Geo-electric investigation of the groundwater Potential distribution within the Northern Basement Complex of Nigeria

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ABSTRACT: Kaduna, a town within the crystalline hydro-geological province of the Basement Complex of northern Nigeria, is faced with an increasing demand for water due to high population growth rate and growing prosperity. Hence there is dependence on groundwater in meeting the water needs of the area. It is therefore important to delineate the water potential regions of aquifer units within the study area. To achieve this, two important hydraulic properties – hydraulic conductivity and transmissivity, of the aquifer media in the area were computed. A geoelectric survey was carried out involving Vertical Electrical Sounding (VES) to investigate the sub-surface depth using the Schulmberger technique. Abem Tarrameter SAS 1000 was used and twenty points were sounded in area. Data obtained were processed using the Earth Imager 1D Version 2.0.4 software to display results in a log-log graph. Values for transmissivity and hydraulic conductivity were computed. The data together with the coordinate of points for each station, obtained using a Garmin global positioning system (GPS), was employed to plot 2D and 3D contour maps. This was done with the aid of Surfer 11 software. In conclusion, transmissivity values recorded is within a range of 1.31 m^2/day to 20.08 m^2/day, with an average value of 19.12 m^2/day. Hydraulic conductivity values range from 6.5827 x 10^{-6} m/s to 9.7225 x 10^{-6} m/s with an average value of 7.5358 x 10^{-6} m/s. Aquifer thickness recorded a range of value between 2.00 m to 31.00 m with an average of 15.66 m. Groundwater yield in the study area is adequate to sustain water supply need of communities like Afaka and Riga Chikun. Other places like Kurumi Mashi and Makera will have just enough water for private use. There is a strong positive correlation between transmissivity and aquifer thickness, while there was no correlation between aquifer transmissivity and aquifer resistivity.

Keyword: Hydraulic conductivity, transmissivity, groundwater, aquifer, groundwater,vertical electrical sounding (VES).

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1. INTRODUCTION

Kaduna is faced with an increasing demand for water due to high population growth rate and growing prosperity. Especially in a time where taps being supplied pipe-borne water from the state water board are no longer running but dry. Thus, the importance of groundwater in meeting water needs cannot be over-emphasized. Groundwater occurs in the interstices or pore spaces of weathered crystalline basement and sedimentary rocks within geological medium called aquifer. Sometimes, they occur in inter-connected fractures or fissures of fresh crystalline rock, in which case they are referred to as fractured aquifer. The aquifers of the Basement Complex rocks are the regolith and the fractures in the fresh bedrock which are known to be inter-connected at depth [1], [2]. However, [3] described regolith aquifer in the crystalline basement of Nigeria as partly overlain by a shallow, porous aquifer within the lateritic soil cover.

The occurrence of groundwater may vary from one place to another depending on the aquifer inherent hydraulic properties. Thus, the transmissivity and hydraulic conductivity of an aquifer both depends on the properties of the medium (rock material) as well as of the fluid or water [4]. Knowledge of these two can be used to determine the groundwater potentiality of an area during exploitation of the resource. Conventional method of determining hydraulic properties is by drilling/pumping test, although expensive and time consuming. A relatively inexpensive and quick method employs the Dar Zarrouk parameters [5], together with results from geo-electrical surveys. There are several works that has shown that the Dar Zarrouk parameter (of transmissivity and conductivity) and the geologic information of an area can be used to compute the distribution of water potential surfaces: [6], [5], [7], [8], [9], [10], [4].

According [11], the areas underlain by migmatite-gneiss complex and schists of the Younger Metasediments represent generally a poor groundwater terrain due to their lithological and structural characteristics. These unconsolidated materials are known to reflect some dominant hydrologic properties, and the highest groundwater yield in Basement Complex area are found in areas of thick overburden overlying fractured zones and are characterized by relatively low resistivity, [12], [13], [14].

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This study aims to employ hydro-geophysical parameters which include the Dar Zarrouk parameter and geoelectrical resistivity data to estimate the hydraulic conductivity (K) and transmissivivty (T) in order to determine the groundwater potential distribution of the study area.

2. LOCATION AND GEOLOGY OF THE STUDY AREA

The area is bounded by latitudes 10°25'N and 10°46'N and Longitudes 7°21'E and 7°32'E. It covers towns that include Afaka, Riga-Chikun, Kurmin-Mashi and Makera in Kaduna State. It covers an area of approximately 780.84 Km^2, in the Basement Complex of North Central Nigeria (Fig. 1).

The Nigerian basement complex forms a part of the Pan-African mobile belt and lies between the West African and Congo Cratons [15]. According to [16], the Northern Nigerian Basement Complex is underlain by three main groups of rocks namely:

1. Migmatites and (high grade) gneisses derived from Birrimain sedimentary rocks through high grade metamorphism and granitization;
2. Younger Metasediments of Upper Proterozoic age which are low grade metamorphic rocks that were folded along with the migmatite and gneisses during the Pan-African orogeny;
3. Older Granite series which were intruded during the Pan-African orogeny.

