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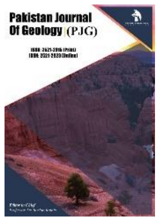

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RESEARCH ARTICLE

INVESTIGATION OF AQUIFER PROTECTIVE CAPACITY USING ELECTRICAL RESISTIVITY METHOD IN FEDERAL UNIVERSITY OTUOKE CAMPUS, OGBIA LGA OF BAYELSA STATE, NIGERIA

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ABSTRACT

The ability of the overburden material to protect the shallow aquifer of the Federal University Otuoke in Ogbia LGA of Bayelsa State was investigated using Electrical Method. Ten (10) Vertical Electrical Soundings (VES) stations were occupied across the study area using Schlumberger configuration. The data obtained was modelled using IP2WIN resistivity software to obtain first order geo-electric parameters-layer thickness and resistivity, information from the first order parameters were used to numerically determine the Total Longitudinal Conductance which is a second order geo-electric parameter. Results of the Total Longitudinal Conductance computed was then used to classify the rating of the Aquifer Protective Capacity of the overburden material across the study area into excellent, very good, good, moderate, weak and poor. Results revealed that locations occupied by VES stations 1, 2 and 3 had an Aquifer Protective Capacity rating classified as poor, which implied that the shallow aquifer in this area are vulnerable or prone to contaminants infiltrating through the overburden material from surface sources. VES station 4 had a moderate APC rating, which implied that the overburden material in this area will slow down but not totally impede the infiltration of surface contaminants. VES stations 4 to 10 all showed good APC rating, implying non vulnerability of the shallow aquifer in this sampled area to infiltration by surface contaminants and pollutants.

KEYWORDS

Aquifer, Dar-Zarrouk, Electrical, Otuoke, Resistivity, Vulnerability

1. INTRODUCTION

Water is a primary natural resource required for both plants and animals to flourish. Water exists on the surface of the earth as creeks, streams, lakes, lagoons, rivers and the oceans; it can also be found in porous geologic medium beneath the earth's surface as groundwater. In developing communities of the Niger Delta an increase in economic activities, poor waste management practices and non-enforcement of environmental laws has rendered surface water bodies a preferred site for dumping of waste, this is because of the general belief that water as a natural solvent would dissolve any waste material disposed in it. This unwholesome practice has resulted in an extensive contamination and subsequent pollution of most surface water bodies. Since surface water bodies are prone to pollution, groundwater has become the only viable alternative source of potable water for the teeming populace (Etu-Efeotor and Akpokodge, 1990; Udom and Amah, 2006; Okiongbo and Douglas, 2013; Oborie and Nwankwoala, 2014; Olatunji et al, 2015; Oki and Oboshenure, 2017).

Groundwater occurs in the pore spaces of geologic medium beneath the surface of the earth. Groundwater reservoirs known as aquifers are naturally replenished or recharged by infiltrated or percolated rainwater and other surface water sources; this implies that there is a hydraulic connectivity between surface and groundwater. Since surface water is prone to pollution; a connection between surface and groundwater would mean there is a potential for groundwater to be vulnerable to pollution from surface water sources. The vulnerability of aquifers is to a large extent dependent on the protective capacity of the overburden geologic medium above the aquifer to filter off pollutants or impede the flow of polluted surface water as it tends to percolate through it (Olorunfemi et al, 1998; Akana et al, 2016; Ayuk, 2019; Oboshenure and Airen, 2021; Okolo et al, 2024).

Geophysical methods exploits variations in physical properties of the earth to investigate and acquire surface information of subsurface variations with which we can classify or characterize the subsurface geology. The Electrical Resistivity method is based on contrasts in resistivity of earth materials. It has successfully been employed in delineating geology interfaces, environmental studies and hydrogeological investigations (Telford, 1990; Olorunfemi and Fasuyi, 1993; Loke and Baker, 1996b; Loke, 1997; Kearey et al, 2002). The Vertical Electrical Sounding (VES) is a method of electrical survey that can be used to determine geo-electric parameters (layer resistivity and thickness) of individual subsurface layers. Henriett in 1976 showed that the Dar Zarrouk parameters (Longitudinal Conductance - L and Transverse Resistivity - T) proposed by Maillet in 1947 which can be obtained numerically from geo-electric parameters may be used in aquifer vulnerability assessment, since the protective capacity of a geologic material is directly proportional to its unit conductance in mhos (Olorunfemi et al., 1998; Oladapo et al., 2004; Abiola et al, 2009; Akana et al, 2015). The Federal University Otuoke is a major hub of activities in the community. Since the inception of the university, the school community has experienced a surge in servicing businesses and population. Increase

