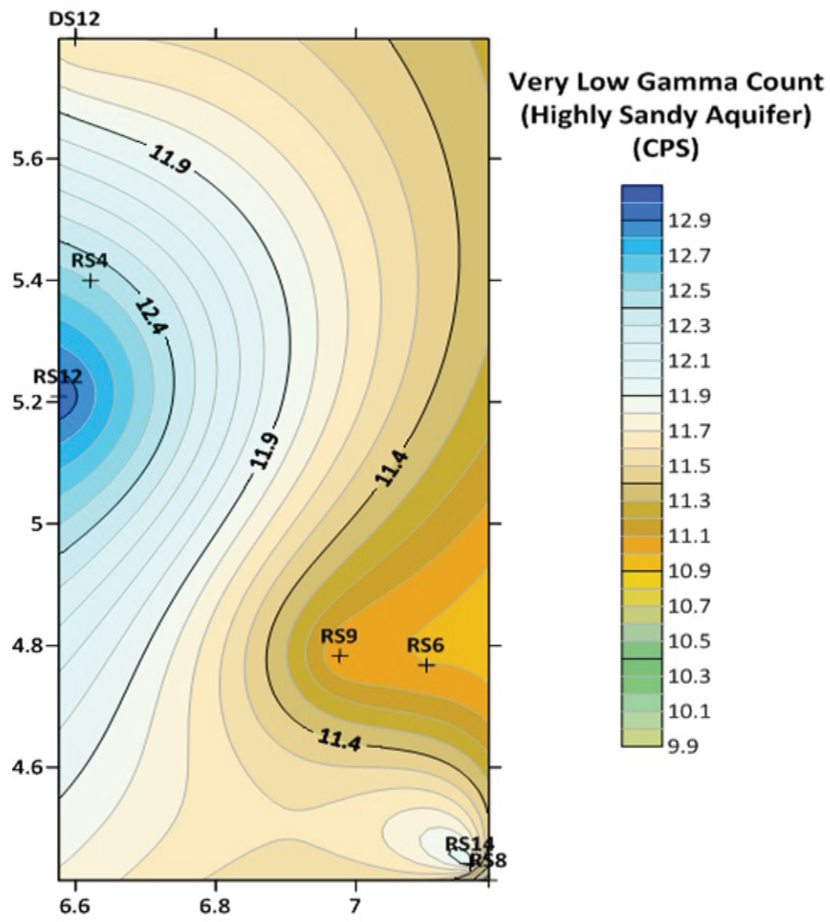

Figure 16: Very low gamma count plot of the area.

