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GEOELECTRIC SOUNDINGS FOR THE DETERMINATION OF AQUIFER CHARACTERISTICS IN ANJAGWA, NASARAWA STATE NIGERIA

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Abstract: A total of fifteen (15) Schlumberger Vertical Electrical Soundings (VES) were carried out in Anjagwa area of Nasarawa State, Nigeria, using a maximum current electrode separation of 500 m. The data were interpreted using a conventional partial curve-matching method to obtain initial model parameters, which were used in a computer program IXID to obtain final parameters. Aquifer parameters of longitudinal conductance and transmissivity were obtained using Dar-Zarouk parameters. The results of interpretation revealed four to five geoelectric layers. High transmissivity values are recorded at VES 3, 4, and 5 with high thicknesses, which imply that thick aquifer materials have higher transmissivity values than areas underlain by relatively thin aquifer materials. Such result is expected because transmissivity is a function of aquifer thickness.

Keywords: Anjagwa, aquifer, geoelectric, isoresistivity, Schlumberger vertical electrical soundings, transmissivity

Introduction

The study area consists of two communities located within Akwanga-West Development Area of Nasarawa State, Nigeria. The study area is underlined by Basement Complex rocks of North Nigeria. Most boreholes in the study area are highly productive as a result of the fractured nature of the host rocks in the area. However, the evolution of a proper water resources management program requires data input from a variety of sources including hydrologic, geologic and hydrogeologic survey as well as pump testing and water analysis (Mbonu *et al.*, 1991).

The determination of aquifer characteristics of hydraulic conductivity and transmissivity will help in determining the natural flow of water through an aquifer and its response to fluid extraction. Good attempt has been made by numbers of authors to predict aquifer hydraulic properties from surface electrical soundings (Kelly, 1997; Niwas & Singhal, 1981; Onuoha & Mbazi, 1988). In the current research we try to determine some of the aquifer characteristics calculated from results of geoelectric soundings.

Materials and Methods

Geology of the study area

The research area with its access roads and location of sounding stations is presented in Fig. 1. A network of roads and footpaths make access to most parts of the area possible. The study area lies between latitude $N09^0\ 3'0'' - 09^0\ 4'0''$ and longitude $E08^0\ 18'30'' - 08^0\ 22'49''$. The area understudy is underlain by Precambrian rocks of the Nigeria Basement Complex. The weathering of the crystalline Basement Complex rocks under tropical condition is well known to produce a sequence of unconsolidated material whose thickness and lateral extent vary extensively (Jatau *et al.*, 2013). Groundwater localization within the Basement Complex occurs either in the weathered mantle or in the fracturing, fissuring and jointing systems of the bedrock (Olayinka & Olorunfemi, 1992). These unconsolidated materials are known to reflect some dominant hydrologic properties and the higher groundwater yield in Basement Complex area are found in areas of thick overburden overlying fractured zones and are characterized by relatively low resistivity (Jatau *et al.*, 2013). The Basement complex rocks in the study area are mostly biotite granite, gneiss, quartzite (Fig. 2).

