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Research Article

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Characterization of Aquifer using Geostatistical Analysis of the Geoelectrical Parameters of Ijebu-igbo South Western, Nigeria

Sofiat A. Adekoya*, Joseph O. Coker, Omolara A. Adenuga

Department of Physics, Olabisi Onabanjo University, Nigeria

Abstract Electrical Resistivity method is widely used to investigate groundwater potential zones. This method was carried out at Ijebu-Igbo to determine depth to basement of locations in the study area and to delineate possible zones that can serve as aquifer. Ten (10) Vertical Electrical Sounding (VES) was conducted using Schlumberger electrode configuration in the investigated area. The field data were interpreted using both manual and computer iterations. The Geoelectrical Parameters analyzed includes resistivity and thickness of Topsoil, Weathered and fractured /fresh basement resistivity and thicknesses and depth to basement. Geostatistical analysis done is Longitudinal Conductance, Hydraulic Conductivity and Transmissivity. Based on the electrical resistivity survey conducted in the study area, the interpreted result revealed 3-4 geoelectric layers overlying the resistive basement, the topsoil, the weathered basement, partially weathered basement and fresh basement. The aquifer thickness has a mean value of 13.56m while the overburden thickness ranges from 8.8 to 43.9m. The evaluation of aquifer protective capacity has helped to classifythe area into moderate, weak and poor protective capacities with 50% of the study area zoned as weak to moderate aquifer protective capacity zone and the remaining half of the location falls into poor groundwater potential zone.

Keywords Aquifer, Electrical resistivity method, Geoelectric layers, Geostatistical Analysis, Groundwater

Introduction

Groundwater is generally taken as been the “free gift from God” and is often called a “hidden resource” because it cannot be seen in the same way as water in a river, lake or reservoir. The volumes of groundwater are large, however, it is estimated that there is about one hundred times more fresh groundwater beneath the Earth than all the freshwater in rivers and lakes [1]. Groundwater resources are gaining increasing importance and they represent an increasing proportion of the water supplies used for different applications [2].

Groundwater is the water that lies beneath the ground surface, filling the pore space between grains in bodies of sedimentary rock, filling cracks and crevices in all types of rock [3]. The primary source of groundwater is rain and snow that falls to the ground. A portion of this precipitation percolates down into the ground to become groundwater [4]. Recent researches shows that there is abundant groundwater potential that can serve the entire nation if properly exploited and it is readily available and is often the only source of fresh water available [5], therefore the development of ground water aquifer mapping and exploration constitute a viable option to the availability of quality water.

Ijebuigbo falls within the basement complex area of Nigeria hence, exploration of groundwater in this area is a very challenging and difficult task when the promising groundwater zones are associated with fractured and fissured media [6]. In hard rock environment, the groundwater aquifer depends mainly on the thickness of the weathered/fractured layer overlying the basement [7]. The weathered material, which constitutes the overburden, has high porosity and contains a significant amount of water, and, at the same time, it presents low permeability due to its relatively high clay content [8].

Geophysical survey involving electrical resistivity method constitutes one of the most reliable means, outside direct mechanical drilling, through which basement structures such as ancient river channels, basement depressions and fractured zones that are of hydrogeological significance can be mapped [9-12]. Analysis of these measurements can reveal how the physical properties of the earth's interior vary vertically and laterally and reflecting the subsurface geology.

However, this research is based on finding solutions to the problem of non-availability of government pipe borne water in Ijebu-Igbo which has adverse effect on the entire populace of Ijebu-Igbo. This research is aimed at determining the depth to the basement of locations in the study area and to delineate possible zones that can serve as aquifer from the various zones of anomalous Resistivity.