Ajakaiye *et al.* [17], reports that the oldest rocks are metesediments, which have been transformed to gneisses and migmatites during two tectono-metamorphic cycles. The first orogenic cycle characterized a period of deformation and folding during the epiorogenic uplift, [18]. The age suggested for this was the Eburnean, (1850 ± 250) Ma by syntectonic metamorphism of probably siltstones and mudstones. The second orogeny occurred after the Pan- African (650 ± 150) Ma, as a result of contact metamorphism due to thermal effect of the Granitic intrusion during the Eburnean Orogeny according to [19]. This marked the end of the Pan-African event in Nigeria. The area under study is represented by two distinct lithological units, namely the Older Granite suite and the gneissic rocks (see Fig. 1). However, 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 [20].

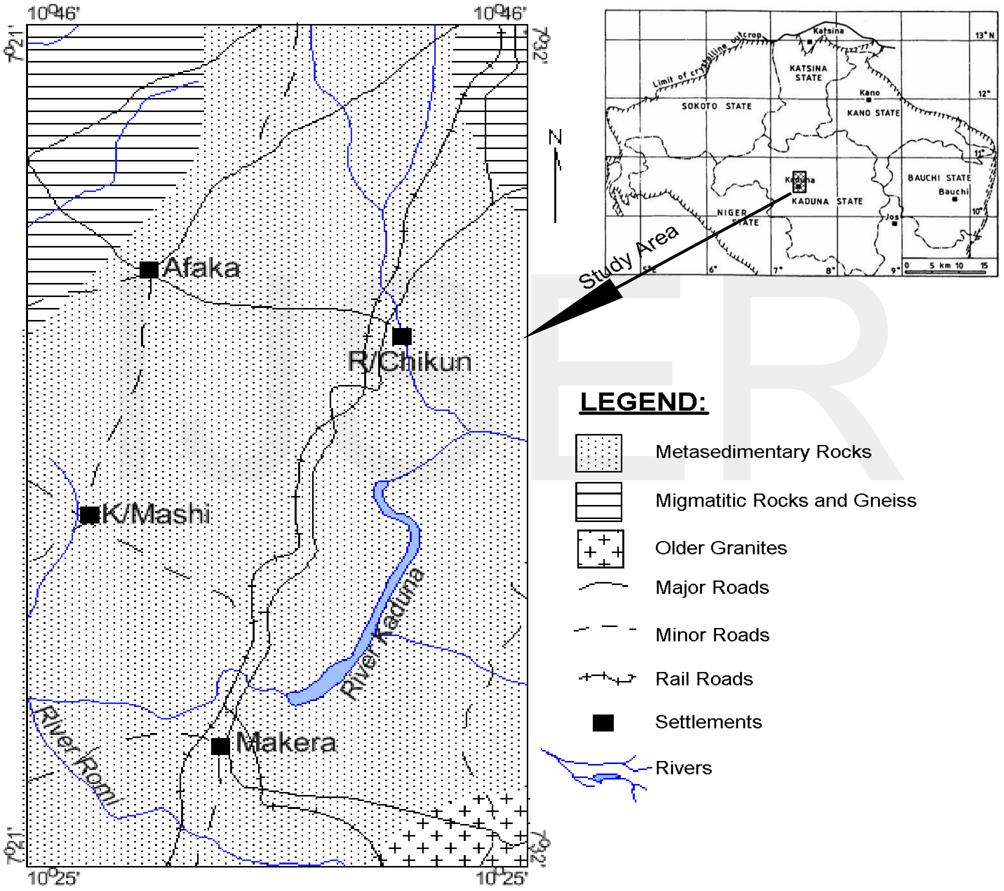


Fig. 1: The Geology and Location of the Study Area.

3. THEORETICAL BACKGROUNDS

Geologists have used resistivity information to quantitatively assess the permeability of clay alluvium over the years. From the geologic conditions, it is sometimes convenient to relate the Dar Zarrouk parameters of transmissivity and conductivity to explore for water. The yield of a bore hole can be determined from the hydraulic transmissivity. Several authors have explained the expressions used for exploration of groundwater by geo-electrical resistivity method. For instance, [21], [22], [23], [24], [25] have all carried out studies relating to the Dar-Zarrouk parameters.

On a broader view, geophysicists apply Physics Laws to study the earths subsurface. Thus, groundwater flow in a porous medium is governed by Darcy's law and it is analogous to the Ohms law. Details of the theories can be found in [4] and [26] respectively. The Dar-Zarrouk parameters used in this work are the conductivity (K) and the transmissivity (T).

Hydraulic Conductivity (K) is a measure of the ability of a formation to transmit water. It is expressed in m s^{-1}. While transmissivity (T) is the time-rate of flow of water at the prevailing field temperature under a unit hydraulic gradient through a vertical strip of aquifer of unit width and extending through the entire saturated thickness of the aquifer. It is expressed in m^2 d^{-1} or m^2 s^{-1}.

Darcy's law, in terms of T, can be expressed as;

$$Q = TIL \qquad (1)$$

Where Q = rate of flow, I = hydraulic gradient, L = width of the flow section, measured at right angles to the direction of flow.