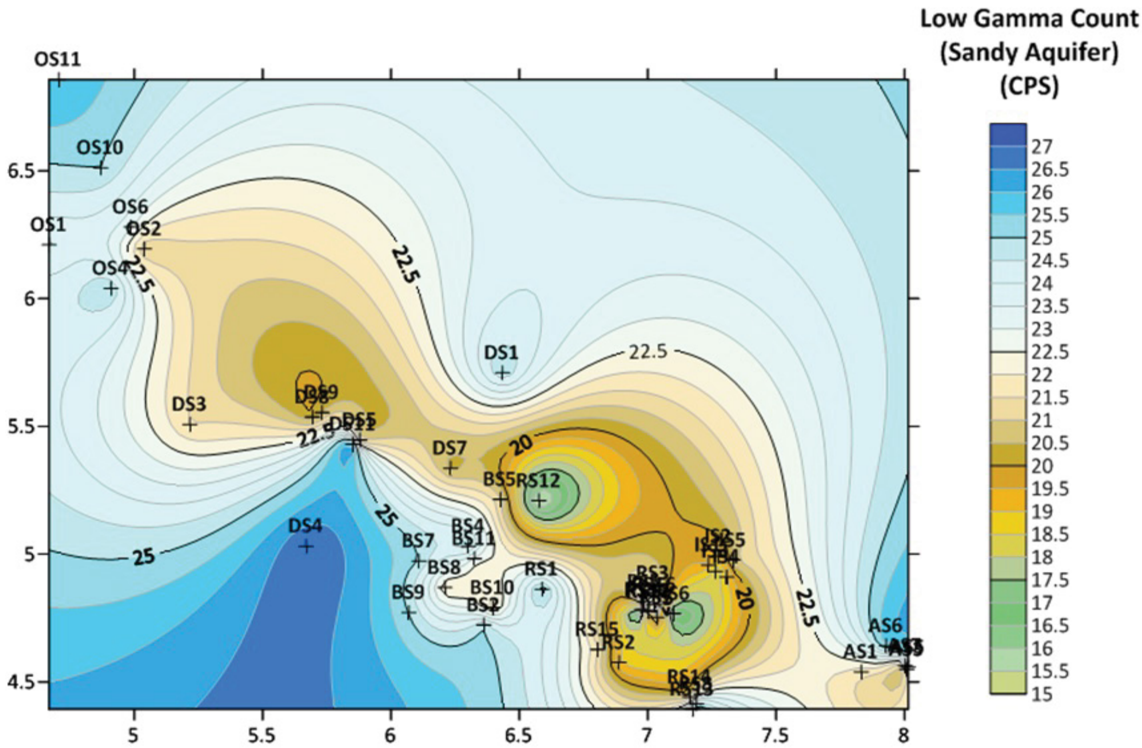

Figure 17: Low gamma count plot of the area.

signify sandy aquifers and have counts ranging from 15 to over 27 CPS. The Southwestern part of the study area has a relatively high gamma count than the surrounding areas within this category of sandy aquifers. A rising plume of relatively high value within the low gamma account domain was encountered within the southwestern part of the study areas. It eventually caps up around the Ojobo area of Delta State. There exists a near-linear trend along Northwest-Southwest direction of gamma counts ranging from 17.5 to 22.5 CPS showing well-deposited and probably proper structurally aligned sandy units that serve as good aquifer systems within those localities (Figure 17). The medium gamma count areas indicate zones dominated by slightly clayey aquifers with counts ranging from 20 to 45 CPS (Figure 18). This type of aquifer unit has a relatively high value of greater than 40 CPS occurring mainly around the OrientanIlaje, AwoyeIlaje and Odoloseino areas of Ondo State. Its relatively low value occurs around the Southern and Northeastern parts of the study areas.

Porosity of aquifer material

The average aquifer porosity plot is shown in Figure 19. Four classes of porosities were delineated which include: high, medium, low and very low porosities. The majority of the research areas are dominated by high porosity aquifer materials greater than 65%. The Southern fringe of the study area contains aquifers occurring in low porosity to medium with porosity values ranging from 21 to 36%. Medium porosity aquifers are seen within the Northwestern part of the study area with porosity values ranging from 36 to 65% (Figure 19).

Fresh water/saline water delineation

The study clearly shows the saltwater aquifer boundary within the Bonny and Finima areas. The saltwater aquifer boundary is undulating with an average of 145 metres in Bonny and some parts of Finima and 218 metres in Finima water board. The fresh water/saline water aquifer delineation for the Bille and Finima areas is over 200 metres depth. While the fresh water/saline water aquifer delineation for the Onne, Amadi creeks, Amadi flats area is less than 100 metres. The freshwater/saline water aquifer delineation for the Bille, Kidney Island and Amadi creek areas shows the saline

