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DEDUCTION OF GROUNDWATER POTENTIAL FROM GEO-ELECTRIC DATA IN SARDAUNA MEMORIAL COLLEGE KADUNA, NORTH-WESTERN NIGERIA

BY

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Abstract

Vertical Electrical Sounding (VES) employing the Schlumberger Electrode configuration was used to provide information about the subsurface lithology with the aim of evaluating its groundwater potential through deductions from Geo-electric data. A total of 25 VES points ware sounded along the five profiles with five sounding station per profile, covering a total area of about 10000M^2. The VES data acquired were used to produce the VES curves, the coefficient of reflection and longitudinal conductance map. The VES curves were interpreted using **ipi2win** resistivity computer software and the iso-maps of the coefficient of reflection and longitudinal conductance ware produced using **surfer11** software. The results of the investigation revealed that the survey area is dominated by a maximum of four layers, namely; top soil which is mainly dominated by lateritic soil, the weathered basement, the fractured basement and the fresh basement. The water bearing zone (aquifer) was captured within the fractured zones of the study area and the excellent locations were identified to be located at south-west zone of the study area because of the positive correlation between the two maps produced. This area was having a high promising potential for borehole citing

Introduction

Groundwater exploration is gaining more and more importance in Nigeria owning to the ever increasing demand for water supplies. Already ten percent of the world's population is affected by chronic water, scarcity and this is likely to rise to one-third by 2025 (WHO,1996). The water scarcity experienced by people led to the search for surface water supply. Surface water which mostly occurs ins rivers are subjected to pollution. It is sad to say that most of the rivers in Nigeria are highly polluted, the pollutants being as a result of man activities via industrial and petroleum exploration activities. Despite the reported favorable groundwater situations the world over, the Nigeria situation appears to be restricted by the fact that more than half of the country is underlain by sedimentary formation. These rocks comprise mainly of sandstones, Shales, Clay and hard crystalline impervious rocks which are either igneous and or lime stone (Offodile,1993) Groundwater accounts for about one – third of the earth's water or about 20 times more than the total found in the rivers and lakes (fadhil, 2009) .Very deep lying groundwater can remain undisturbed for thousand or millions of years. Groundwater is of major importance to civilization because it is the largest reserve of drinkable water in region where human can live. Groundwater may appear at the surface in the form of springs, or it may be tapped by boreholes. During the dry periods it can also sustain the flow of surface water and even where the latter is readily available; groundwater is often preferable because it tends to be less contaminated by waste and organisms. The rate of movement of groundwater depends on type of subsurface material in a given Area.

The present water hardship experienced by inhabitant of Sardauna Memorial College is as a result of increase in the population due to the rapid development of the area, and this have put high demand on water assessment and management. In a bid to ameliorate this present condition, it has become imperative to carry out a geophysical survey which will provide information to the people on the water bearing formation and groundwater potential of the area. It is therefore expected that the results obtained from this work would produce detailed information on the groundwater condition and recommend areas where wells could be located within the study area. The present research is aimed at investigating the groundwater potential of the study area through the application of Electrical resistivity method to deduce zones of high groundwater potential.

Statement of Problem

Investigations for groundwater in complex basement structure is a difficult task since these structures control the groundwater flow and are more favorable site for the groundwater accumulation. Also Groundwater occurrence in basement rock is limited to the upper weathered section and fracture of the underlying fresh rock (Olorunfemi and Fasuyi, 1993) so, locating the exact point for its development has been problematic, hence the need for this research. Therefore, this research to investigate the occurrence of groundwater in basement rock located at Sardauna memorial college (S.M.C), in Kaduna North local government area of Kaduna state using Vertical Electrical Sounding (VES).

Aim and Objectives of the Study

The aim of this research work is to investigate the groundwater potential at the study area through the use of Geo-electric data. This will be achieved through the following objectives

I. To determine the number subsurface layers, their resistivity, thicknesses, and depth
II. To Investigate the hydrological conditions of the area with the view of delineating the potential area for groundwater development;
III. To produce the map of geo-electric parameter and correlate the maps in other to Locate possible and suitable site for productive boreholes in the study area.