In a confined aquifer like that of the study area,

$$T = Kb \qquad (2)$$

Where b is the saturated thickness of the aquifer and K is assumed to be an isotropic and constant across the thickness of the aquifer which may be horizontal or dipping [4].

There exist a relationship between transmissivity (T) and resisitivity (ϱ). This relationship which can be expressed as K is either decreasing or increasing and it has generally been proved to contain an exponential fit between transmissivity (T) and resisitivity (ϱ) [24], [25], [4]. The present study area is located in a basement complex region with evidence of hard rocks. Based on [27], depending on the geologic formation of the study area, the value of K in equation 2 can be expressed as;

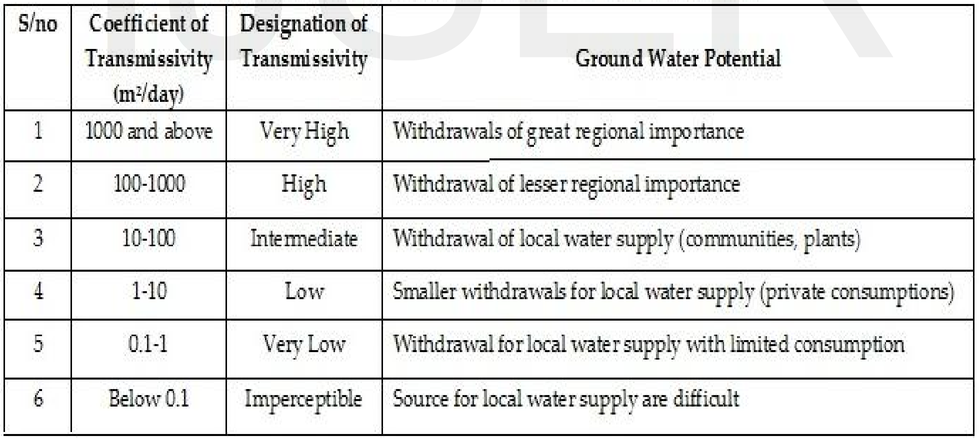
$$K = b \times 8 \times 10^{-6} e^{-(0.0013\rho)} \qquad (3)$$

Where b = the aquifer thickness (m), ϱ = the resistivity of the aquifer in (Ωm).

Knowledge of permeability and transmissivity distribution is decisive for any groundwater development or consideration. In hydro-geologic maps, transmissivity has been the best hydraulic property to clearly express ground water potentia [28], Table 1.

In this research work, the Schlumberger array technique has been used to obtain the Vertical Electric Sounding (VES) from which the thickness and resistivity of the aquifer was obtained. Fig. 2 shows the location of the VES points around the study area.

Table 1
Classification of Transmissivity magnitude (Culled from [28]).



S/no	Coefficient of Transmissivity (m^2/day)	Designation of Transmissivity	Ground Water Potential
1	1000 and above	Very High	Withdrawals of great regional importance
2	100-1000	High	Withdrawal of lesser regional importance
3	10-100	Intermediate	Withdrawal of local water supply (communities, plants)
4	1-10	Low	Smaller withdrawals for local water supply (private consumptions)
5	0.1-1	Very Low	Withdrawal for local water supply with limited consumption
6	Below 0.1	Imperceptible	Source for local water supply are difficult

Table 2
Range of values for hydraulic conductivity for some geologic material (culled from [4]).

Lithology	**Relative value Hydraulic conductivity (m/s)**													
	1	10^{-1}	10^{-2}	10^{-3}	10^{-4}	10^{-5}	10^{-6}	10^{-7}	10^{-8}	10^{-9}	10^{-10}	10^{-11}	10^{-12}	10^{-13}
	Very High ↔			High ↔		Moderate ↔			Low ↔			Very Low ↔		
Gravel	↔	↔	↔	↔										
Clean sand			↔	↔	↔	↔								
Silty sand					↔	↔	↔	↔						
Sandstone (fractured)					↔	↔	↔	↔						
Limestone & Dolomite								↔	↔	↔	↔			
Vesicular & fractured basalt						↔	↔	↔	↔					
Fractured & weathered crystalline rocks							↔	↔	↔	↔				
Massive cryst-alline rocks										↔	↔	↔	↔	

4. MATERIAL AND METHODS

The schulmberger technique which is best for probing depth was used to acquire the Vertical Electrical Sounding (VES) data. This technique has long been used to source for water in any type of geologic setting. In this study, Abem Tarrameter SAS 1000 was used and twenty points was sounded in areas were drilling could be done as shown in Fig. 2. The data collected was processed using the EarthImager 1D Version 2.0.4 software. This software was able to display a processed result in a log-log graph. From the result, the weathered aquifer was identified with its resistivity as shown in Table 2. By using equations 2 and 3, values for transmissivity and hydraulic conductivity were computed (see Table 3). These data, together with the coordinate of points for each station was plotted to obtain using a Garmin global positioning system (GPS) and obtained a 2-dimensional contour maps as shown in Fig. 2, 3, 4, 5 and 6 below. This was done with the aid of Surfer 11 software.