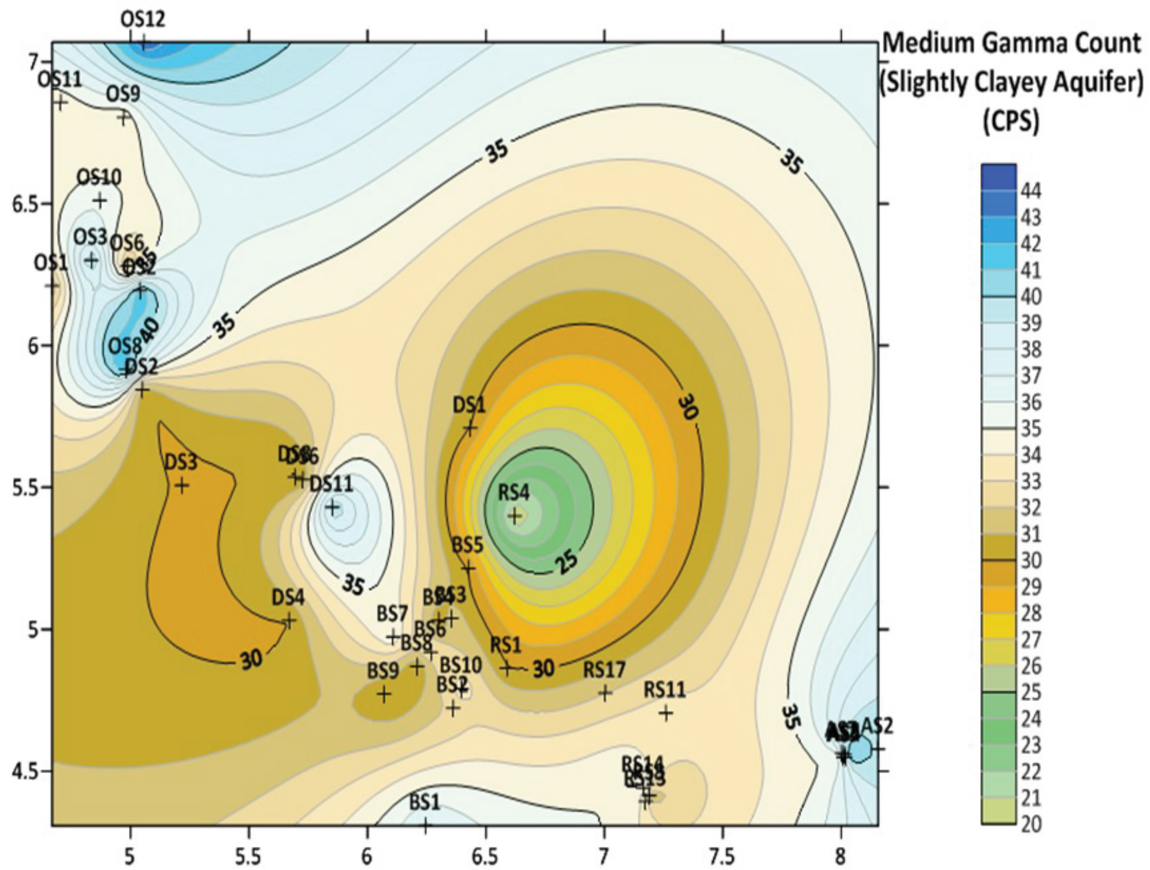

Figure 18: Medium gamma count plot of the area.

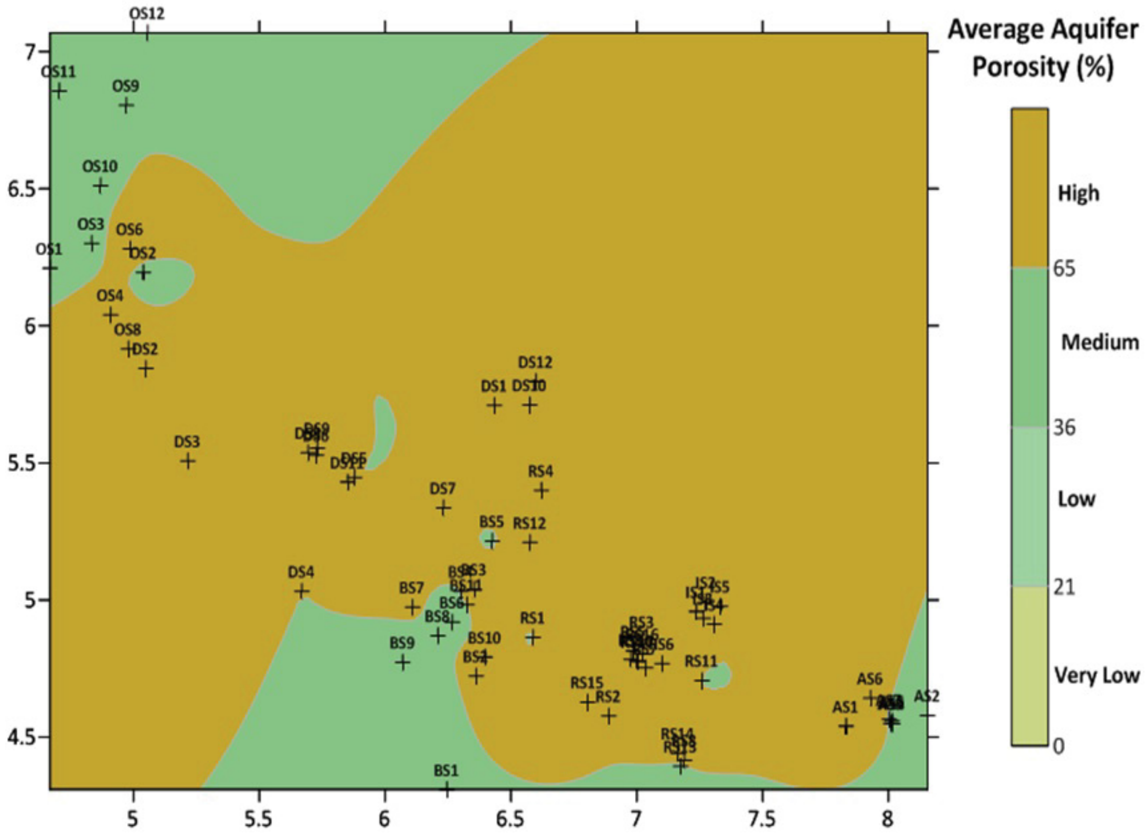

Figure 19: Average aquifer porosity plot of the area.