Location of the Study Area

The study area under investigation lies in Sardauna Memorial College (SMC) Kaduna. It is located between Latitude $10^0\,346.00^1$N and $10^0\,347.4^1$N, Longitude $72^0\,658.87^1$E and $72^0\,658.00^1$E. It is a field with dimension 200m by 50. The produced orthographic projection map of the study area shown in Fig.1 below:

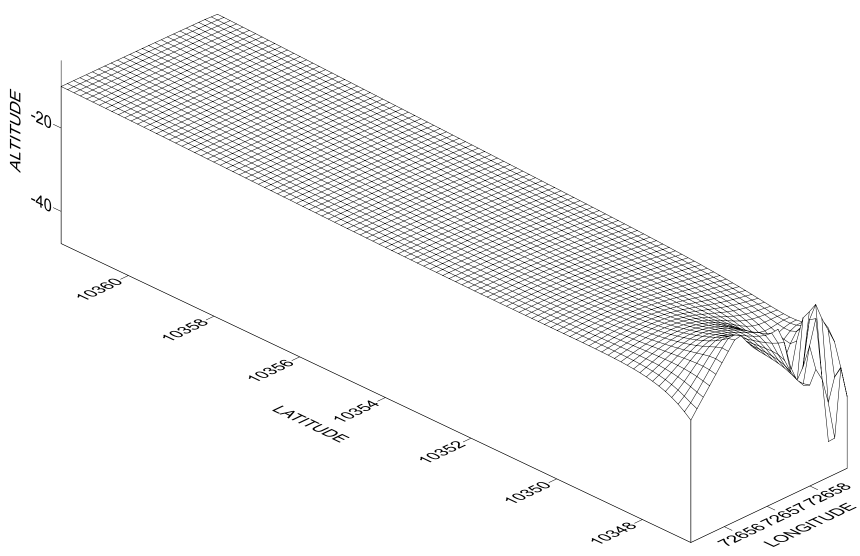

Fig.1 Orthographic Projection Map of the study area

Review of Previous Related Studies

Abdullahi and Udensi (2008) carried out vertical Electrical sounding Applied to Hydrogeology and Engineering investigation at Kaduna Polytechnic staff Quarters, Kaduna, Nigeria. The investigation is aimed to delineate the best site for locating borehole and construction of engineering structure. The result of their work delineated a maximum of four geologic units comprising of the upmost layer (laterite, river-sand and gravel) followed by clayey sand, weathered basement and fracture/fresh basement .They also identified weathered/fracture basement zone as the main aquifer unit and high resistivity basement zones as competent zones for siting engineering construction works. Aboh, (2009) worked on the assessment of the aquifers in some selected village in Chikun local government area, Kaduna state, Nigeria using the Vertical Electrical Sounding (VES) technique with the aim of determining the configuration of the aquifer within the study areas. The study specifically identify the nature, extent and spatial distribution of the component of the aquifer in the study areas in order to provide information on the groundwater potentials for improved exploitation of the water resources. The results suggest that the area is underlain by three to five layers. The geologic section derived from the analyzed geo-electric section suggest that the alluvial deposits of sand, silt and sandy clay as well as the weathered and fracture basement rock constitute the aquifer in the study areas. The average thickness of the aquifer was found to be 25m while the resistivity values of the aquifer component range from 100Ωm to 250Ωm.

Dogara , *et al.*, (2016); carry out about thirty(30) Vertical Electrical Soundings(VES) at Ungwan Ma'aji Dan-honou Village(Kaduna millennium city) using Schlumberger Electrode array, with the aim of identifying areas of high aquifer potential suitable for borehole drilling .The interpretation of the acquired field data suggests that the study area is underlain by three to five geoelectric layers with the weathered/fractured basement layer as the aquifer unit in the study area which has resistivity and thickness ranging from 36Ωm to 656Ωm and 10.0m to 48.7m respectively. Alao, (2016) investigate thirty (30) Vertical Electrical Sounding (VES) points in Millennium city, Kaduna, using schlumberger electrode configuration with maximum current electrode spacing of 100m. The interpreted data revealed that the study area is underlain by three to five geologic formations. He concluded that areas with high thickness of the weathered layer and low resistivity values underlain by the fracture zone have been successfully identified as potential aquifer zone and are target areas for groundwater exploitation.

