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Research Article

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Geostatistical Analysis of the Geolectrical Parameters of Mechanic Village, Bodija, South Western Nigeria

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Abstract Geostatistical Analysis of the Geolectrical parameters obtained at mechanic village Bodija Ibadan was evaluated using Electrical Resistivity sounding method. Seven electrical soundings were conducted using the Schlumberger configuration. The parameters analyzed are resistivity and thickness of topsoil, resistivity and thickness of aquifer, resistivity of bedrock, overburden thickness, longitudinal unit conductance, hydraulic conductivity and transmissivity. The range of values recorded by the longitudinal unit conductance was (0.01-0.29 Siemen), hydraulic conductivity $1.16x10^{-5}$-$4.45x10^{-5}$ m/s) and transmissivity ($7.8x10^{-5}$-$197x10^{-5}m^2/s$) could be attributed to the clay content in the aquifers which affect the porosity of the layer. The resistivity of weathered layer has a low range of values 22.3-171 Ωm with an average value of 101.7ohm-m and a low standard deviation value of 12.8. The low range in value of the layer signifies the extent of yield of boreholes. Weathered and fractured horizons which underlie VES stations constitute the aquifer zones was identified. The overburden layer of the study area is relatively thick and has low resistivity, therefore should be considered for groundwater exploration.

Keywords Aquifer zones, fractured horizon, Geolectrical parameters, Geostatistical analysis, Weathered layer

Introduction

Groundwater is a preferred water source in many instances because, having been filtrated by the soil, its quality is generally good. Also, it is readily available and often regarded as the only source of freshwater available due to its better spatial extension and distribution. It also represents 97 % of the planet's fresh water [1]. The availability of quality water resources has always been the primary concern of societies in semi-arid and arid regions, even in areas of more abundant rainfall, the problem of obtaining adequate supply of quality water is generally becoming more acute due to ever increasing population and industrialization. As a result of this, surface water cannot be dependable throughout the year, hence, there is need to look for other alternatives to supplement surface water. This makes the world depend on the largest available source of quality fresh water which lies underground and this is referred to as Groundwater. It is the water held in the subsurface within the zone of saturation under hydrostatic pressure below water table [2].

There are numerous methods that can be used for groundwater exploration such as remote sensing, geologic method, electrical resistivity, electromagnetic method and induced polarization. Among these methods, the electrical resistivity method is the most useful for groundwater exploration most especially in the Basement terrain. Groundwater can be in Sedimentary terrain where it is less difficult to exploit except for its chemical composition. It can also be in the Basement Complex terrain where it can be a bit difficult to locate especially in areas underlain by crystalline unfractured or unweathered rocks. The research for groundwater today has become essential, due to its relative low cost and its chance of obtaining quality water from the bedrock.

In the work of [3], they noted that the delineation of water occurrence in weathered rocks can be greatly accomplished by the use of suitable techniques. Crystalline basement rocks in Nigeria are located in areas of high relief where runoff is high and infiltration rate is very low [4]. These rocks are devoid of primary porosity and permeability.

In the study of underground structures for the identification of water bearings layers, electrical resistivity method is usually found suitable [5].

Location and Geology of the study Area

The study area is located on latitude 7.4358 ^{o}N and longitude 3.9191 ^{o}E in Bodija, mechanic village Ibadan; and lies within the South-Western part of the Nigerian Precambrian basement complex, occupying approximately 50 % of the surface area of the country, as part of the pan African crystalline shield (fig 1).

The dominant rock types in Ibadan area are quartzite, banded gneiss and granite gneiss. Associated rock suites found in all the major outcrops in the study area include pegmatite and quartz veins. Generally, wells from quartzite produce more water than wells from other rock types. This is because their transmissivity and permeability are higher due to the presence of fissures and quartzite veins [6-7].