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in population has also given rise to increased waste generation. Indiscriminate disposal of waste within the campus environment has a potential of resulting in contamination and pollution of shallow aquifer in the area. Threat to the shallow aquifer which is the primary source of potable water on campus has necessitated this investigation to guide the decision of waste disposal sites within the growing campus to forestall environmental and health hazards. The Vertical Electrical Sounding geophysical technique was employed to determine geo-electric parameters in the area from which the longitudinal unit conductance was numerically analyzed to classify the aquifer protective capacity of the overburden material across the campus.

2. MATERIALS AND METHODS

2.1 Geology of study area

The research area is the main campus of the Federal University Otuoke, located in Otuoke community in Ogbia Local Government Area of Bayelsa State. It lies within Latitudes 04°42´23.4" N - 04°47´52.9" N and Longitudes 06°19´32.5" E - 06°19´44.5" E (Figure 1). The area is a low lying floodplain with most areas having elevation of a few meters above sea level. Otuoke community is drained by a network of creeks linked to tributaries of the River Nun which terminates at the Atlantic Ocean. It is accessible by a network of major and minor roads linking coastal communities to the state capital Yenagoa.

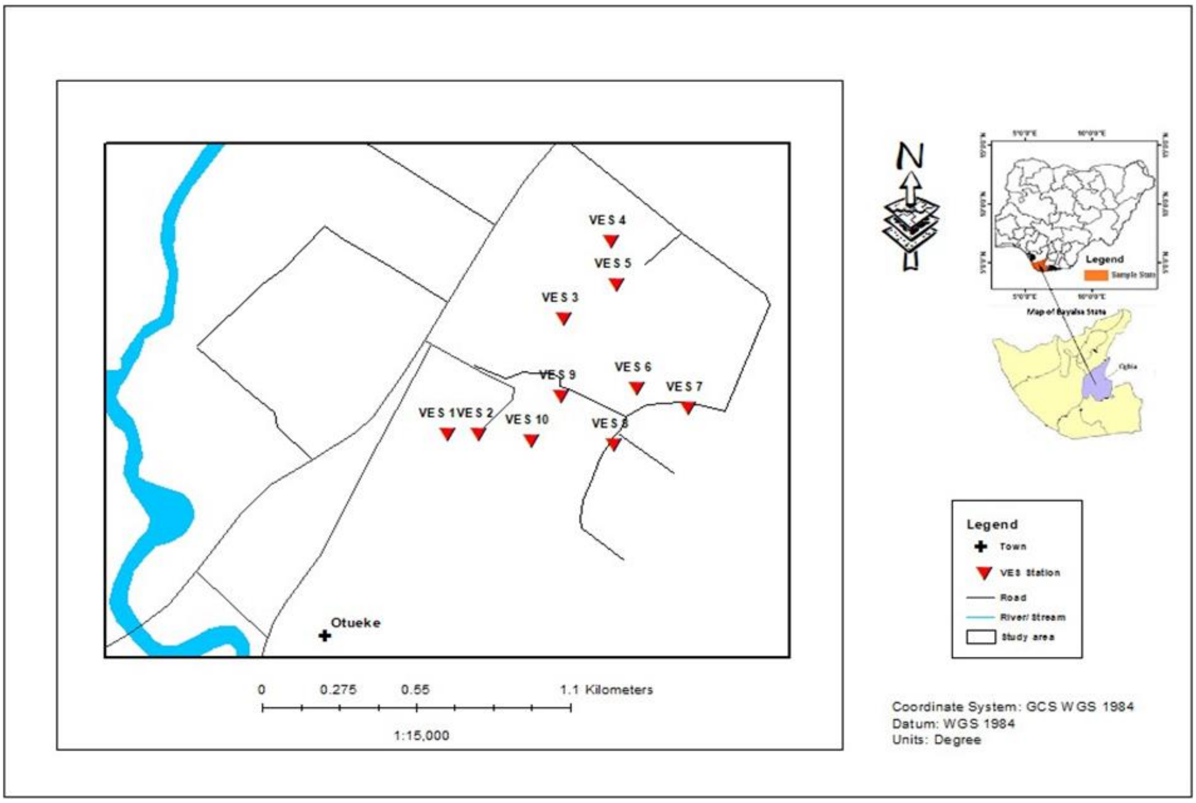

Figure 1: Map of the study area and locations of the investigated exposure (Oyetade et al., 2021)

The Niger Delta Basin is comprised of a very thick sediment assemblage formed by a failed arm of a triple junction "RRR" fault system when South American and the African plates where pulled apart by tectonic forces during the Late Jurassic, opening up the Atlantic Ocean (Burke, 1972). Sediments of the Niger Delta basin span over an area of 70, 000 sq. km with a depth of over 12 km to the basement complex at the middle of the basin (Whiteman, 1982; Tuttle et al, 1999). The basin is bound on the Northwest by the Benin flank, to the East by the Calabar Flank and to the South by the Atlantic Ocean which drains the basin (Murat, 1972). Three stratigraphic units exists in the Niger Delta basin namely from the oldest; the Akata Formation, the Agbada Formation and Agbada Formation. The Akata Formation is characterized by a marine depositional environment comprising of dark grey shales. The Agbada Formation comprises of a sequence of sandstones and shales characteristic of transitional or deltaic depositional environment. The Benin Formation which is the youngest stratigraphic unit is composed chiefly of sandstones with some intercalations of shales which characteristic of a continental depositional environment (Short and Stauble, 1978; Avbovbo, 1978; Kogbe, 1989).