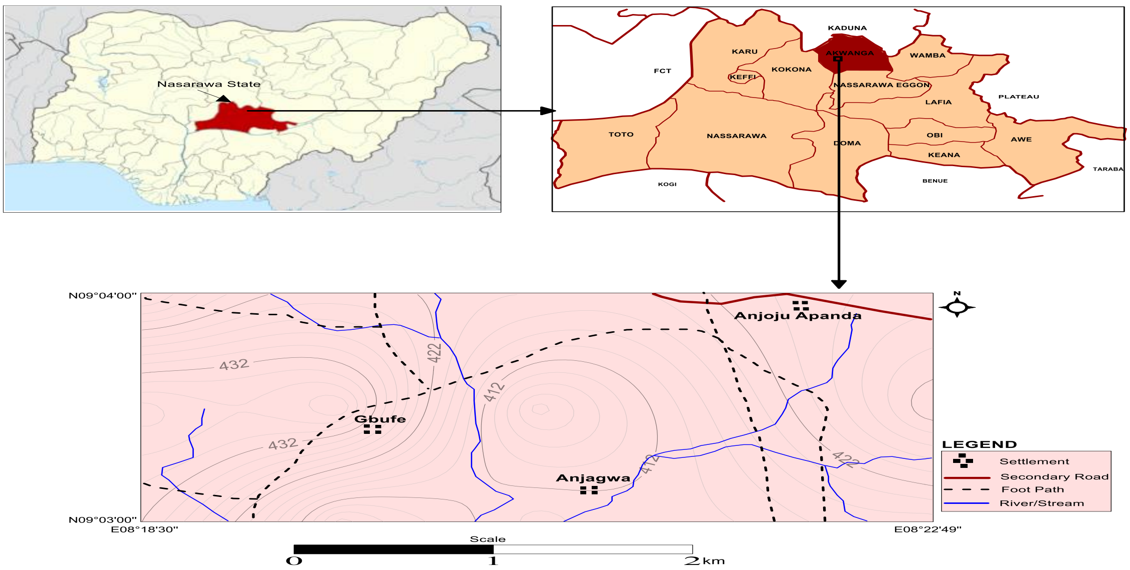
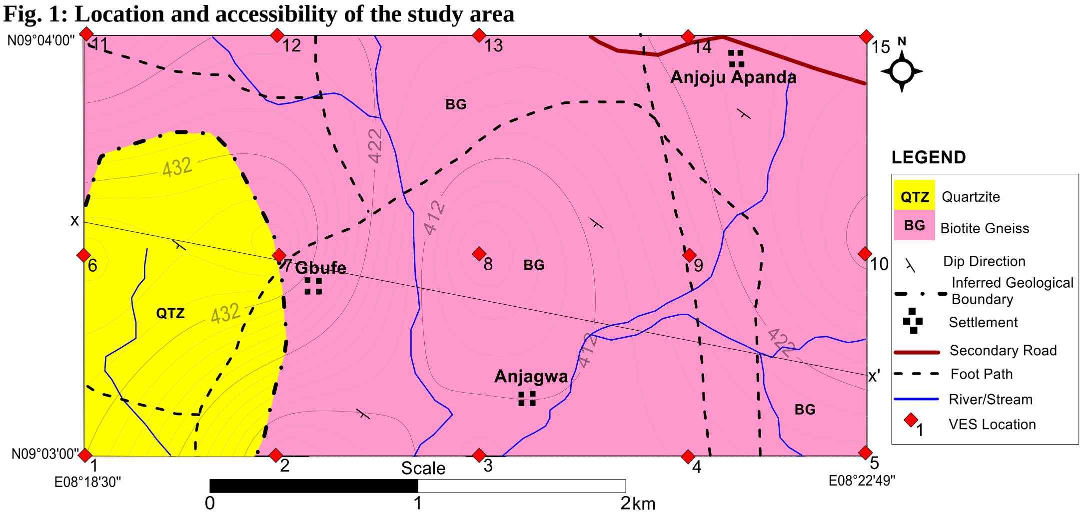