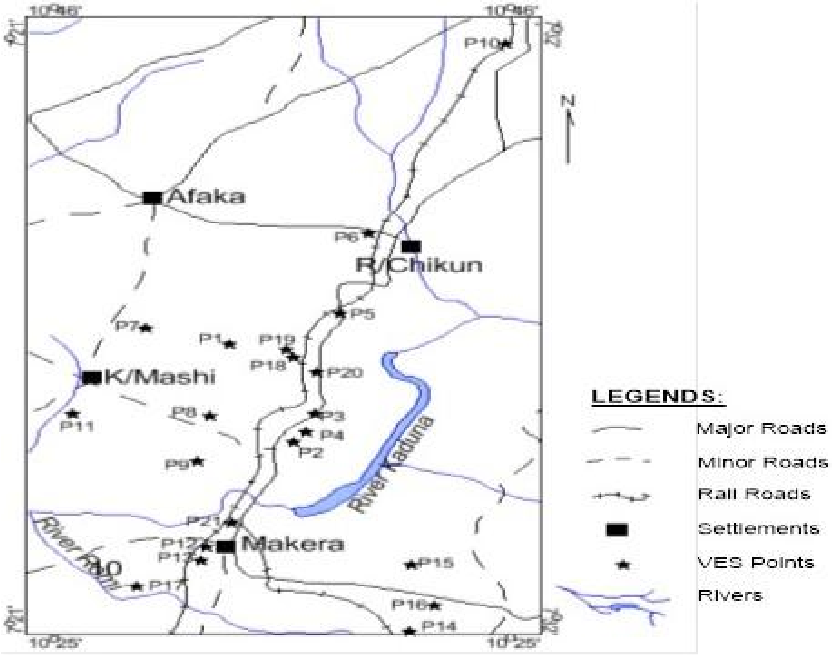


Fig. 2. Vertical Electrical Sounding (VES) points in the Study Area.

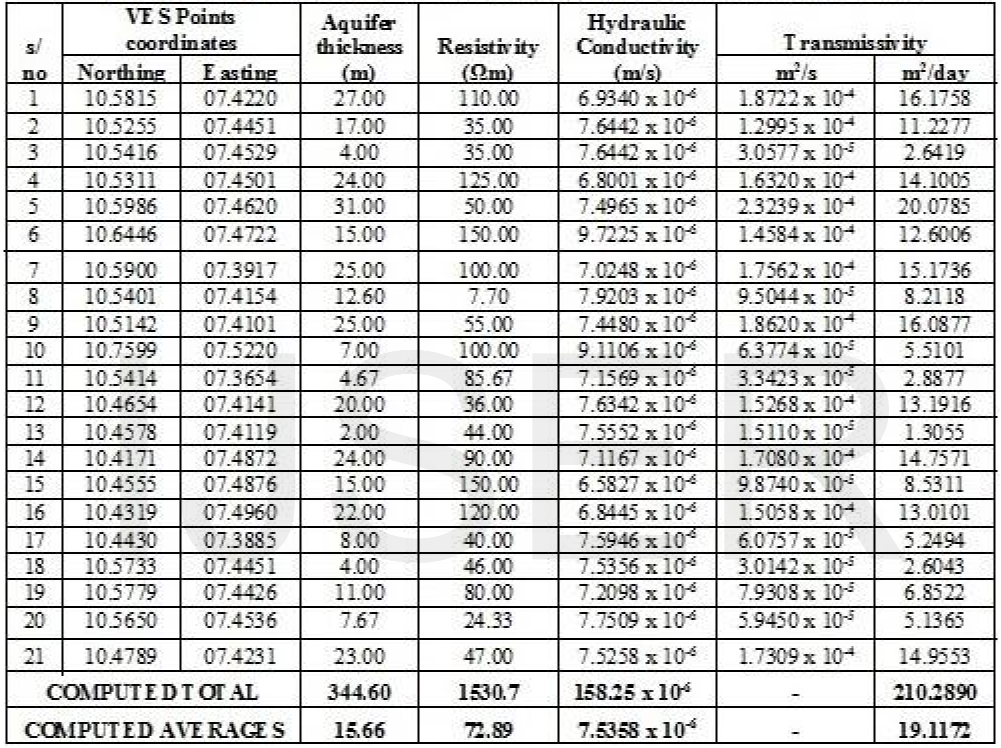
5. RESULTS DISCUSSION

Results obtained from the vertical electrical sounding was documented in Table 3 showing co-ordinates of VES points with the estimated thickness of the aquifer, its associated resistivity value, and the computed total and average values for conductivity and transmissivity according to the equations (2) and (3).

These data were used to obtain contour maps for the aquifers' thickness, resistivity, hydraulic conductivity and transmissivity. They are represented by Fig. 3, 4, 5 and 6. Fig. 7 is the combined aquifer transmissivity contour map and the study area map while Fig. 8 is the combined aquifer conductivity contour map and the study area map.