2.2 *Study design*

The basis of Electrical Resistivity method is the variation in response of different earth materials to the flow of electrical current. The method involves an introduction of Electrical Current (I) into the ground through current electrodes and using two potential electrodes to record the resultant Potential Difference (V) between them, thus, measuring the electrical impedance of the subsurface geology. The Apparent Resistivity measured is then a function of the measured impedance and the geometry of the electrode array. The background of the method is succinctly explained in earlier literature (Telford et al., 1990; Loke and Baker; 1996b; Loke, 1997; Keary et al., 2002).

This study utilized data from 10 (ten) Vertical Electrical Soundings (VES) stations across the area using the Eurojet self-averaging digital resistivity meter. The Schlumberger configuration was used in this study because it is fast and results are less likely to be influenced by lateral sub-surface variations. The process of data acquisition involved introducing electrical current to the ground by two current electrodes (A and B) and then measuring the resultant potential difference (ΔV) between the potential electrodes (M and N) which were fixed between the current electrodes. The centre point of the electrode array remained fixed but the spacing of the current and potential electrodes was progressively increased in line with the sounding programme for sampling varying depth levels. The depth investigated was considered as a quarter of the current electrode spacing AB and aided by secondary information of depth to the shallow aquifer in the area. A product of the Resistance measured and a Geometric Factor which was determined by the electrode configuration in the field was used to determine Apparent Resistivity. The computed Apparent Resistivity data were inverted using a computer aided 1-D inversion modelling software known as IP2Win to generate geo-electric profiles and parameters for each VES point sampled. Models were constrained with secondary lithological information obtained from boreholes in the vicinity of the study area and literature. The first order geo-electric parameters (layer resistivity and thickness) obtained from the 10 VES stations were then used as a basis for further numerical analysis.