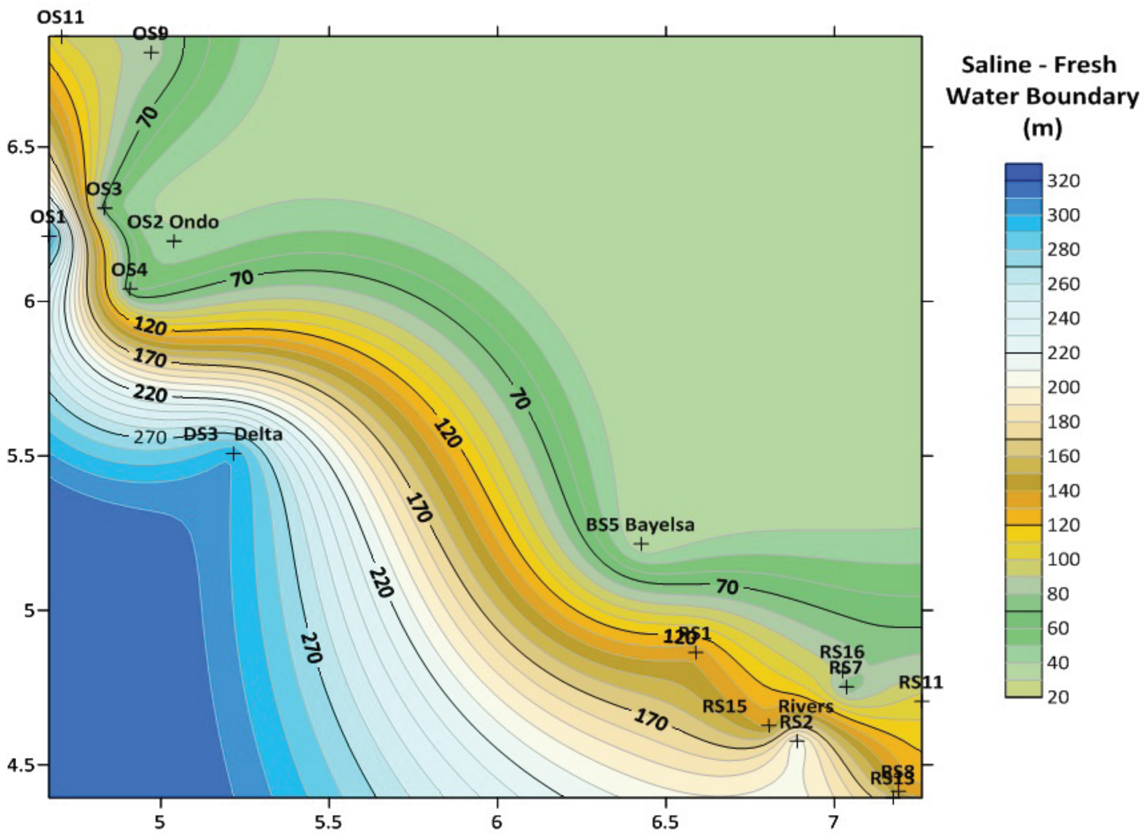

Figure 20: Saline-fresh water contact plot of the area.

water aquifer boundary to be over 200 metres in Bille and less than 100 metres in Kidney Island and Amadi creek areas. These freshwater/saline water aquifer boundaries imply that below these depths, there are no more saline water aquifers up the depth of investigation within the study area. The water below the saline water aquifer line is fresh. The freshwater aquifers are confined by thick clay layers and have no interference from other aquifers. The plot of the saline–freshwater boundary is as clearly displayed in Figure 20. From the figure, it can be observed that the boundary between saline and freshwater varies from location to location within the study area. The boundary was observed to be shallow within the Tunu flow station of Bayelsa State; NLNG Amadi Creek and Amadi Crack 2 of Rivers State; Erunallaje, Akpata Ijaw, Ayetoro and Adoloseimo areas of Ondo State. Deep saline-fresh water boundary occurs around Bonny water, Fanima water Beard, Bille, Idama, Kula and Asaramatoru areas of Rivers State; Jinrinwo and Abealalallaje area of Ondo State as well as Ogidigben area of Delta State. The Depth to Fresh-Saline water boundary is shown in Table 2.