Electrical Methods

Electrical Methods have been extensively used in groundwater geophysical investigation because of the correlation that often exist between electrical properties, geologic formations and their fluid content (Stewart, 1986). Most electrical techniques induce an electrical current in the ground by directly coupling with the ground. The resulting electrical potential is then used to measure the variation in ground conductivity, or its inverse, resistivity. Different material and the fluids within them will show different abilities to conduct electric current. In general, sequences with high clay content show higher conductivity as do saturated sequences and especially sequences where saline (or sometimes other contamination) fluid are present. Common field practice for electrical surveying relies on directly placing an electrical current into the ground (direct current electrical resistivity surveying) and measuring the response (electrical potential drop) to that current over a distance

Application of Geo-Electrical Method in Aquifer

The geo-electrical method is extensively applied in aquifer studies for various purposes, including aquifer characterization, groundwater exploration, and contaminant plume delineation.

- Aquifer Mapping and Characterization: Geo-electrical surveys help in delineating aquifer geometry, identifying lithological variations, and estimating aquifer properties such as hydraulic conductivity and porosity (Revil & Cathles, 1999).
- Groundwater Exploration: Geo-electrical methods are used to locate potential groundwater resources by mapping subsurface resistivity anomalies indicative of saturated zones (Aizebeokhai & Oyeyemi, 2014).

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- Aquifer Monitoring and Management: Continuous or periodic geo-electrical surveys can monitor changes in aquifer properties, groundwater levels, and contaminant plumes over time, aiding in aquifer management and remediation efforts (Slater & Lesmes, 2002).
- Saltwater Intrusion Detection: Geo-electrical surveys can delineate the extent and movement of saltwater intrusion into freshwater aquifers by mapping changes in resistivity associated with salinity gradients (Johnson & Appel, 2001).
- Aquifer Vulnerability Assessment: By integrating geo-electrical data with hydrogeological models, aquifer vulnerability to pollution from surface activities or industrial sites can be assessed (Masi *et al.,* 2018).

Theory of Electrical Resistivity

According to Keller and Fresknecht (1996), the simplest approach to the theory of the earth resistivity measurement is to consider a continuous current flowing in an isotropic homogenous medium whereby the point electrodes delivering current (I) amperes is located at the surface of the medium (Telford 1990) fig.2. The equation giving its potential about a single point source of current is given in equation 2.1

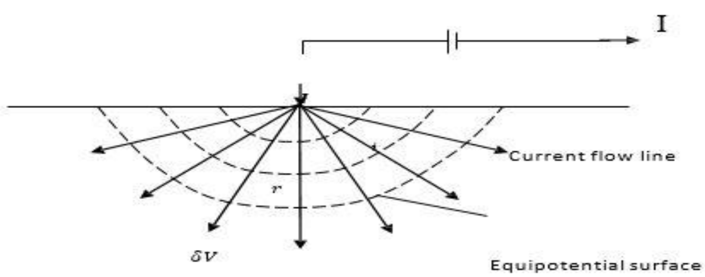

Fig.2 current flow from a single surface electrode

i. Ohm's law

$J = \sigma E$ (2.1)

i. The divergence condition

$\nabla . J = 0$ (2.2)

The electric field is the gradient of a scalar potential

$E = -\nabla U$ (2.3)

Substituting (2.3) into equation (2.1) gives

$J = -\sigma \nabla U = -\frac{1}{\rho} \nabla U$ (2.4)

Substituting equation (2.4) into equation (2.2) gives

$\nabla . j = \nabla . (-1\frac{1}{\rho} \nabla U) = -\frac{1}{\rho} \nabla^2 U = 0$ (2.5)

Where U is a scalar potential function defined such that E is its gradient as in equation (2.3). in spherical polar coordinates the laplace equation is :

$\nabla^2 U = \frac{1}{r2} \frac{\partial}{\partial r}(r^2 \frac{\partial U}{\partial r}) + \frac{1}{r2\ sin\theta} \frac{\partial}{\partial \theta}\left(\sin\theta \frac{\partial u}{\partial \theta}\right) + \frac{1}{r2} \frac{1}{\mathrm{r2sin2}\ \theta \partial \psi 2} = 0$ (2.6)