Fig. 1: Location and accessibility of the study area



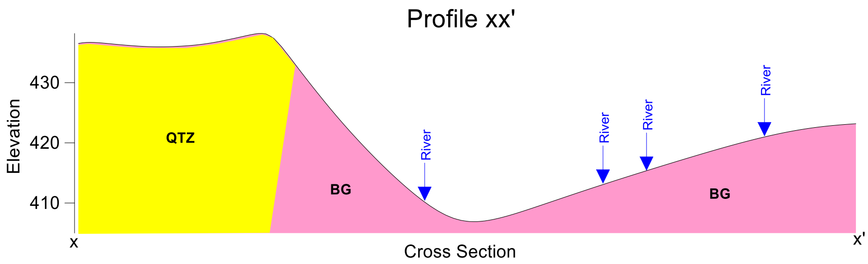


Fig. 2: Geology of the study area showing VES locations

Table 1: Summary of results from computer modeling for all sounding stations

S/N	VES Station	No. of Layers	Resistivity of Layers				Thickness of Layers			Elevation of Layers				Conductance of Layers		
			P1	P2	P3	P4	T1	T2	T3	H1	H2	H3	H4	C1	C2	C3
1		4	767.6	1549	99.58	381.2	2.47	1.74	3.25	472	470	467	463	0.00323	0.00113	0.0327
2		4	317.4	89.44	93.77	133.6	1.33	1.55	1.06	471.1	472.6	471.5	449.2	0.00421	0.0173	0.014
3		4	1329.4	658.8	187.3	508.3	1.37	0.54	1.76	475.1	474.5	472.8	461.8	0.00104	8.38E-04	0.00942
4		4	310.9	234.5	104.5	80.45	1.52	1.67	7.07	477.2	476.9	475.2	468.2	0.00489	0.00716	0.0677
5		4	1012	903.5	825.3	229.6	1.2	1.49	1.43	482.2	480.7	479.3	475	0.00119	1.51E-04	0.00173
6		4	388.3	155.6	36.14	1237.3	2.66	1.59	2.38	477.8	476.2	473.8	471.4	0.00764	0.102	0.0659
7		4	673	258	290	525	3	4.5	7.5	473.5	469	461.5	456.5	0.00446	1.74E-02	0.0258
8		4	7584.3	2885.4	1194.1	713.3	1.35	2.09	5	494.1	492	487	481.1	1.79E-04	7.27E-04	0.00419
9		4	4633.1	1736.1	687.8	2005.6	1.16	2.06	3.8	480.8	478.8	474.9	471.3	2.52E-04	5.54E-03	0.00554
10		4	5018.7	1025.1	1673	3580	2.42	5.27	4.15	499.5	494.2	490.1	486.8	4.39E-04	5.14E-03	0.00248
11		4	3445	3150	1500	1800	1.5	1.5	7	455	453.5	446.5	436.5	4.35E-04	4.76E-04	0.0467
12		4	2004	2259	600	420	3	2	15	472.5	470.5	455.5	445.5	1.50E-03	8.85E-04	0.025
13		4	1583	2370	2118	700	1.5	1.5	25	467	465.5	463.5	438.5	8.91E-04	6.33E-04	9.44E-04
14		4	1697	2289	2136	1073	1.5	1.49	2	464.9	463.5	461.5	421.5	8.85E-04	6.55E-04	9.36E-04
15		4	1240	2700	1800	953	1.5	1.5	17	480	478	461.5	441.5	1.21E-03	5.56E-04	0.00944

Data acquisition and interpretation

A total of fifteen (15) Vertical Electrical Sounding (VES) was acquired from the study area (Table 1). They were acquired in the study area with a maximum current electrode separation (AB) of 80 m. Each VES point was taken along the grid with about 500 m interval. Three logs of boreholes drilled across the cross-section area within the study area were collected. These boreholes logs were used as a control to cross-examine the interpretations from the VES curves using IXID software.

The instrument used was the Omega resistivity meter, a digital averaging instrument for direct current resistivity work. The data were plotted on I-D iterative software using the conventional partial curve matching technique, in conjunction with auxiliary point diagrams (Kellar & Frischknecht, 1966), in which various layers and thickness were interpreted. After the field survey, the measured field Resistance (R) in ohms was converted to apparent resistivity (ρa) in ohm-meters using the formula: $\rho_a = R \times K$. The interpreted data were also contoured and interpreted using the SURFER 10 software.