Location and Geology of the study area

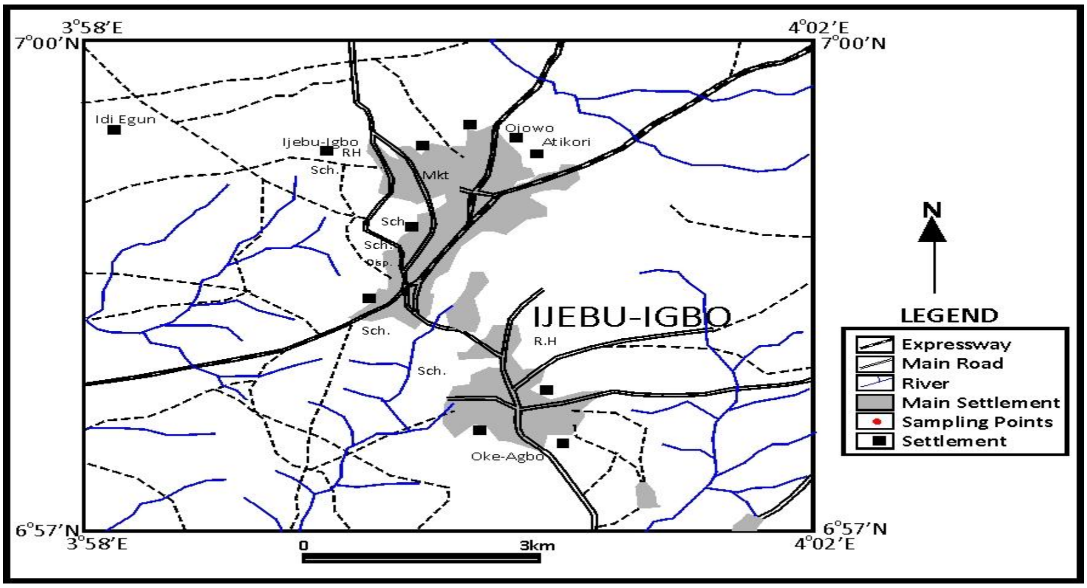

Figure 1: Location Map of the study area showing the sounding points

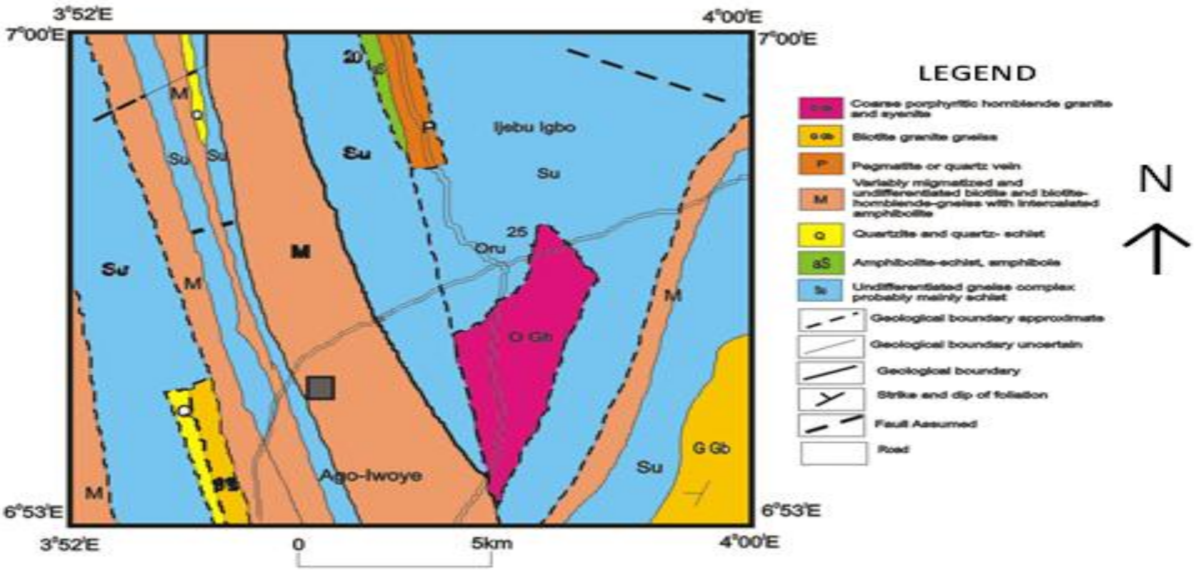

Figure 2: Geology map of the study area

Ijebu-Igbo figure 1 lies within latitude 6^0 57' N to 7^0 00' N and longitude 3^0 58' E to 4^0 02' E with an area extent of approximately 27.4 square kilometers. It is easily accessed through the Ago-Iwoye–Ijebu Igbo road that passes through Oru-Ijebu. The study area which is a part of Ogun state has the same climate that is characterized by a typical tropical climate consisting of alternating wet and dry season. The wet season typically lasts from March/April to October/November and the dry season last for the rest of the year starting from October /November to March/April.