Methodology

Electrical resistivity method was used in this study. The fundamental equation for resistivity survey is derived from Ohm's law [8-9]

$$\rho = RA/L \qquad (1)$$

where, p is resistivity, L is length of homogenous conducting cylinder and A is cross sectional area. For the solid earth, whose material is predominantly made up of silicates and basically non-conductors, the presence of water in the pore spaces of the soil and in the rock fractures enhances the conductivity of the earth when an electrical current I is passed through it, thus making a semi-conductor. Since the earth is not like a straight wire and it is anisotropic, then equation 1 is thus customized to:

$$\rho = \Delta V/I.\ 2\pi r \qquad (2)$$

where, ΔV is change in voltage and r is the radius of current electrode's small hemisphere. Since the earth is not homogenous, equation 2 is used to define an apparent resistivity ρ_a which is the resistivity the earth would have if it were homogenous

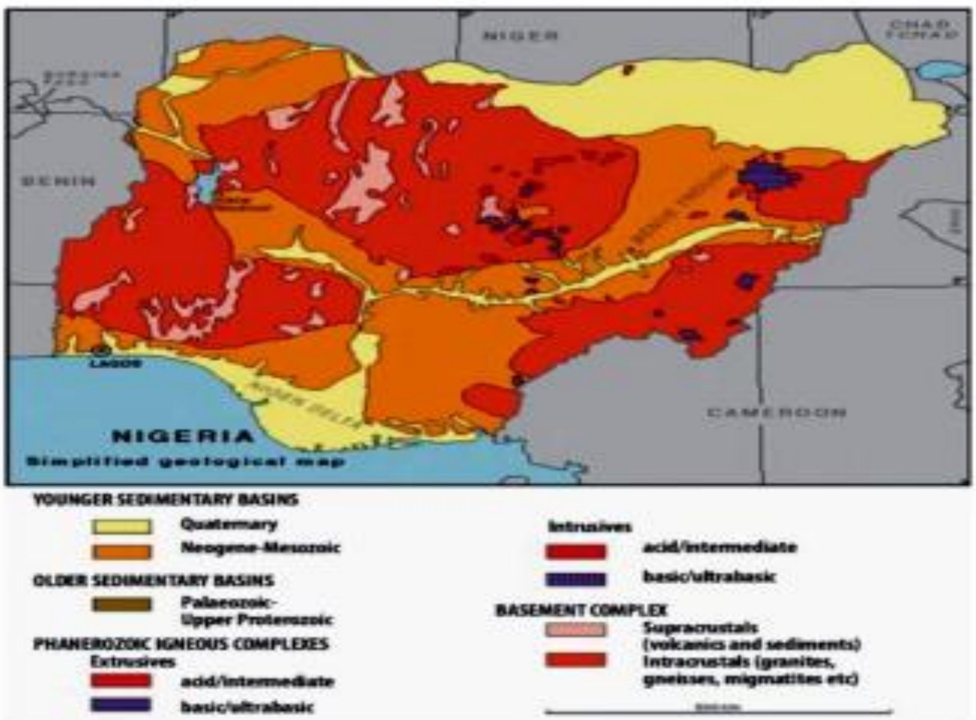

Figure 1: Regional Map of Nigeria (after Ajibade 1979)

$$\rho a == \Delta V/I.\ 2\pi r \qquad (3)$$

where, 2πr is then defined as a geometrical factor G fixed for a given electrode configuration. The schlumberger configuration was used in this study. The geometric factor G is thus given as:

$$G = \frac{2\pi}{\{\left(\frac{1}{AM}\right)-\left(\frac{1}{BM}\right)-\left(\frac{1}{AN}\right)+\left(\frac{1}{BN}\right)\}}. \quad (4)$$