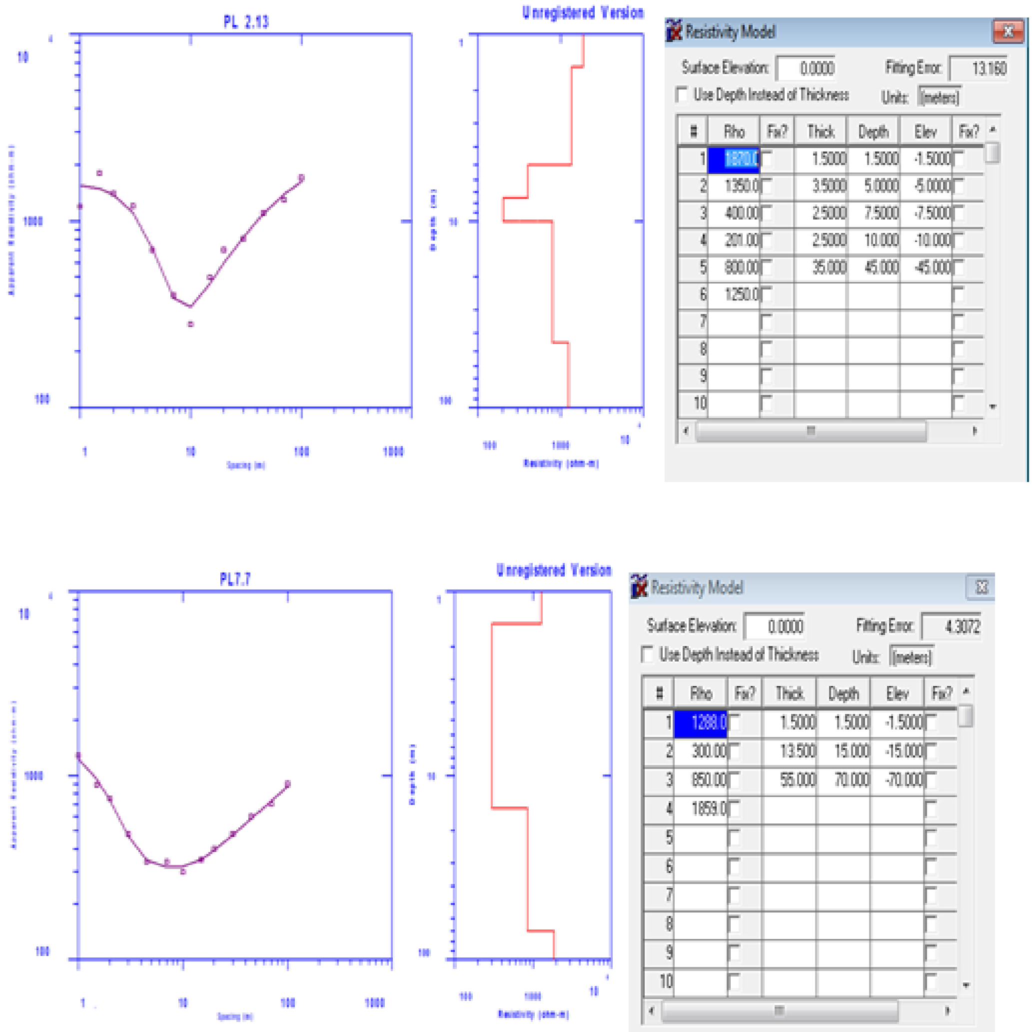


Fig. 3: Typical field soundings

Model parameters

The model parameters were obtained by considering a unit square cross-sectional area cut of a group of n-layers of infinite lateral extent. The total transverse unit resistance R is given by equation (1)

$R = \sum_{i=1}^{n} h_i \rho_i$ (1)

where h_i *and* ρ_i are the layer thickness and resistivity of ith layer in the section, respectively

The total longitudinal conductance S is given by equation (2)

$S = \sum_{i=1}^{n} h_i / \rho_i$ (2)

The longitudinal conductance S_i can also be represented by equation (3)

$S_i = \sigma_i h_i$ (3)

where σ_i is the layer conductivity. Conductivity in this case is analogous to the layer transmissivity T_{ri} used in groundwater hydrology, given by equation (4)

$T_{ri} = K_i h_i$ (4)

Where K_i is the hydraulic conductivity of the ith layer of thickness hi. R and S of equations (1) and (2) are called the Dar Zarrouk parameters, which have been shown to be powerful interpretation aids in groundwater surveys (Zhody *et al.*, 1974). Niwas and Singhal (1981) have determined analytically the relationship between aquifer transmissivity Tr and transverse resistance R on one hand and between the transmissivity and aquifer longitudinal conductance S on the other. This is shown in equation (5);

$T_r = K\sigma R = {}^{KS}/_{\sigma} = Kh$ (5)

In areas where the geologic setting and water quality do not vary greatly, the product $K\sigma$ remains fairly constant (Niwas and Singhal, 1981). Thus knowing the values of K from the existing boreholes and σ from the sounding interpretation around the boreholes, one can estimate the transmissivity and its variation from place to place from determination of R or S for the aquifer. Which of the latter two set of parameters is used usually depends upon whether σ and h are equivalent.