Lithologic cross-section

The correlation of the Lithologic cross-section along the Northwest-Southeast direction is shown in Figure 21. The different geologic units encountered are clay, clayey sand, sand, sandy clay as well as saturated sand. The saturated sand horizons were observed to form the freshwater aquifer systems of the area while the clayey sand and sandy clay units harbour the ferrous and saline aquifer systems in the area.

Conclusion

The study has revealed that the area consists of a multiple-aquifer systems with three categories of aquifers delineated as Deep (410-600 m), Medium (135-409 m) and Shallow (5-134 m) aquifers. The depth to potable water around Port Harcourt Onne areas is shallower than in the Bonny, Finima and Bille areas. The study also showed that there is no saltwater aquifer below 150 meters in Bonny. To obtain a potable water supply within the study area, the resistivity value of the aquifer should be above 600 Ohm-m. This is the threshold aquifer resistivity value for potable water as established by this study. Based on the amount of gamma Count per

Table 2: Depth to saline-fresh water boundary.

S/N	Lat	Long	Borehole ID	Location	Fresh-Saline Water Contact/Boundary (m)
1	4.4142	7.1898	RS8	Bonny Water	135
2	4.3933	7.1744	RS13	Finima Water Board	163
3	4.5763	6.8888	RS2	Bille	208
4	4.6269	6.8051	RS15	Idama Rivers	135
5	4.7049	7.2597	RS11	Kula Rivers	105
6	4.802	7.025	RS16	NLNG Amadi Creek	90
7	4.7518	7.0357	RS7	Amadi Creek 2	70
8	4.8632	6.588	RS1	Asaramatoru	137
9	6.8572	4.7053	OS11	Jinrinwo Ondo	100
10	6.8048	4.9717	OS9	Erunallaje Ondo	86
11	6.0399	4.9092	OS4	Akpata Ijaw Ondo	58
12	6.3011	4.8339	OS3	Ayetoro Ondo	60
13	6.1946	5.0392	OS2	Adoloseimo Ondo	44
14	6.2106	4.668	OS1	Abealalallaje	318
15	5.2147	6.4261	BS5	Tunu Flow Station	30
16	5.5075	5.2162	DS3	Ogidigben	300
17	4.6913	7.1544	RS5	Onne	70
18	4.3078	6.2456	BS1	Brass	100