The study area is part of the Southwestern Basement Complex of Nigeria and it is a representative of both the migmatite gneiss complex and the older granite, which shows structural disposition. The main lithologies include the amphibolites, migmatite gneisses, granites and pegmatites. The migmatite-gneiss complex occupies the Southwestern part and the South-eastern part of the area while older granite occupies the north, east and some parts of the western area (figure 2).

Materials and Methods

The electrical resistivity method involves the determination of subsurface resistivity distribution by taking ground surface measurements [13]. The true resistivity of the subsurface is estimated from these measurements. This requires passing electrical current (I) into the ground by means of two electrodes and the potential difference (ΔV) is measured between another pair of electrodes. Its apparent resistivity is represented by equation (1) [14]:

$$\rho_a = \frac{\Delta v}{I} G \qquad (1)$$

Where ρ_a is apparent resistivity and G is the geometric factor which value depends on the electrode array's geometric spread. . The mode of measurement adopted is the vertical electrical sounding (VES). For vertical electrical sounding technique involving the Schlumberger array with a four electrode configuration, the mid-point of the array is kept fixed while the distance between the current electrodes is progressively increased.

Hence, the apparent resistivity value is calculated using the equation (2) according to [13].

$$\rho_a = \frac{\pi R \left({}^{AB}/{}_2\right)^2}{MN} \qquad (2)$$

Where AB is current electrode spacing, MN is potential electrode spacing, R is electrical resistance and π is a constant equal to 3.142; from the expression in equation (2) that is for Schlumberger array, the distance between the potential electrodes is small compared to the distance [5].

The field data of the Vertical Electrical Sounding (VES) was processed with the WinResist software. The resistivity value and distance (AB/2) for each point at every station was entered into the software, after which the software plots the curve. The software then performs iteration to smoothen the curve until it gives a curve of best fit. The final smoothed curve is displayed with the Geoelectric parameters for each VES station given.

Results and Discussion

Table 1 shows the typical view of the parameters of the subsurface as obtained from the interpreted results.

The difference in the resistivity values of VES which is as a result of the inhomogeneity of the subsurface reveals three to four distinct layers which range from topsoil, weathered basement, partial weathered basement and fresh basement. The resistivity of the topsoil ranges from 551.6Ωm -828.6Ωm and thickness ranging from 1.3m-4.4m.The average resistivity value for the topsoil is 693.89Ωm and average thickness of 2.92m. The weathered basement has an average resistivity value of 257.77Ωm and average thickness of 13.56m. The resistivity range for this layer is between 103.8 – 691.1Ωm and the aquifer thickness has a range of value between 6.5m and 39.8m.

The overburden thickness has maximum value of 43.9m at VES 6. The last layer is inferred to be the fresh basement with average resistivity of 21345.12 and high resistivity of between 2477.7 and 1000000Ωm. The VES data obtained in the study area were analyzed and interpreted. The result is then used to compute the Longitudinal Conductance(S), Hydraulic Conductivity(K) and Transmissivity(T). The statistical analysis such as Mean, Median, Mode, Variance, Standard deviation and Skewness of this set of data were also carried out (Table 2.0).

Table 1: Summary of the Geoelectric parameters

VES No	Top Layer Resistivity(Ohm-m) (Ωm)	TopLayer Thickness (m)	WEATHEREDLAYER RESISTIVITY (Ωm)	BEDROCK RESISTIVITY (Ωm)	AQUI-FER THIC-KNESS (m)	OVERBURDEN THICKNESS (m)	LONGITUDINAL CONDUCTANCE (S)	HYDRAULIC CONDUCTIVITY X10^{-5} (m/s)	TRANSMISSIVITYX10^{-4} (m^2/s)
1	741.4	4.1	177.6	8378	13.3	17.4	0.075	4.66	6.19
2	698	1.9	524.2	15998.	16.3	18.2	0.031	16.97	27.67
3	645.5	2.3	103.8	29278.	10.4	12.9	0.100	2.45	2.55
4	828.6	1.7	117.4	100000	7.5	9.5	0.064	2.84	2.13
5	551.6	1.3	357.2	4842.6	7.5	8.8	0.021	10.73	8.05
6	721.7	4.1	691.1	3629.4	9.8	43.9	0.058	23.61	94.00
7	659.2	2	121	14095	17.9	19.5	0.148	2.94	5.27
8	706.7	4.4	128	31648	6.5	10.9	0.051	3.15	2.05
9	609.7	4.1	123	3103.4	7.8	11.9	0.063	3.00	2.34
10	777	3.3	234.4	2477.7	8.6	11.9	0.037	6.49	5.58