Results and Discussion

Interpretive cross-section AB (Fig. 4) has been constructed using the results of the VES and the geological data obtained from the existing existing boreholes. Cross –section AB (Figure), a southwest –southeast cross-section, shows the presence of five continuous geoelectric layers. The first layer being the top soil consists of sand, laterite and clay, while the second layer is mostly laterite. The third layer consists of weathered rocks. The fourth layer consists of fractured and saturated rocks, this layer constitute the water bearing zones. This layer is prolific aquifer tapped by some productive water boreholes drilled in the area. This known thin clay bands separating this aquifer (aquitards) were not resolved in this sounding, probably due to suspension. The deepest geoelectric layer observed by our sounding consists of conductive material with resistivities ranging from$150 - 650\ \Omega m$. Depth from surface to this layer ranging from 50 – 70 m.

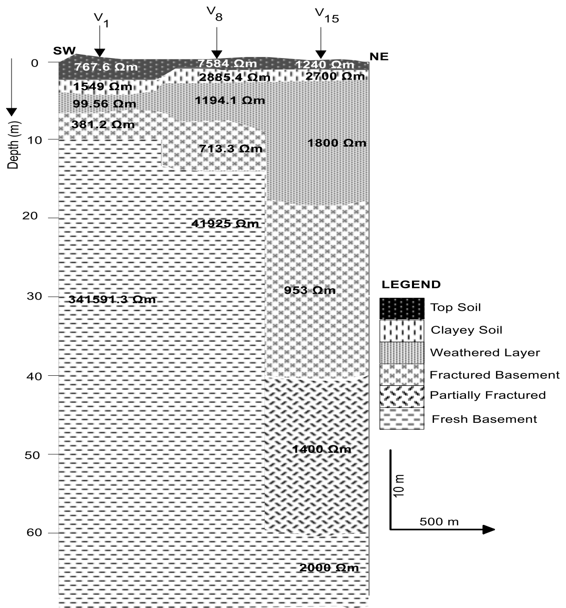


Fig. 4: interpretive cross-section across A-B

Isopach map of the aquiferous zone and isoresistivity map

The aquiferous zone appears thick enough for drilling of productive boreholes over the entire area, the isopach map constructed from VES results (Fig. 5) shows that this aquifer varies in thickness being thinnest in the vicinity of VES 8, 9,10,13,14, and 15 with thickness ranging from 20 – 45 m. The second zone corresponds to the relatively thick aquifer, with thickness ranging from 50 – 70 m in the vicinity of VES 1, 2, 3, 4, 5, 6, 7, 11 and 12.

The isoresistivity map for AB/2=60m (Fig. 6) shows that two distinct zones can be identified within the area on the basis of resistivity values. Northeastern part is underlain relatively with high resitivities values rangimg from $2800 - 4200\ \Omega m$ which covers VES 13, 14, 15 and 8 mostly. The southern part of the study area mostly has low resistivities values ranging from $200 - 800\ \Omega m$.

Aquifer transmissivity

Aquifer characteristics for the area calculated from VES results are shown in Table 1. The transmissivity of the aquiferous zone and its variation from place to place can be estimated including those areas where borehole data are not available. This is achieved by using the analytical relationships between aquifer transmissivity and transverse resistance, and between transmissivity and longitudinal conductance (equation 5). Transmissivity values are at VES 3, 4 and 5 with high thicknesses (Fig. 7) which implies that thick aquifer materials have higher transmissivity values than areas underlain by relatively thin aquifer materials. Such result is expected because transmissivity is a function of aquifer thickness.