If only a single source of current is considered, complete symmetry of current flow with respect to θ and φ direction may be assumed so that derivatives taken in these directions may be eliminated from equation

$\frac{d}{dr}(r^2 \frac{dU}{dr}) = 0$ (2.7)

This may be integrated directly: thus,

$(r^2 \frac{dU}{dr}) = C$ (2.8)

Or

$\frac{dU}{dr} = \frac{C}{r2}$ (2.9)

and

$U = -\frac{C}{r} + D$ (2.10)

Where C and D are constant, but U = 0 When r⟶ ∞ Thus we get D = 0 .In addition all the current flows through a hemispherical surface in the medium. Thus, the total current crossing a hemispherical surface is giving by

$I= 2\pi r^2 J$ (2.11)

Substituting equation (2.4) into equation (2.11)

$I = 2\pi r^2 (-\frac{1}{\rho}\frac{dU}{dr})$ (3.12)

$I = 2\pi r^2 (-\frac{1}{\rho}\frac{C}{r2}) = -\frac{2\pi C}{\rho}$ (2.13)

From above $C = -\frac{I\rho}{2\pi}$ and substituting this in equation (2.15)

$U= - (-\frac{I\rho}{2\pi})\frac{1}{r} + D = 0$ (2.14)

If we now consider an arrangement consisting of a pair of current C1, C2 and a pair of potential electrodes P1, P2 as shown in fig 3. Current electrodes M and N act as source and sink, respectively .At the detection electrode P1 the potential due to the source C1 is $+\frac{I\rho}{2\pi r1}$ while the potential due to the sink C2 is $-\frac{I\rho}{2\pi r2}$

The combined potential at P1 is

$V_1=\frac{I\rho}{2\pi r1} - \frac{I\rho}{2\pi r2} = \frac{I\rho}{2\pi}(\frac{1}{r1} - \frac{1}{r2})$ (2.15)

Similarly, the resultant potential at P2

$V_2 = \frac{I\rho}{2\pi r3} - \frac{I\rho}{2\pi r4} = \frac{I\rho}{2\pi}(\frac{1}{r3} - \frac{1}{r4})$ (2.16)

The potential difference measure by a voltmeter connected between P1 and P2 is

$\Delta V = V_1 - V_2 = \frac{I\rho}{2\pi}\{ (\frac{1}{r1} - \frac{1}{r2}) \} - (\frac{1}{r3} - \frac{1}{r4}) \}$ (2.17)

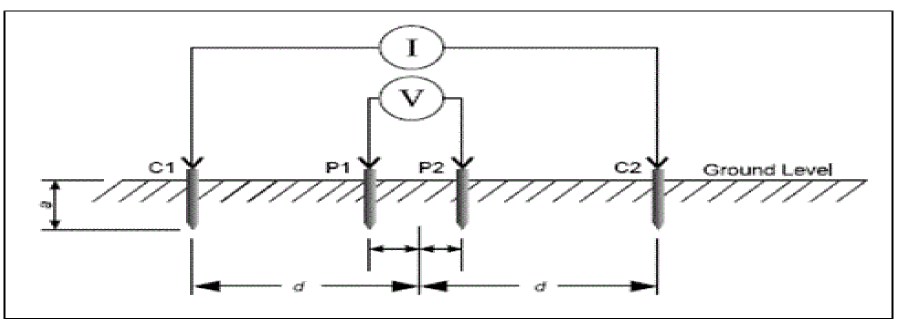

Fig. 3 the general Schlumberger configuration of a pair of current electrodes (C1, C2) and a pair of potential electrodes (P1, P2).

Apparent Resistivity

If we re-arrange the terms in equation (2.13) so as to make ρ the subject of the formula we have

$\rho = \frac{2\pi\Delta V}{I} = \frac{\Delta V}{I}\, k$ (2.18)

Where $K = \left[\frac{2\pi}{(\frac{1}{r1}-\frac{1}{r2})-(\frac{1}{r3}-\frac{1}{r4})}\right]$ is known as geometric factor

The physical quantities measured in the determination of field resistivity are the current I flowing between two electrodes; the difference in potential ΔV between two measuring point M and N and the distance between the various electrodes. Thus, by measuring ΔV and I and knowing the geometric factor (K), we obtain the resistivity ρ. Equation (2.18) can be used to compute the resistivity (ρ) of the earth only if the earth is completely uniform. Thus, over homogeneous isotropic ground this resistivity will be constant for any electrode arrangement. So if the current is maintained constant and the electrode are move around .the potential difference ΔV will adjust at each configuration to keep the ratio ($\frac{\Delta V K}{I}$) constant. Hence the equation (2.18) applies for the ordinary four terminal array used in measuring earth resistivity.