Ground Water Protective Capacity Evaluation

The Geoelectric parameters derived based on apparent resistivity and thickness includes the Longitudinal Conductance(S), Hydraulic Conductivity (K) and Transmissivity (T) [15].

Longitudinal Conductance (S) is related to clay content which increases the porosity of a layer but decreases its permeability [8]. Since permeability decreases with an increase in conductance, it is given as

$$S_i = {}^{h_i}/_{\rho_i} \qquad (3)$$

Where h_i and ρ_i are the ith layer thickness and resistivity respectively [16]

The earth medium acts as a natural filter to percolating fluid. The highly impervious clayey overburden which is characterized by relatively high longitudinal conductance offers protection to the underlying aquifer [17].

Table 2: GeoStatistics of Aquifer Protective Capacity Rating

Geoelectric Parameter	Range	Mean	Median	Mode	S.D.	Variance	Skewness
Topsoil Resistivity (Ωm)	551.6-828.6	693.94	702.35	828.6	81.07	6571.67	-0.12827
Topsoil Thickness (m)	1.3-4.4	2.92	2.8	4.4	1.20	1.43	0.006491
Weathered Resistivity (Ωm)	103.8-691.1	257.77	152.8	691.1	203.51	41415.48	1.435765
Bedrock Resistivity (Ωm)	2477.7-100000	21345.1	11236.5	100000	29589.6	875544903	2.480255
Aquifer Thickness (m)	6.5-17.9	13.56	9.5	39.8	10.03	100.67	2.341511
Overburden Thickness (m)	8.8-43.9	16.49	12.4	43.9	10.32	106.49	2.453988
Longitudinal Conductance	0.021-0.148	0.0647	0.06050	0.14793	0.04	0.00137353	1.293862
Hydraulic Conductance x10^{-5}	2.45-23.61	7.69	3.90	24.00	7.27	0.00053	1.547648
Transmissivity x10^{-4}	2.05-94.00	15.58	5.43	94.00	28.59	817.38	2.800529

Table 2 shows the modified Geostatistics of Aquifer Protective Capacity Rating. The Longitudinal Conductance obtained from the study area range from 0.021 to 0.148Siemen and according to table 2.0 and figure 3.0 the area could be zoned as moderate(VES 3 and 7)to weak (VES 2, 5 and 10) and poor (VES 1,4,6,8 and 9) ground water protective capacity. From table 2.0 the standard deviation is 0.04, since the standard deviation of weathered resistivity is high (203.51) confirm the relationship of proportionality between them which is inverse and thus is positively skewed.