Mailet defined the second order geo-electric parameters referred to as the Dar-Zarrouk (D-Z) parameters; this comprised of the resistance normal to the face for a cross sectional unit area known as the Transverse Unit Resistance (T) and the conductance parallel to the face for a unit cross-section area known as the Total Longitudinal Unit Conductance (S) (Mailet, 1947). The first order geo-electric parameters resistivity and thickness for individual subsurface layers obtained by VES was used by Henriet in 1976 to compute the D-Z parameters from which aquifer protective capacity and aquifer properties were determined. For a single homogenous and isotropic layer of resistivity ρ_1 and thickness h_1 the Total

Longitundinal Conductance S and Traverse Unit Resistance T will be given as in equations 1 and 2 below:

Total Longitudinal Unit Conductance $S = \frac{hi}{\rho i}$ (1)

Traverse Unit Resistance $T = \rho_1 * h_1$ (2)

Where a section consists of n number of homogenous layers with thickness h_1, h_2, h_3, h_4, h_5 ……. h_n and resistivity $\rho_1, \rho_2, \rho_3, \rho_4, \rho_5$ …….ρ_n for a block of unit square area. S and T will thus be given as in equations 3 and 4 below:

Total Longitudinal Unit Conductance $S = \frac{h1}{\rho 1} + \frac{h2}{\rho 2} + \frac{h3}{\rho 3} + \ldots \frac{hn}{\rho n} = \sum_{i=1}^{n} \frac{hi}{\rho i}$ (3)

Total Traverse Unit Resistance $T = \rho_1 * h_1 + \rho_2 * h_2 + \rho_3 * h_3 + \ldots \rho_n * h_n = \sum_{i=1}^{n} \rho i * hi$ (4)

Protective capacity of the overburden material has been established to have a direct proportionality to its Total Longitudinal Unit Conductance as such S is of keen interest in this investigation (Olorunfemi et al., 1998; Oladapo et al., 2004; Atakpo and Ayolabi, 2009; Oboshenure and Airen, 2021).

Aquifer protective capacity is the ability of the overburden material above the aquifer unit to impede the percolation of surface contaminants and pollutants. Clays with low resistivity values are porous but non permeable and are usually associated with high longitudinal unit conductance values, whereas, sand and gravels with high resistivity are highly porous and permeable and are associated with low longitudinal unit conductance values. Early classification of Aquifer Protective Capacity presented in Tables 1 and 2 by Henriet and later modified by Oladapo et al., respectively shows that high Total Longitudinal Unit Conductance values corresponded with excellent and good APC rating while low longitudinal conductance values are associated with poor and weak APC ratings (Henriet, 1976; Oladapo et al., 2004). In this study, the modified rating by Oladapo et al (2004) has been employed.

Table 1: Total Longitudinal Unit Conductance - Protective Capacity rating (Henriet, 1976)

Total Longitudinal Unit Conductance (mhos)	Overburden Protective Capacity Classification
< 0.10	Poor
0.1 – 0.19	Weak
0.2 - 0.69	Moderate
0.7 – 1.0	Good

Table 2: Modified Total Longitudinal Unit Conductance - Protective Capacity rating (Oladapo et al., 2004)

Total Longitudinal Unit Conductance (mhos)	Overburden Protective Capacity Classification
> 10	Excellent
5 – 10	Very Good
0.7 – 4.9	Good
0.2 – 0.69	Moderate
0.1 – 0.19	Weak
< 0.1	Poor