Transmissivity values recorded are within a range of 1.31 m^2/day to 20.08 m^2/day, with an average value of 19.12 m^2/day. Hydraulic conductivity values range from 6.5827 x 10^{-6} m/s to 9.7225 x 10^{-6} m/s with an average value of 7.5358 x 10^{-6} m/s. Aquifer thickness recorded a range of value between 2.00 m to 31.00 m with an average of 15.66 m.

TABLE 3
VES points with calculated Conductivity and Transmissivity values.



s/ no	VES Points coordinates		Aquifer thickness (m)	Resistivity (Ωm)	Hydraulic Conductivity (m/s)	Transmissivity	
	Northing	Easting				m^2/s	m^2/day
1	10.5815	07.4220	27.00	110.00	6.9340 x 10^{-6}	1.8722 x 10^{-4}	16.1758
2	10.5255	07.4451	17.00	35.00	7.6442 x 10^{-6}	1.2995 x 10^{-4}	11.2277
3	10.5416	07.4529	4.00	35.00	7.6442 x 10^{-6}	3.0577 x 10^{-5}	2.6419
4	10.5311	07.4501	24.00	125.00	6.8001 x 10^{-6}	1.6320 x 10^{-4}	14.1005
5	10.5986	07.4620	31.00	50.00	7.4965 x 10^{-6}	2.3239 x 10^{-4}	20.0785
6	10.6446	07.4722	15.00	150.00	9.7225 x 10^{-6}	1.4584 x 10^{-4}	12.6006
7	10.5900	07.3917	25.00	100.00	7.0248 x 10^{-6}	1.7562 x 10^{-4}	15.1736
8	10.5401	07.4154	12.60	7.70	7.9203 x 10^{-6}	9.5044 x 10^{-5}	8.2118
9	10.5142	07.4101	25.00	55.00	7.4480 x 10^{-6}	1.8620 x 10^{-4}	16.0877
10	10.7599	07.5220	7.00	100.00	9.1106 x 10^{-6}	6.3774 x 10^{-5}	5.5101
11	10.5414	07.3654	4.67	85.67	7.1569 x 10^{-6}	3.3423 x 10^{-5}	2.8877
12	10.4654	07.4141	20.00	36.00	7.6342 x 10^{-6}	1.5268 x 10^{-4}	13.1916
13	10.4578	07.4119	2.00	44.00	7.5552 x 10^{-6}	1.5110 x 10^{-5}	1.3055
14	10.4171	07.4872	24.00	90.00	7.1167 x 10^{-6}	1.7080 x 10^{-4}	14.7571
15	10.4555	07.4876	15.00	150.00	6.5827 x 10^{-6}	9.8740 x 10^{-5}	8.5311
16	10.4319	07.4960	22.00	120.00	6.8445 x 10^{-6}	1.5058 x 10^{-4}	13.0101
17	10.4430	07.3885	8.00	40.00	7.5946 x 10^{-6}	6.0757 x 10^{-5}	5.2494
18	10.5733	07.4451	4.00	46.00	7.5356 x 10^{-6}	3.0142 x 10^{-5}	2.6043
19	10.5779	07.4426	11.00	80.00	7.2098 x 10^{-6}	7.9308 x 10^{-5}	6.8522
20	10.5650	07.4536	7.67	24.33	7.7509 x 10^{-6}	5.9450 x 10^{-5}	5.1365
21	10.4789	07.4231	23.00	47.00	7.5258 x 10^{-6}	1.7309 x 10^{-4}	14.9553
COMPUTED TOTAL			**344.60**	**1530.7**	**158.25 x 10^{-6}**	-	**210.2890**
COMPUTED AVERAGES			**15.66**	**72.89**	**7.5358 x 10^{-6}**	-	**19.1172**

Thus, on the basis of its average transmssivity values the study area can be classified to have 'intermediate' transmissivity according to [28] classification, see Table 1. On the basis of the entire range of data collected (1.31 m^2/day to 20.08 m^2/day), the area was generally classified to have 'low to intermediate' transmissivity distribution as shown in table 1. This is because the distribution of groundwater potential on the basis of its transmiissivity, were reflected in the transmissivity contour map (Fig. 6). Relatively higher potential for water is located at the middle of the study area, extending towards both the northwest and southeast direction. This area is estimated to cover probably about 75-80% of the entire study area and on the basis of their transmissivity values recorded shows intermediate potential. Furthermore, location indicating transmissivity values of less than 10.00 m^2/day represented by the blue colour are classified as the 'low transmissivity' potential areas. They occupy approximately 20-25% of the study area. When the transmissivity map is draped over the study area map, settlements with intermediate groundwater potential for local use include; Riga Chikun, Afaka, and Makera, while Kurmin Mashi is located in the low groundwater potential area.

Regions that record low transmissivity occur around areas with exposures of rock outcrop. This is probably so because of low porosities where the crystalline rocks are poorly fractured. They correspond to the areas with small aquifer thickness, see Fig. 3 and 4. Groundwater in the study area occurs within two aquifers - the Soft Overburden Aquifer and Fractured Crystalline Aquifer. This is evident as when type of aquifer medium conforms to the desired range of values obtained from the hydraulic conductivity as shown in Table 2.