If the earth is not uniform or is inhomogeneous however, and the electrode spacing is varied, then the ratio will be generals' change. The result is a different value of ρ for each measurement. Obviously the magnitude is intimately involved with the arrangement of electrodes (Telford *et al.*, 1990). This measured quantity is known as the apparent resistivity ρ_a and equation (2.18) may be used as a definition for the apparent resistivity of the earth .so, apparent resistivity is defined as the product of the geometric factor calculated for a homogeneous medium and the resistance actually measured in a non-homogeneous environment.

Material Used

i. Ohmega Resistivity Meter (Ω)
ii. Electrodes
iii. G.P.S
iv. Ranging Pole
v. Measuring Tape
vi. Hammer
vii. Crocodile Clip
viii. Connecting Cables

Data Collection

The current electrodes and the potential electrodes were driven into the ground at the marked point (VES POINT). The electrodes were hammered dip down into the ground so as to obtain contact between the ground and the electrodes (fig.3). In each case at each VES point, the potential electrodes were fixed symmetrically about the VES point while the current electrode spacing was expanded symmetrically and progressively about the Centre of the array. When the potential difference measured between the potential electrodes became too small for the potential to be measured accurately the half potential electrode spacing (MN/2) was increased and the measurement continued according to some selected (AB/2 versus MN/2) interval. This is known as changeover or cross over point. The half current electrodes spacing (AB/2) range from 1 to 100m while the half potential electrodes spacing (MN/2) range from 0.3 to 5m.The array used for this survey is Schlumberger array the, advantages of the Schlumberger array are fewer electrodes need to be moved to each sounding and the cable length for the potential electrode is shorter. Schlumberger sounding generally have better resolution, greater probing depth, and less time-consuming field deployment than the wenner array. The disadvantages are that long current electrode cable is required, the recording instrument needs to be very sensitive, and the array may be difficult or confusing to coordinate amongst the field crew (Keller, 1966).

Result Interpretation

Vertical Electrical sounding curves that can be obtained from **ipi2win** which is interpreted qualitatively using simple curve shape give the number of the subsurface layer, their resistivity, thickness and depth for each layers (fig.4).
This information obtained from the computer modeling (curve) were used to produce the contour such as iso-resistivity map using the software called **surfer 11**

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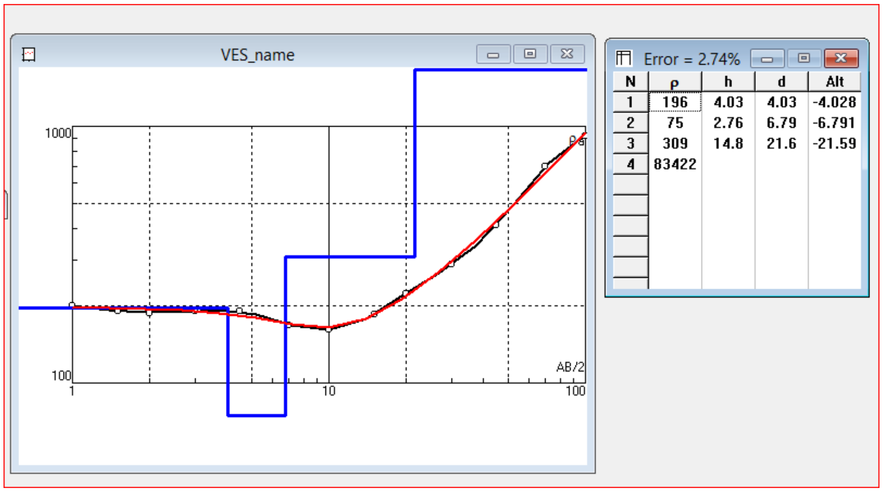