3. RESULTS AND DISCUSSION

Results of the inverted field data of the Ten (10) VES points investigated in this study are presented in Figure 2 and Table 3 below. The results presented show the model, number of layers delineated by each VES, the individual layer resistivity and thickness, geo-electric curve type, lithological classification, computed Total Longitudinal Unit Conductance and the Aquifer Protective Capacity Rating for all stations occupied. VES 1 is characterized by 3 geo-electric layers of the K curve type with a silty sandstone overburden with resistivity 298.9 Ωm and thickness of 0.7 m, underlain by layers of sandstone of varying grades and saturation with layer resistivities 1142.8 Ωm, 2976.9 Ωm and corresponding thicknesses of 9.2 m and 45.8 m from top to bottom respectively. The computed Total Longitudinal Unit Conductance for this station is 0.025 mho which falls within poor APC rating. VES 2 delineated 4 geo-electric layers associated with the AA curve type. This profile revealed a top soil with a resistivity of 54.6 Ωm characteristic of clayey soil with a thickness of 0.8 m, it is underlain by successive layers of sandstone of varying grades from top to bottom with respective resistivities of 352 Ωm, 1710.4 Ωm, 4999.7 Ωm and thicknesses 10.5 m, 69.6 m, 31.8 m. The Total Longitudinal Unit Conductance of VES 2 is 0.089 mho which is classified APC as poor. VES 3 profiled 5 geo-electric layers of the AKH curve type. The resistivity of the overburden material is 66.3 Ωm associated with clays, it has a thickness of 0.7 m. Underlying the clayey overburden are successive layers of sandstone of varying grades represented by various resistivities and thicknesses of 595. 5 Ωm and 4.0 m for layer 2, 1293.3 Ωm and 8.1 m for layer 3, 437.6 Ωm and 24.4 m for layer 4, 5599.3 Ωm and 56.2 m for layer 5 with a Total Longitudinal Unit Conductance of 0.087 mho rated as poor APC. VES 4 delineated 4 geo-electric layers associated with the HK curve type. The top soil has a resistivity of 146.3 Ωm characteristic of silt with a thickness of 0.6 m, beneath the overburden is a layer with resistivity of 35.4 Ωm characteristic of clay 3.2 m thick. Underlying the clayey material is layer characterized as silty sandstone with a resistivity of 216.8 Ωm and a thickness of 5.7 m. The fourth layer has a resistivity of 58.7 Ωm associated with clay having a thickness of 30.7 m. The computed Total Longitudinal Unit Conductance is 0.642 mho which falls under a moderate APC rating.

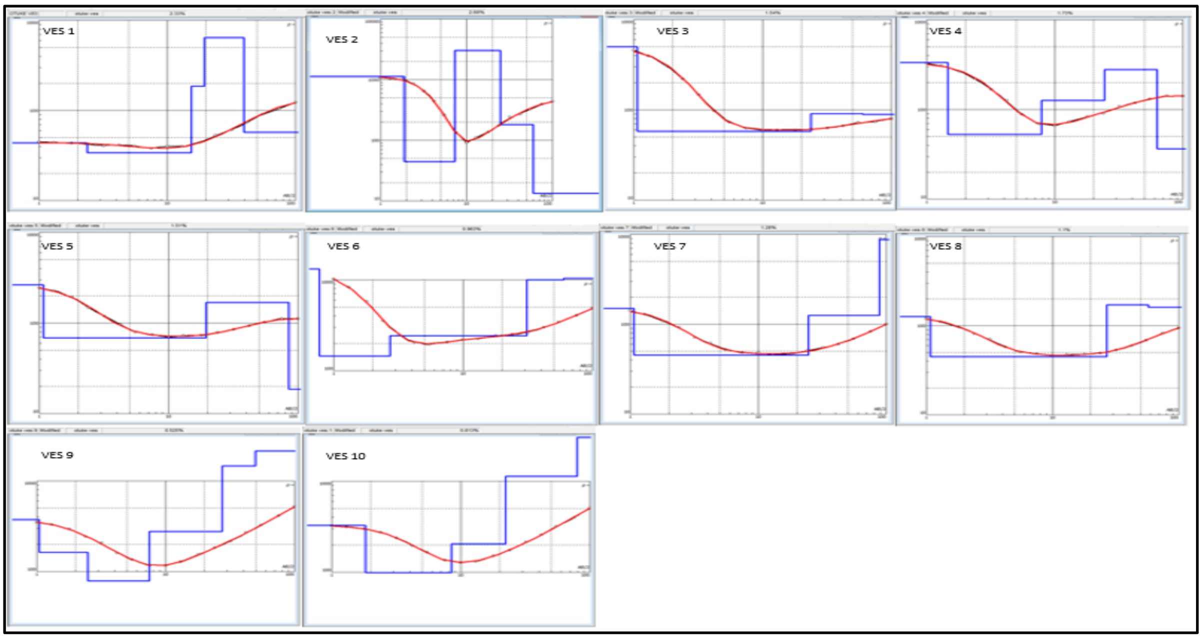

Figure 2: Results of the modelled VES data showing geo-electric curve types for all 10 station

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Table 3: Results of modelled VES data showing Geo-Electric Parameters, Curve Type, Lithology, Computed Longitudinal Conductance and Protective Capacity Rating.