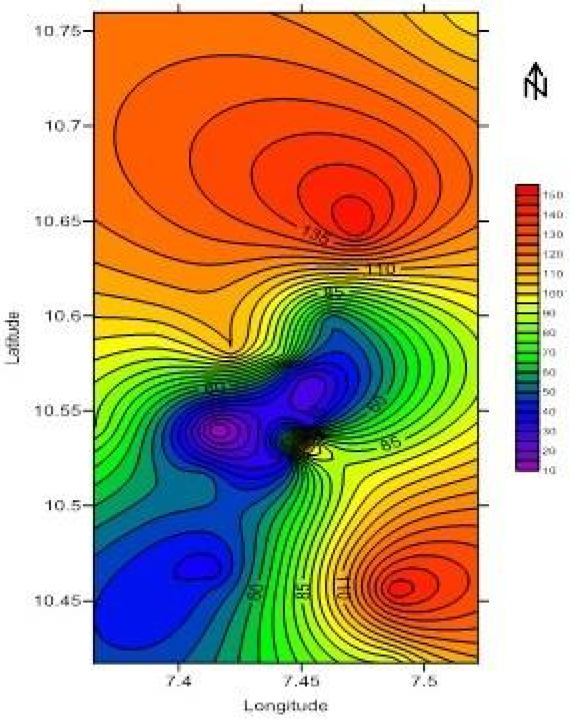


Fig.3. Aquifer Resistivity contour map.

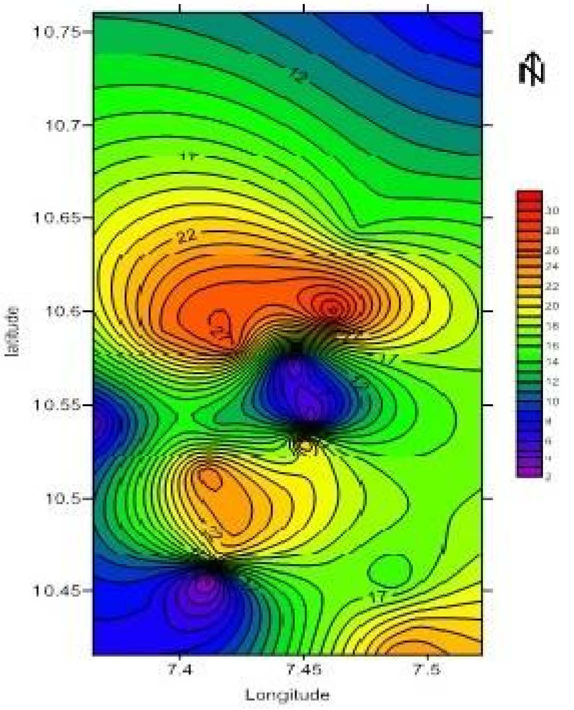


Fig. 4. Aquifer thickness contour map.

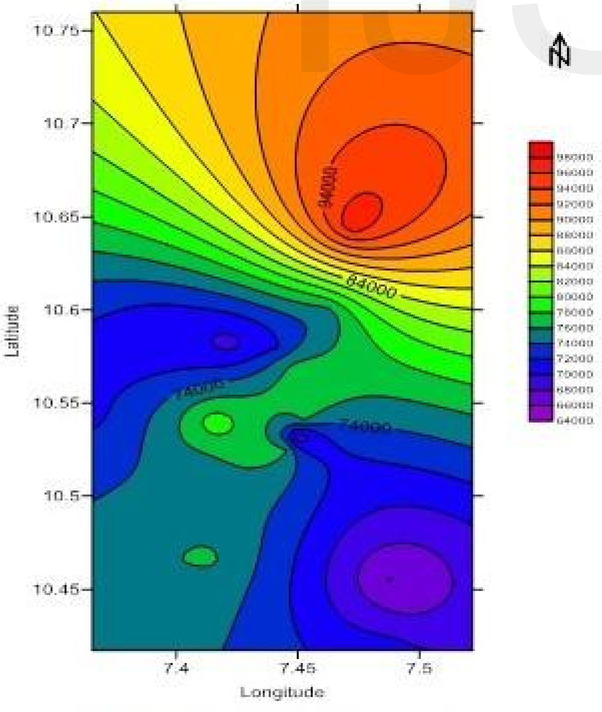


Fig 5. Conductivity contour map.

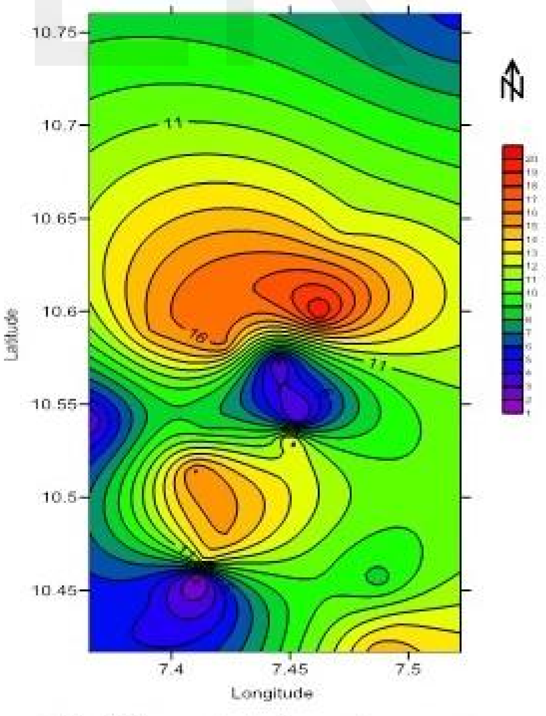


Fig. 6. Transmissivity contour map.