Table 1: Summary of results from computer modeling for all sounding stations

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10		4	5018.7	1025.1	1673	3580	2.42	5.27	4.15	499.5	494.2	490.1	486.8	4.39E-04	5.14E-03	0.00248
11		4	3445	3150	1500	1800	1.5	1.5	7	455	453.5	446.5	436.5	4.35E-04	4.76E-04	0.0467
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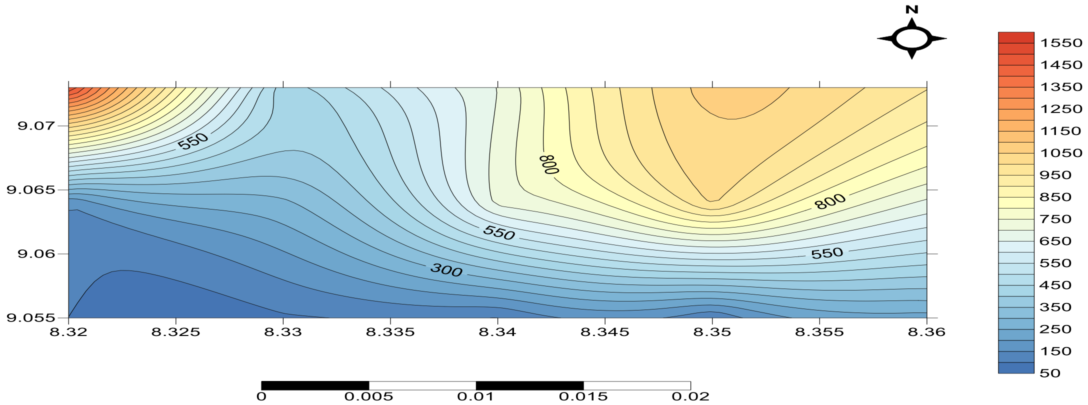