VES Station	Station Co-ordinates	Layer	Resistivity ρ (Ωm)	Thickness h (m)	Depth (m)	Curve Type	Lithology	Total Longitudinal Unit Conductance ($\frac{h}{\rho}$) mho	Total Longitudinal Unit Conductance $\sum_{i=1}^{n}(\frac{h}{\rho})$ mho	Aquifer Protective Capacity Rating
1	04.79085° 006.32014°	1	298.9	0.7	0.7	K	Silty Sandstone	0.002	0.025	Poor
		2	1142.8	9.2	9.9		Sandstone	0.008		
		3	2976.9	45.8	55.7		Sandstone	0.015		
2	04.79181° 006.32039°	1	54.6	0.8	0.8	AA	Clay	0.014	0.089	Poor
		2	352.0	10.5	11.3		Sandstone	0.029		
		3	1710.4	69.6	80.9		Sandstone	0.040		
		4	4999.7	31.8	112.7		Sandstone	0.006		
3	04.7956° 006.32312°	1	66.3	0.7	0.7	AKH	Clay	0.010	0.087	Poor
		2	595.3	4.0	4.8		Sandstone	0.006		
		3	1293.3	8.1	12.8		Sandstone	0.006		
		4	437.6	24.4	37.2		Sandstone	0.055		
		5	5599.3	56.2	93.4		Sandstone	0.010		
4	04.79781° 006.3247°	1	146.3	0.6	0.6	HK	Siltstone	0.004	0.642	Moderate
		2	35.4	3.2	3.8		Clay	0.090		
		3	216.8	5.7	9.5		Silty Sandstone	0.026		
		4	58.7	30.7	40.2		Clay	0.522		
5	04.79699° 006.32479°	1	123.3	0.9	0.9	HK	Siltstone	0.007	0.9	Good
		2	31.8	4.1	5.0		Clay	0.128		
		3	212.0	22.1	27.1		Silty Sandstone	0.104		
		4	43.1	28.5	55.6		Clay	0.661		
6	04.79329° 006.32547°	1	102.4	0.8	0.8	QH	Siltstone	0.007	1.036	Good
		2	22.1	3.0	3.8		Clay	0.135		
		3	9.7	3.4	7.2		Clay	0.350		
		4	58.0	31.6	38.8		Clay	0.544		
7	04.79266° 006.32713°	1	88.5	0.6	0.6	QH	Silty Clay	0.006	0.936	Good
		2	23.2	2.4	3.1		Clay	0.103		
		3	8.6	3.3	6.4		Clay	0.383		
		4	39.6	17.6	24.0		Clay	0.444		
8	04.79145° 006.32475°	1	101.5	0.8	0.8	QH	Siltstone	0.007	1.023	Good
		2	20.8	2.5	3.2		Clay	0.120		
		3	5.7	1.8	50		Clay	0.315		
		4	53.8	31.3	36.4		Clay	0.581		
9	04.79307° 006.32305°	1	100.5	0.7	0.7	QH	Siltstone	0.006	1.092	Good
		2	19.6	2.3	2.9		Clay	0.117		
		3	7.4	3.4	6.4		Clay	0.459		
		4	50.5	25.8	32.1		Clay	0.510		
10	04.79159° 006.32209°	1	70.7	0.8	0.8	QH	Silty Clay	0.011	1.155	Good
		2	24.6	3.1	4.0		Clay	0.126		
		3	14.3	5.4	9.4		Clay	0.377		
		4	65.5	42.0	51.4		Clay	0.641		