In Schlumberger array, AM = $\frac{a-b}{2}$, BM = $\frac{a+b}{2}$, AN = $\frac{a+b}{2}$and BN = $\frac{a-b}{2}$. (5)

$$\text{I.e. } G = \frac{2\pi}{\{\left(\frac{1}{a}\right)-\left(\frac{b}{2}\right)-\left(\frac{1}{a}\right)+\left(\frac{b}{2}\right)-\left(\frac{1}{a}\right)+\left(\frac{b}{2}\right)-\left(\frac{1}{a}\right)+\left(\frac{b}{2}\right)+\left(\frac{1}{a}\right)-\left(\frac{b}{2}\right)\}} \quad (6)$$

$$= \pi\,(a^2/b - b/4) \quad (7)$$

From p_a = GR =π R (a^2/b – b/4) where a is half array length and b is the minimum spacing between the potential electrodes. In this work the Schlumberger array was employed because it requires less man- power and it is less sensitive to the effects of near surface lateral in homogeneities than the Wenner arrangement [10-11]. These advantages bring about a realistic quantitative interpretation of field data obtained.

Where AB is current electrode spacing and MN is spacing between potential electrodes (fig. 2)

Schlumberger Electrode Configuration

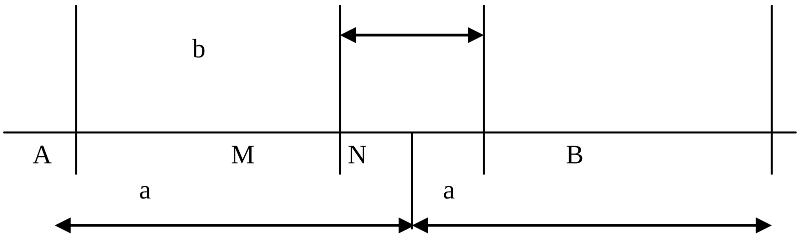

Figure 2: Schlumberger Electrode Configuration

The electrical resistivity survey of the area can give information at locations where neither gravity nor magnetic anomalies can exist for horizontal bedding. Furthermore, the electrical resistivity method can be used where structure is not too complicated; apparent resistivity can be estimated with minimum error although the apparent resistivity is diagnostic to some extent, of the actual resistivity of a zone in the vicinity of electrode array, the apparent resistivity reflects the true resistivity only in homogenous ground. The resistivity of rock formation varies over a wide range depending on the resistivity of the rock grains, pore size, shape, grain size, water content and saturation quality and temperature. Schlumberger electrode Configuration was adopted for the acquisition of seven (7) vertical electrical sounding data in the study area. The ABEM SAS 1000 equipment used displays the resistance of the earth materials in Ohms.

Results and Discussion

Simple statistical analysis of the geoelectrical parameters has been carried out on the seven schlumberger VES data obtained from the study location.Basic parameters analyzed include resistivity and thickness of topsoil,resistivity and thickness of aquifer layer, resistivity of bedrock,overburden thickness,longitudinal unit conductance,hydraulic conductivity, and transmissivity. The results of geoelectric parameters and geostatistical analysis are hereby presented in tables 1 and 2 respectively using statistical package for sciences (SPSS).

Table 1: Geoelectric Parameters Analyzed

VES NO	TOP Layer Resistivity (Ωm)	TOP Layer Thickness (m)	Weathered Resistivity (Ωm)	Weathered Thickness (m)	Bedrock Resistivity (Ωm)	Overburden Thickness (m)	Longitudinal Conductance (Siemen)	Hydraulic Conductance (m/s)	Transimissi-vity (m^2/s)
1	191.8	1	76.4	8.3	231.5	12.3	0.1	1.69	20.8
2	472.1	1.8	122	31.7	2239.2	33.5	0.01	2.97	99.5
3	242.6	1.1	148	10.1	277.9	11.1	0.06	3.74	41.5
4	162.3	1.6	22.3	3.5	201.5	5.1	0.15	3.9	19.9
5	145.1	1	171	28.7	881.7	31.8	0.16	4.45	141.5
6	168.9	1.1	116	34.2	2134	70.6	0.29	2.8	197.7
7	117.7	1.4	55.9	10.376	2028.6	6.8	0.18	1.16	7.8