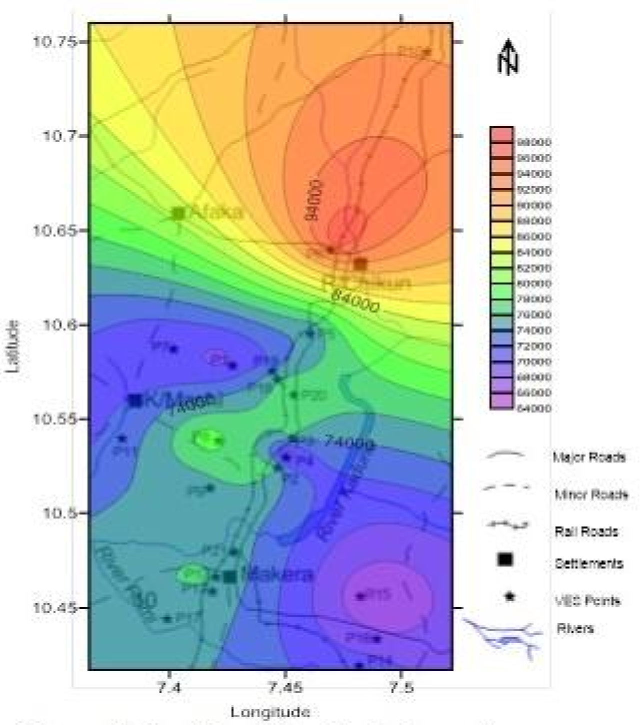


Figure 7: Combined Conductivity contour map on the Study Area.

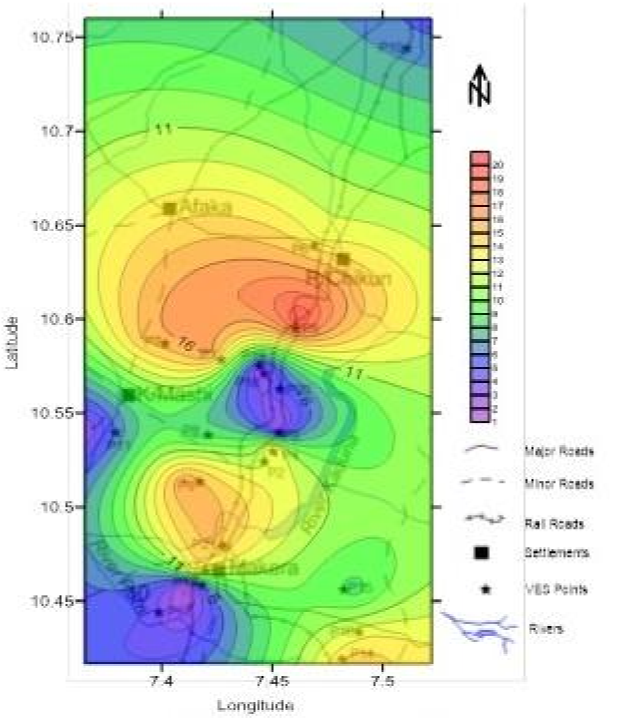


Figure 8: Combined Transmissivity contour map on the Study Area.