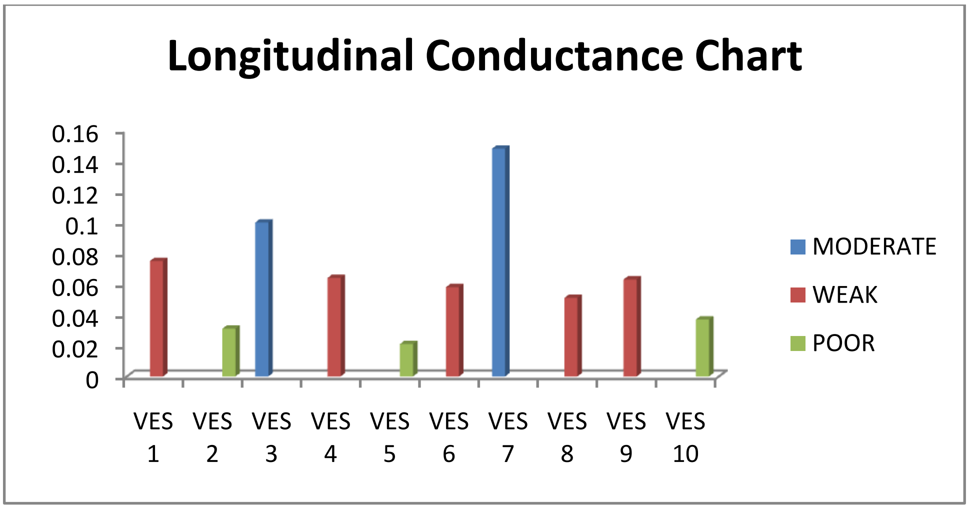

Figure 3: Histogram Chart of the Longitudinal Conductance

Hydraulic Conductivity (K)

Hydraulic Conductivity (K) is the rate of flow under a unit hydraulic gradient through a unit cross-sectional area of an aquifer. It is a measure of a material's capacity to transmit water and it is given as

$$K = 95.5x10^{9}\rho^{1.195} \quad (4)$$

where ρ is the resistivity of the porous layer in Ohm-m [16].

The hydraulic conductivity of the study area has a range of value between $2.45x10^{-5}$ to $23.61x\ 10^{-5}$ m/s. Hydraulic Conductivity (K) is directly proportional to resistivity ρ. Therefore as K increases, ρ also increases unlike in Longitudinal Conductance where the reverse is the case.

The relevance of this Groundwater protective capacity map is that it can be used to select alternate areas with moderate amount of Groundwater in the absence of completely weathered basement rocks with appreciable thickness values that contain good amount of Groundwater potential [17].

In this study, the occurrence of appreciable amount of water is between 16 to over 23 m/s and resistivity values that range between 524 and 691Ωm with relative aquifer thickness of 16m (VES 2) and over 39m (VES 6). Figure 4 shows the histogram chart of hydraulic conductivity.

On the other hand, good occurrence of groundwater with the Hydraulic Conductivity within a range 1.0 to 10.0 supposed to be good potential water zone according to [17], but in this work, the range of the value is between $(2.45 – 23.61)\ x\ 10^{-5}$m/s. All the aquifer thickness are relatively less than 15m except at VES 6(39.8m) which is relatively thick and coincide with the interpretation of the Longitudinal Conductance as a weaker or moderately groundwater potential zone . The standard deviation value is relatively high with 7.27 than the one recorded in longitudinal conductance as a result of high value of S.D of weathered resistivity value of 203.51 since Hydraulic conductance is directly proportional to resistivity and it is positively skewed.

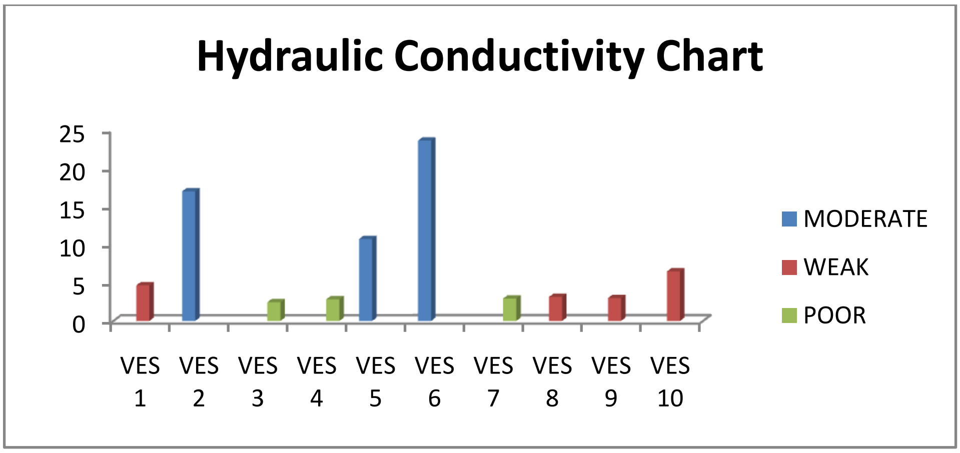

Figure 4: Histogram Chart of Hydraulic Conductivity

Transmissivity (T) is the rate of flow under a unit hydraulic gradient through a unit width of aquifer of thickness h. It is also defined as 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 and it is given as

$$T = Kh \quad (5)$$

where K is the coefficient of conductivity (m/s), h is the aquifer thickness (m). Thus the relationship is obtained as in hydraulic conductivity.