Table 2: Results of Geostatistical Analysis

Geoelectric Parameters	Range	Mean	Median	Mode	S.D	Variance	Skewness
Topsoil Resistivity	117-472	214.3	168.9	117.7	120.1	14442.21	2.1
Topsoil Thickness	1-1.8	1.28	1.1	1	0.318	0.101	0.78
Weathered Resistivity	22.3-171	101.7	116	22.3	52.7	2782.7	-0.26
Weathered Thickness	3.5-34	18	10.3	3.5	12.8	165	0.307
Bedrock Resistivity	201-2239	1142	881.7	201	957.6	916991	0.19
Overburden Thickness	5.1-70	24.5	12.3	5.1	23.3	546.2	1.5
Longitudinal Conductivity	0.01-0.29	0.13	0.15	0.01	0.09	0.00822	0.4
Hydraulic Conductivity	1.16-4.45	2.95	2.97	1.16	1.2	1.43178	-0.44
Transmissivity	7.8-197	75.5	41.5	7.8	72.6	5281.26	0.87

Resistivity and thickness of Topsoil

The value of topsoil resistivity ranges from 117-472 Ωm. The range of resistivity values suggests similarities in the composition of materials constituting the topsoil in the study area. The mean value of topsoil thickness is 1.28m with a very low standard deviation of 0.318.

Resistivity and thickness of weathered layer

The resistivity of weathered layer has a low range of values between 22.3-171 Ωm. The low range in value of the layer determines to a significant extent the yield of boreholes [12]. The resistivity suggests lithology in the suite of sandy clay, clayey sand and shale/clay to be widespread. Hydrogeologically, the weathered layer is relevant in groundwater prospecting when it is thick enough, above minimum thickness of 10m suggested by [13], the layer could support hand dug well [14]. In this study area, the average value for the aquifer is 24.18m with a variance value of 165m which is relatively low and measures the degree of clustering of the data around the mean.

Resistivity of the Bedrock

It has a high mean value of 2239 Ωm. According to [15], the resistivity values that exceeded 1000 Ωm are of fresh bedrock and if less, the bedrock is fractured and saturated with fresh water. From table 1, it was shown that most location give low resistivity value less than 1000 Ωm (VES 1, 3, 4, 5). This gives a higher percentage of the whole study area. Therefore, it could be stated that areas with low bedrock resistivity's are the fractured zones and of good prospects in term of groundwater abstraction.

Longitudinal Unit Conductance

Using the equation Si = hi/pi where hi and pi are the i^{th} layer thickness and resistivity respectively [7]. The conductance is related to clay content which increases the porosity of a layer but decreases its permeability according to [16]. Figure 3 shows the bar chart of the Longitudinal Conductance of the study area. Since permeability decreases with an increase in conductance, therefore the overburden might have absorption and retention capacity. In the study area the conductance has a range of value between 0.01-0.29 with an average of 0.13 interpreted as weak conductivity according to [17] (Table 3). The longitudinal unit conductance is positively skewed.

Table 3: Modified Longitudinal Conductance/protective capacity rating [17]

Longitudinal unit conductance	Protective capacity rating
>10	Excellent
5- 10	Very Good
0.7 – 4.9	Good
0.2 – 0.69	Moderate
0.1 – 0.19	Weak
< 0.1	Poor