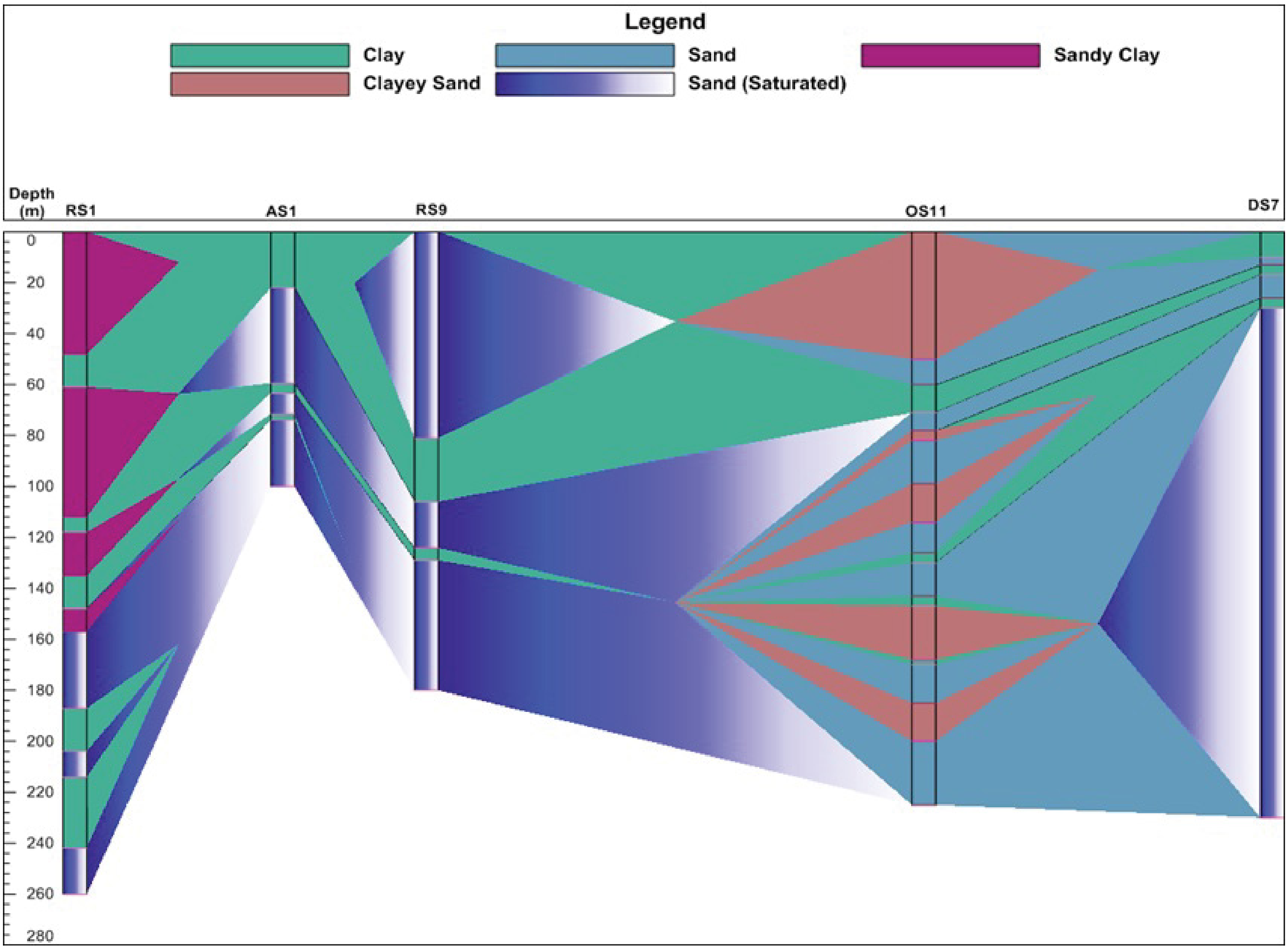

Figure 21: Lithologic cross-section along NW-SE direction.

Second (CPS), the aquifer system in the area can be classified into Very Low Gamma Count (Highly Sandy Aquifers), Low Gamma Count (Sandy Aquifers) and Medium Gamma Count (Slightly Clayey Aquifers). The very low gamma count aquifers indicating high sandy aquifers have counts ranging from 9.9 to 12.9 CPS. Considering the porosity of the aquifer media, aquifer systems of the area are classified as high (> 65%), medium (36-65%), low (21-36%) and very low (< 21%) porosities. Based on the distribution of aquifer resistivity values at different depths where aquifers were mapped, the entire study area was adjudged to have the following aquifer systems viz: Very Low Resistivity Aquifers with values ranging from 0 to 20 Ohm-m (Saline Water), Low Resistivity Aquifers have values ranging from 20 and 100 Ohm-m (High Ferrous Contamination), Medium Resistivity Aquifers with values ranging from 100 to 500 Ohm-m (Low Ferrous Contamination) and High Resistivity Aquifers with values above 600 Ohm-m (Fresh Water with no Saline or Ferrous Contamination). The saline-fresh water boundary varies from location to location within the study area. From this research, we have established that:

1. Salt and Iron contaminated water can occur in association with fresh water without clay demarcation. Tapping only the freshwater effectively depends on the proper placement of the screen and adequate choice of the capacity of the submersible pump, to be installed without disturbing the hydrostatic balance.
2. In the coastal beaches and ridges areas of the Niger Delta, it is more difficult to exploit for groundwater as deep wells are needed to escape from saltwater intrusion and high concentrations of Iron.
3. There exists a gradual increase in the depth of water wells across the depositional environments of the Niger Delta as one traverses from the shore towards the swamps.

4. It is possible to isolate individual aquifers in a given well and identify which particular aquifer(s) contain(s) the major known groundwater pollutants of Chloride and Iron in objectionable concentration within the drilled column.
5. It is possible to run out of fresh water in the Niger Delta through over-extraction of the only available ones.

It is recommended that due to the nature of the aquifers of the coastal area of the Niger Delta, there is an urgent need to protect the aquifers from further contamination by enacting appropriate laws to protect the groundwater of the area and to curtail indiscriminate drilling of boreholes and over-extraction of water from the few freshwater aquifers of the Niger Delta. For critical water need areas where freshwater is not readily available and for over-contaminated areas where the cost of water treatment may be unsustainable, governments and institutions can consider piping water from the coastal plain sand aquifers where there is less contamination to the critical water need areas.

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