In general, Transmissivity for the study area is very low since the values are expected to be higher than the values recorded [16] except for VES 6 with a moderately high value which could be attributed to the thickness of the layer which coincides with the interpretation of Hydraulic conductivity. Figure 5 shows the histogram chart of Transimissivity.

The relevance of this groundwater protective capacity chart is similar to that of Hydraulic conductivity. The standard deviation value is high 28.59 since the Standard deviation of weathered resistivity value of 203.51 is high according to the relationship of direct proportionality which exists between them. It is positively skewed.

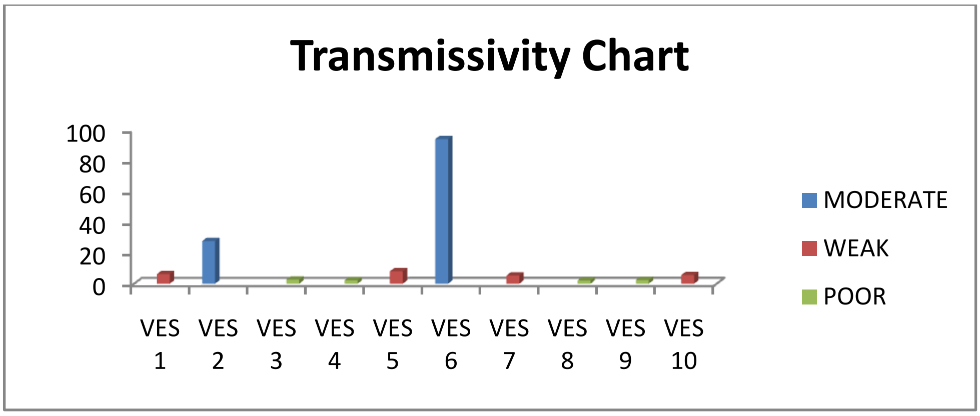

Figure 5: Histogram Chart of Transmissivity

Aquifer thickness map

Aquifer thickness map can be used in ranking geology formation that contains enough water because volume of water from each VES stations is a function of aquifer thickness [17].

The entire study area can be grouped into moderate, weak and poor groundwater potential zones. The research reveals that the moderate water bearing zone occurs at the North eastern part of the study area with a thickness value greater than 15m while the weak occurs at south eastern part and the poor groundwater potential zones the bottom of south western, figure 6.

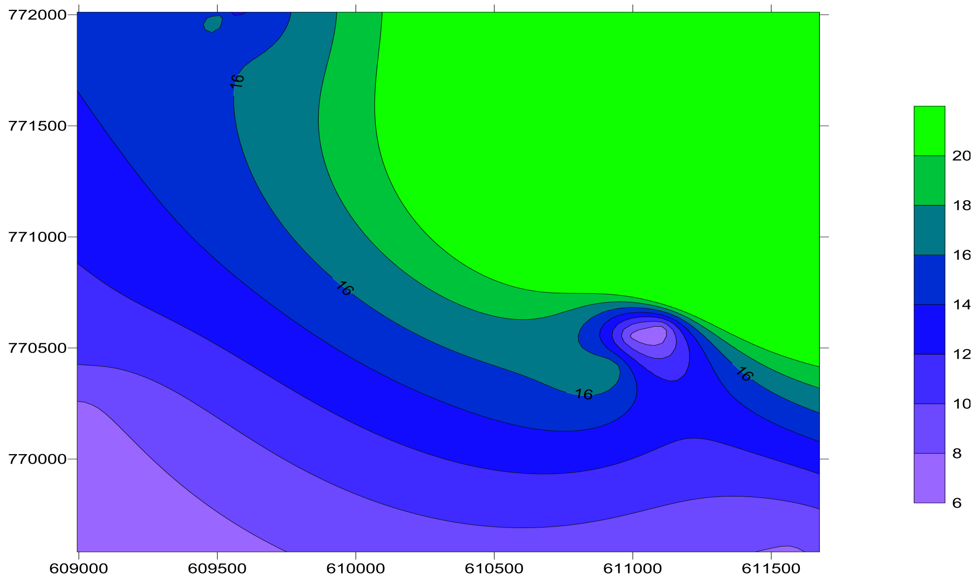

Figure 6: Isopach Map (Aquifer Thickness)

Overburden thickness map

Generally, areas with thick overburden and low percentage of clay in which intergranular flow is dominant are known to have high groundwater potential particularly in basement complex terrain [17-18].