Fig.4 Resistivity curve mode of profile 1VES 1(P1V1)

Coefficient of Reflection (C_R) Map

Figure 5 below shows the coefficient of reflection map of the study area. The map produced with contour interval of 0.05, shows that the coefficient of reflection values varies from 0.2813 to 0.9949 with an average value of 0.721. According to (Olayinka*et al.*, 2000), VES points with coefficient of reflection less than 0.9 are high density water filled fracture zone. Based on the map produced, the part of the mapped area in the north-west, north-east, and small portion of north-west of the study area have coefficient of reflection less than 0.9. Hence, the area is characterized with high density water filled fractures.

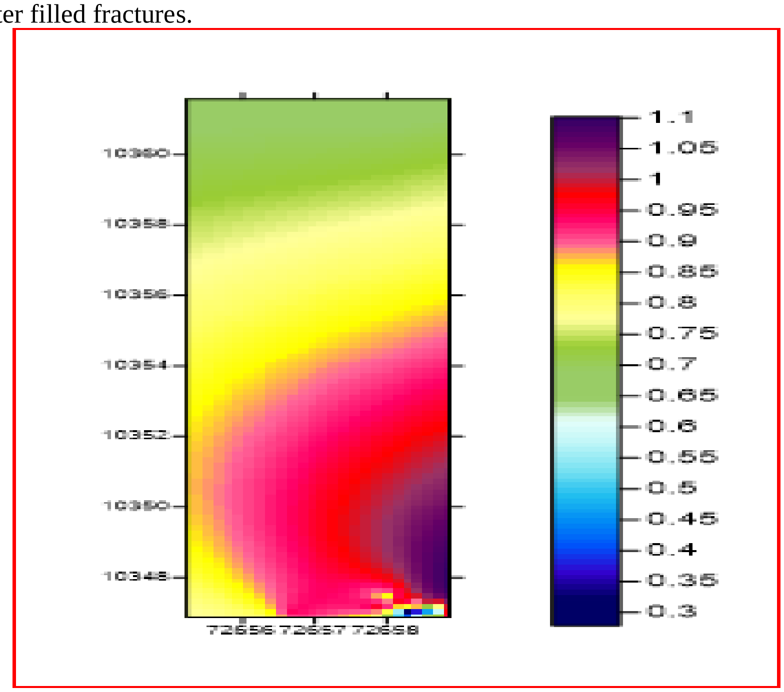

Fig 5 coefficient of Reflection map

Longitudinal Conductance Map

The fig.6 shows a longitudinal coductance iso-map .The conductance values vary from 0.0827Ω^{-1} to 0.6455Ω^{-1} with an average value of 0.360Ω^{-1} . The coductance values increasease toward the south-west of the contour map. As the conductance increases, the resistivity naturally decrease, pointing toward groundwater potential aquifer (Gowd, 2004). The VES ponts fall within south-west is a water bearing zone, this area has a positive correllation with the coefficient of reflection map. Therefore, the zone is regarded as the excellent area for groundwater potential and the north-west is been considered as the moderate zone.

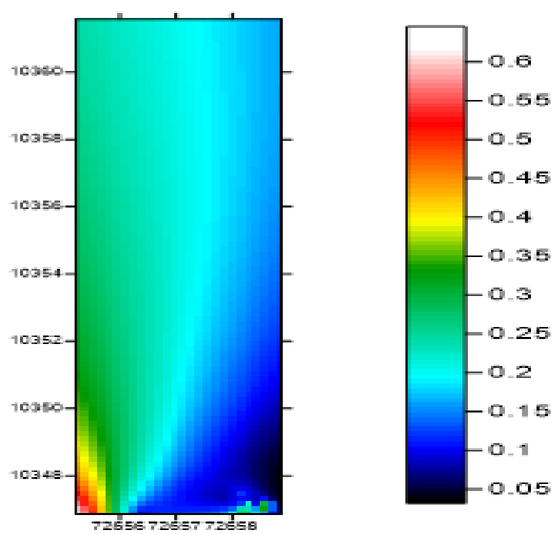

Fig.6 Longitudinal conductance map

The information obtained from the curves (fig4) and that of the maps (fig.5 and 6) using the software called **surfer 11** and **ipi2win**, and also applying equation (2.19 & 2.20), the interpreted results obtained were summarized in table 1 below