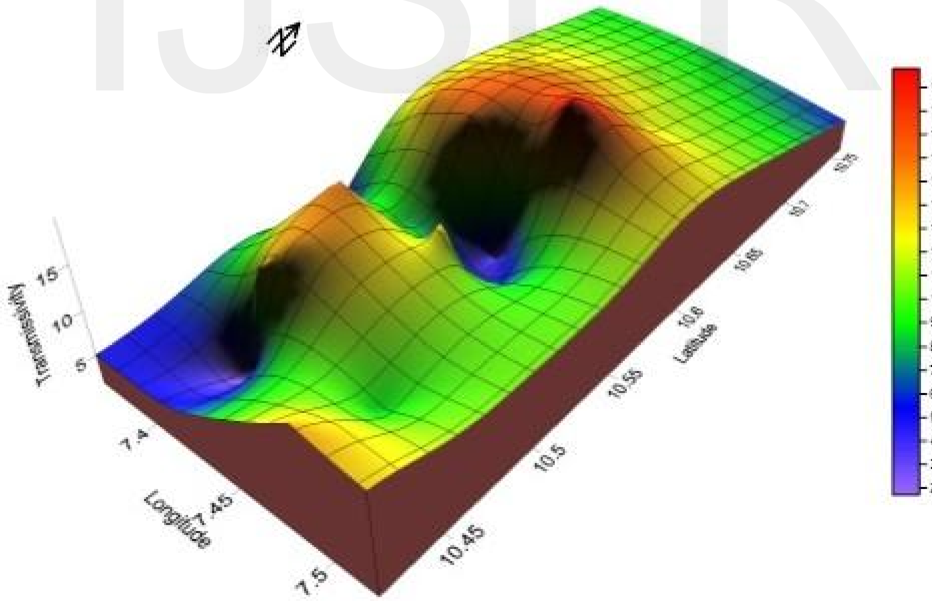
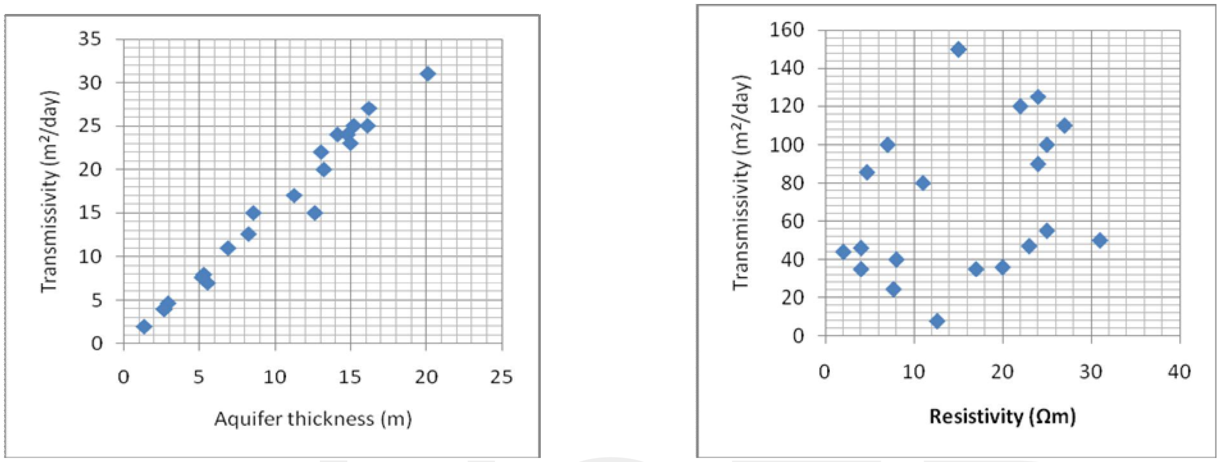


Fig. 9. A 3-D Transmissivity contour map on study Area

Since 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, we can say that from the hydraulic conductivity (see Table 2 and Fig. 8) in the range of 10^{-6} ms^{-1} in the study area is fractured and weathered crystalline rock according to [4]. The Fig. 5 shows the distribution of the conductivity of the study area. Riga Chukin has the highest value.

The aquifer-thickness contour map has shown good correlation when compared to the transmissivity contour map (see Fig. 4 and 6). Transmissivity is characteristic of fluids and the aquifer material but also depends the saturated thickness (compare Fig. 4 and 6). This shows that thicker aquifers can support the storage and yield of more groundwater, which in-turn implies good water potentials. A 2D model showing distribution of hydraulic conductivity (Fig. 7) in the study area is obtained, while the same model for transmissivity distributions is represented in Fig. 8. A 3D model for the transmissivity distribution in the area clearly illustrates potential regions of higher groundwater yield with respect to regions of lower yield. In Fig. 11(a) there is a strong positive correlation between plots of aquifer transmissivity versus aquifer-thickness, while for a plot of aquifer transmissivity versus electrical resisitivity shows no correlation between them. This probably suggest that a thicker weathered overburden store more water, thus the transmissivity will also be high and consequently indicating a higher potential.

On a broad scale, the groundwater potential of this area ranges in quantity from large withdrawal for local water supply (as community consumption) to smaller withdrawal for local supply (private consumption) according to Table 1.



(a) (b)

Fig. 10. A correlation plot of aquifer transmissivity against aquifer thickness is shown in (a) while correlation plot of aquifer transmissivity against electrical resistivity is shown in (b).

6. CONCLUSION

Hydrological parameters are important in ground water prospecting. The conventional methods of obtaining this parameters involves drilling (which is usually expensive), however, a less expensive and faster method of obtaining this parameter was used in this research work to determine the ground water potential of the study area. The geology of the study area has encouraged the use of this technique to determine conductivity and transmissivity values of the area.

The result has been compared with previous standard values. Transmissivity values recorded have a range of 1.31 m^2/day to 20.08 m^2/day. Average transmissivity value computed was 19.12 m^2/day. The ground water potential of this study area has been determined to be from intermediate to low on the transmissivity scale. Localities like Riga Chikun, Afaka, and Makera has been found to have intermediate groundwater potential for local use, while Kurmin Mashi is located in the low groundwater potential area.

This implies that the groundwater yield is adequate to sustain water supply need of communities like Afaka and Riga Chikun. Other places like Kurumi Mashi and Makera will have just enough water for private use. There is a strong positive correlation between transmissivity and aquifer thickness, while there was no correlation between aquifer transmissivity and aquifer resistivity.

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