Figure 7 shows the overburden thickness map and very thick at the south eastern and thin at the south western part of the map depicting poor groundwater potential zone as recorded in aquifer thickness map.

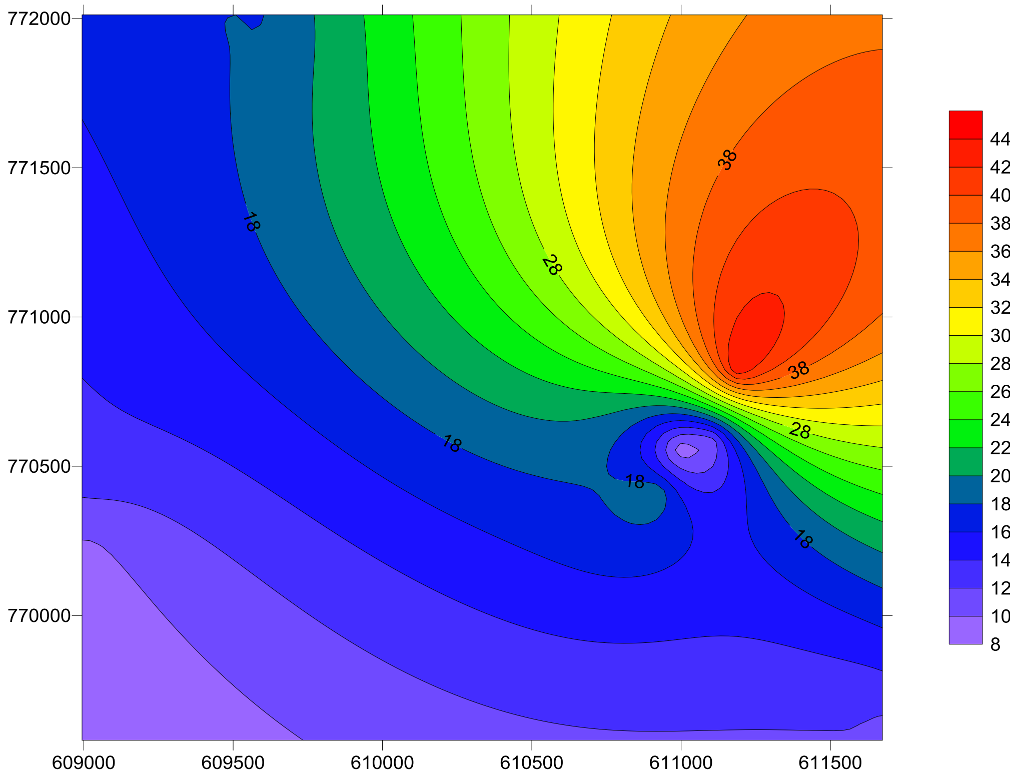

Figure 7: Isopach Map (Overburden thickness)

Conclusion

In conclusion, based on the electrical resistivity survey conducted in the study area, computed geoelectrical parameters (Longitudinal conductance, Hydraulic conductivity, and transmissivity) and the computed geostatistical analysis, the 10 VES points are characterized into moderate, weak and poor aquifer zones. Weathered and fractured zones constitute the aquifer zones and in this study, no fractured zone has been identified. The weathered resistivity has a range of value between 103.8 and 691.1Ωm with a mean value of 257.77 Ωm while the aquifer thickness value range between 6.5 and 17.9m with an average value of 13.56m.

The aquifer thickness map shows that moderate to weak groundwater potential zones are found in the north eastern to south eastern part while the south west is characterized as the groundwater potential zonethemean value of longitudinal conductance is 0.06, hydraulic conductivity is 7.60xx10-5 and Transmissivity is 15.58x10-4. The aquifer zone is moderate which could be attributed to the low thickness of the layer, no fractured zones while all are fresh bedrock.

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