Table 1: Showing Geo-electrical parameters

VES Points	Coefficient of Reflection	Longitudinal Conductance
P1V1	0.9824	0.09
P1V2	0.7589	0.0884
P1V3	0.6692	0.1665
P1V4	0.8157	0.0993
P1V5	0.7628	0.6455
P2V1	0.8373	0.1049

P2V2	0.94	0.1139
P2V3	0.7514	0.1254
P2V4	0.425	0.6371
P2V5	0.2769	0.396
P3V1	0.2917	0.1822
P3V2	0.4047	0.5896
P3V3	0.4047	0.1343
P3V4	0.2855	0.0937
P3V5	0.2813	0.1561
P4V1	0.7615	0.0821
P4V2	0.8839	0.0852
P4V3	0.9979	0.0944
P4V4	0.9531	0.0899
P4V5	0.9737	0.0855
P5V1	0.9821	0.11665
P5V2	0.9949	0.0911
P5V3	0.95996	0.0827
P5V4	0.8309	0.1365
P5V5	0.8042	0.0837

The Longitudinal conductance(S) and co-efficient of Reflection

The longitudinal conductance (S) and co-efficient of reflection are Geo-electrical parameters used to defined the target areas of groundwater potential. High S values indicate relatively thick geologic succession and should be accorded with the highest priority in terms of groundwater potential while low S values reflect thin geologic succession with low groundwater potential (Masi *et al.,* 2018). .Also according to Gowd *et al.*,2004 , as the longitudinal conductance increase the, resistivity naturally decrease pointing toward the groundwater potential .The total longitudinal conductance is given by the expression as

$$S= \sum_{i=1}^{n} \frac{hi}{\rho i} = \frac{h1}{\rho 1} + \frac{h2}{\rho 2} + \frac{h3}{\rho 3} + \text{--------------------------------} - \frac{hn}{\rho n} \qquad (2.19)$$

Where hi and ρi are the saturated thickness of each of the layers and their corresponding resistivity.
The coefficient reflection at a fresh basement rock interface can provide some insight into the aquiferous nature of the basement rocks. According to Olayinka *et al.,* 2000 .He observed that areas of lower reflection coefficient values(< 0.9) exhibit a fracture of the basement rocks, and has a high density water filled fracture .The coefficient of reflection is defined as.

$$C_R = \rho_n - \rho_{n-1}/ \rho_n + \rho_{n-1} \qquad (2.20)$$

Where ρ_n is the resistivity of the n^{th} layer and ρ_{n-1} is the resistivity overlying the n^{th} layer.

Summary

A geophysical survey was carried out with electrical resistivity method using Schlumberger electrode configuration to investigate the subsurface configuration of some parts of Sardauna Memorial College Kaduna state. During the investigation a total of twenty-five (25) VES points were established on five profiles using Schlumberger array configuration. The interpretation revealed three to four subsurface layers. After comparing the two maps it was found that there is agreement between the two from which conclusion was made.

Conclusion

A total of 25 VES ware made along the five profiles with five sounding station per each profile within an area of about 10000M^2,... electrical resistivity method was used to acquired Geo-electric data. The data were processed using computer software. The processed information revealed that the survey area was characterized by four layers with varying resistivity values and thickness. The four layers discovered were top soil that consists of mainly the lateritic soil, the weathered basement, the fractured basement of the pre-Cambrian age and the fresh basement. The aquiferous water bearing zone was identified within the fractured zones of the study area and the excellent locations were identified to be located at south-west zone of the study area. This area was having a high promising potential for borehole citing.

Recommendations

Considering the acute drinking water facing both rural and urban Nigeria; it is therefore necessary to carry out geophysical investigation to access the aquifer layering of the study area. In the study area, there was no record or evidence of any geophysical investigation in the study area in the past. As a result of this, conclusion derived cannot be compared with any previous results. It is recommended therefore; that further geophysical investigations employing other methods should be carried out so as to validate this result and have detailed information about the subsurface in the study area. Also, it is recommended that the south-west zone of the study area should be used for borehole installations.

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