Fig. 5: Isopach map of the aquiferous zone

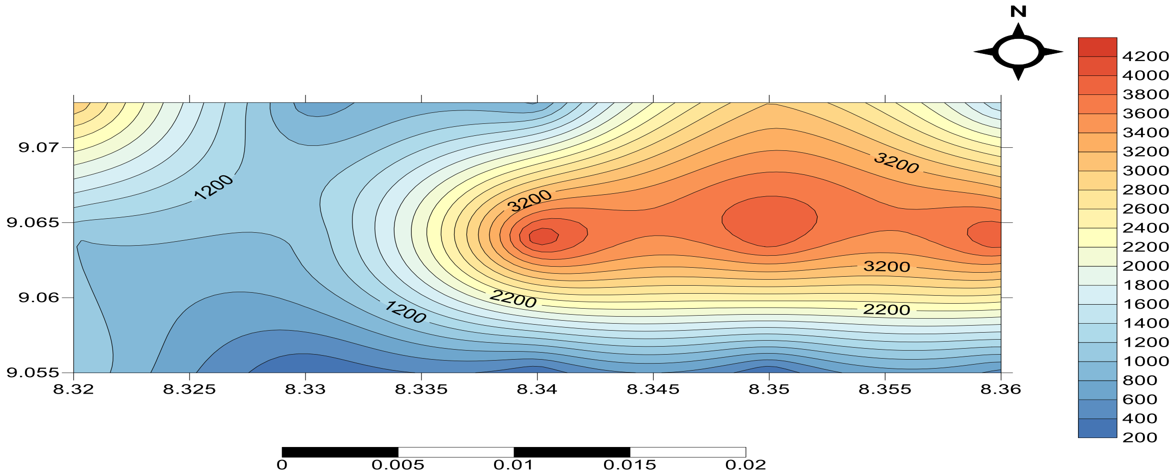

Fig. 6: Isoresistivity map for AB/2=60m

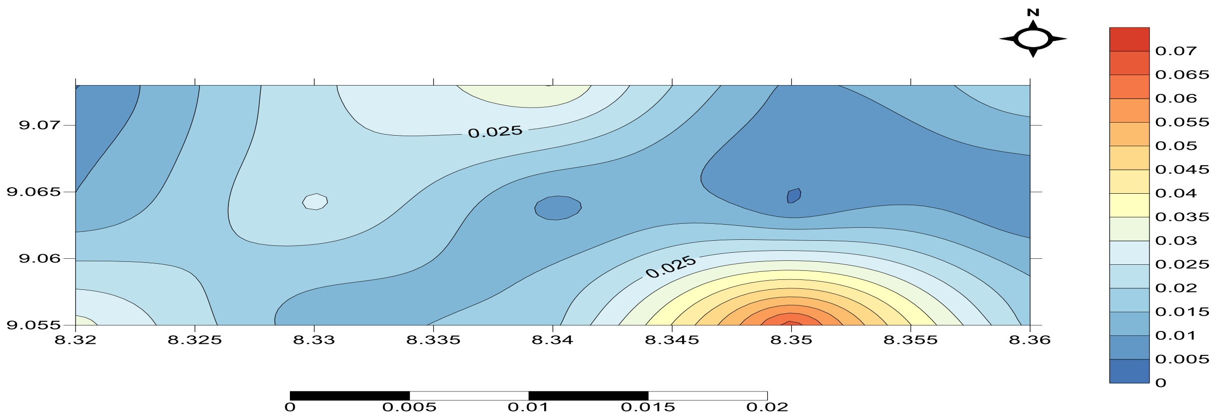

Fig. 7: Contour map of transmissivity values across the study area

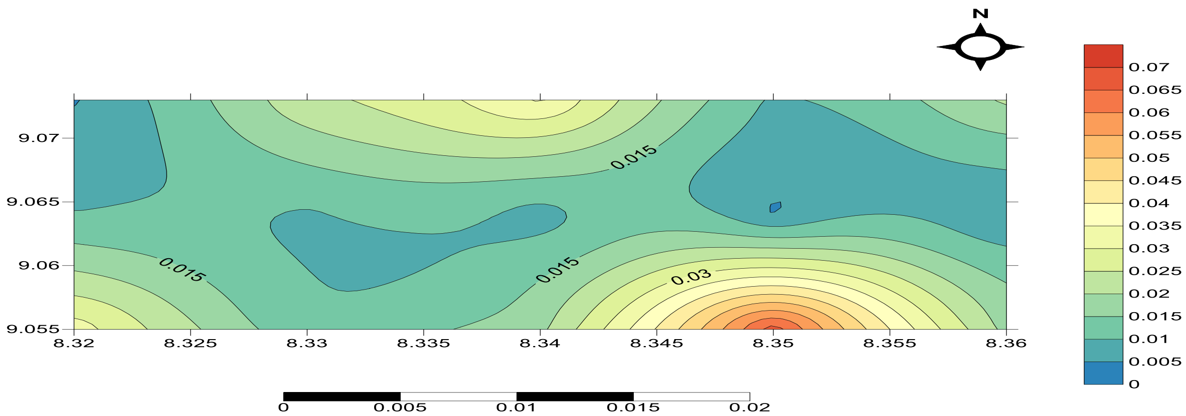

Fig. 8: Longitudinal conductance values for the aquiferous zone in the study areas

Distribution of longitudinal conductance

The distribution of longitudinal conductance values across the study area (Fig. 8) shows that the areas in vicinity of VES 7, 9 and 11 are underlain by relatively resistive (low longitudinal conductance) aquifer materials. This area may not be good prospect for groundwater exploration with high yields expectation. VES 3, 4, and 5 are underlain by thick and conductive aquifer materials and thus are viable for groundwater exploration.

Conclusions

The results gotten from this research work has led to the precise delineation of the aquiferous zone within the study area. This aquifer varies in thickness from place to place VES 3, 4, and 5 being the thickest. The aquifer system in the area can be divided into two distinct zones on the basis of both isoresistivity for AB/2=70m. The difference between zones emanated as a result from changes either in their subsurface geology or water quality.

High transmissivity values are recorded at VES 3, 4, and 5 with high thicknesses, which implies that thick aquifer materials have higher transmissivity values than areas underlain by relatively thin aquifer materials. Such result is expected because transmissivity is a function of aquifer thickness.

Conflict of Interest

Authors declare that there are no conflicts of interest.

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