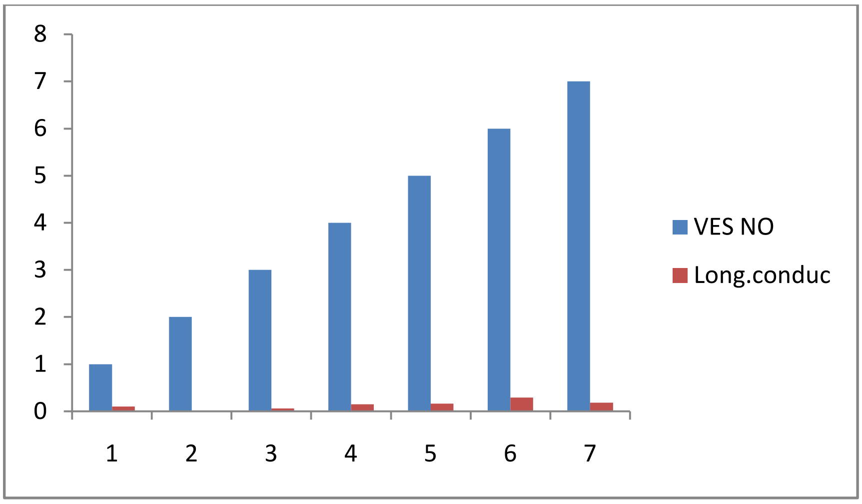

Figure 3: Bar chart of the longitudinal conductance of the study area

Hydraulic Conductivity (K)

Using the relation K $=95.5\times10^{-9}\ \rho^{1.195}$ where ρ is the resistivity of the porous layer in ohm-m [7, 18], the conductivities was found to vary from aquifer to aquifer and range from 1.16×10^{-5} m/s to 4.45×10^{-5} m/s with a mean value of 2.95 m/s. In general, these values are moderate which can be attributed to the clay content in the aquifers and the fact that the degree of hydraulic conductivity between the fractures is low. Figure 4 shows the Bar Chart of the Hydraulic Conductivity.

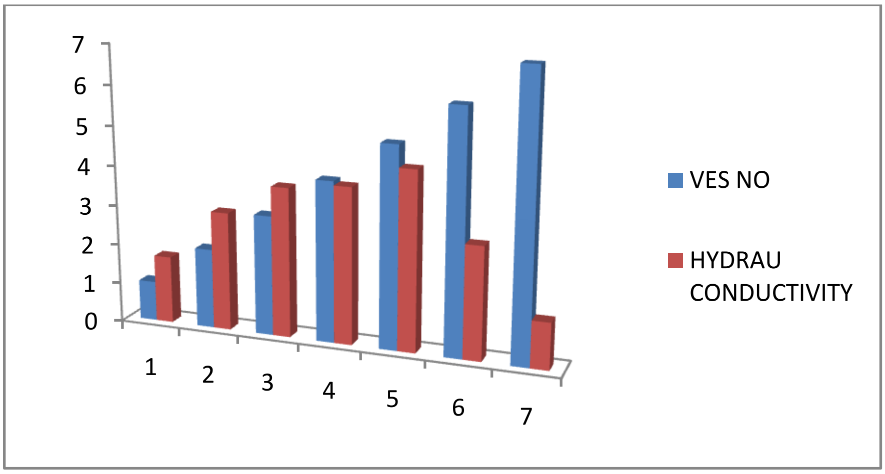

Figure 4: Bar chart of the hydraulic conductivity of the survey area

Transmissivity (T)

It is the rate at which water flows through a vertical strip of the aquifer of unit width and extending to full saturated thickness under hydraulic gradient 1.00.where transmissivity values are high, it implies good groundwater potential. Using T =Kh, where K is the coefficient of conductivity (m/s), h is the aquifer thickness (m), the estimates of T obtained in the study area shows that the value ranges from 7.8×10^{-5} -$197\times10^{-5}m^2/s$ .The transmissivity is very low in few locations; the values are expected to be higher than the values recorded. The weathered nature of the basement rock may be responsible for the relatively low transmissivity values. The average value recorded was 75.5 with a relatively high standard deviation value of 72.6 and it is positively skewed with value 0.87.

Conclusion

Electrical resistivity and geostatistical analysis of mechanic village Bodija, Ibadan has been evaluated. The longitudinal unit conductance value is between 0.01 and 0.29, the hydraulic conductivity value is between 1.16×10^{-5} and 4.45×10^{-5}, transmissivity value is between 7.8×10^{-5} and $197\times10^{-5.}$ The low range of values recorded by the longitudinal unit conductance, hydraulic conductivity and transmissivity could be attributed to the clay content in the aquifer which affects the porosity of the layer.

Weathered and fractured horizons which underlie VES stations constitute the aquifer zones have been identified in the study area and it is recommended that the area with low resistivity values should be considered for groundwater exploration.

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