VES station 5 penetrated four geo-electric layers represented by the HK curve type. The overburden material has a resistivity of 123.3 Ωm characteristic of siltstone which is 0.9 m thick, it is underlain by a clayey layer with a resistivity of 31.8 Ωm which is 4.1 m thick. The third layer has a resistivity of 212 Ωm associated with silty sandstone, having a thickness of 22.1 m. Beneath the silty sandstone layer is a layer with a resistivity of 43.1 Ωm characteristic of clay. The Total Longitudinal Unit Conductance computed from the first order geo-electric parameters is 0.9 mho. The computed value falls into good APC rating. The sixth occupied station (VES 6) delineated a total of 4 geo-electric layers of the QH curve type. The top soil had a resistivity of 102.4 Ωm associated with siltstone with a thickness of 0.8 m. the second to fourth layers are all characterized as successive clayey layers with resistivities 22.1 Ωm, 9.7 Ωm, 58.0 Ωm and thicknesses 3 m, 3.4 m, 31.6 m respectively. The Total Longitudinal Unit Conductance of this VES is 1.036 mho as such the APC is of good rating. VES 7 penetrated four geo-electric layers which represents the QH curve type. The overburden material has a resistivity of 88.5 Ωm associated with silty clay, it has a thickness of 0.6 m. Beneath the overburden are successive layers of clays with first other parameters 23.2 Ωm and 2.4 for layer 2, 8.6 Ωm and 3.3 m for layer 3, 39.6 Ωm and 17.6 m for layer 4. The Total Longitudinal Unit Conductance computed is 0.936 mho which falls under good APC rating. The VES 8 delineated 4 geo-electric layers which represents the QH curve type.

The resistivity of the topsoil is 101.5 Ωm indicative of silt with a thickness of 0.8 m, it is underlain by successive sequences of clay. The second layer has a resistivity of 20.8 Ωm and a thickness of 2.5 m, the third layer has resistivity of 5.7 Ωm with a thickness of 1.8 m and the fourth layer has a resistivity of 53.8 Ωm with a thickness of 31.3 m. The Total Longitudinal Unit Conductance computed for the profile is 1.023 which falls into the good APC rating. The ninth station occupied (VES 9) penetrated a total of four geo-electric layers of the QH curve type. The overburden material had a resistivity of 100.5 Ωm associated with silt 0.7 m thick. The second layer was 2.3 m thick with a resistivity of 19.6 Ωm characteristic of clays. The third layer had a layer thickness of 3.4 m and a resistivity of 7.4 Ωm depicting clays and the fourth layer had a thickness of 25.8 m and a resistivity of 50.5 Ωm also associated with clays. The Total Longitudinal Unit Conductance of VES 9 was 1.092 mhos, this value fell into the class of good APC rating. VES 10 delineated a total of four geo-electric layers of the QH curve type. The geo-electric parameters consisted of a top soil with resistivity of 70.7 Ωm characteristic of silty clays with a thickness of 0.8 m and successive layers of clays with resistivities 24.6 Ωm, 14.3 Ωm, 65.5 Ωm with corresponding successive thicknesses of 3.1 m, 5.4 m, 42.0 m. The computed Total Longitudinal Unit Conductance was 1.155 mho which implied a good APC rating.

4. Conclusion

Electrical Resistivity method has been successfully used to generate first and second order geo-electric parameters to investigate and classify or rate the vulnerability of the shallow aquifer across the Federal University Otuoke campus. Results showed that VES's 1, 2 and 3 have Aquifer Protective Capacity rated poor, hence aquifers in this area are vulnerable or prone to contamination and pollution from surface sources. Any waste disposal site or pollution source located around these stations on the campus has the potential to infiltrate or percolate into the shallow aquifer in the area. VES station 4 has a moderate APC rating, which implied that the overburden material in this area will slow down but not totally impede the infiltration of contaminants from the surface. VES's 4 – 10 all showed good APC rating, implying non vulnerability of shallow aquifers to infiltration and contamination from surface sources. It is strongly recommended that information of overburden vulnerability to contamination be taken into consideration when siting waste disposal or pickup points and also effluent discharge areas across the campus in order to protect the quality of groundwater resource in the area and avert health and environmental implications that can be caused by infiltrated surface pollution sources.

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