Estimation of Aquifer Hydraulic Characteristics in Basement Terrain in Parts of Batagarawa area, Katsina State Nigeria using Geo-electrical Measurement

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ABSTRACT

Geo-electrical survey involving vertical electrical sounding (VES) was carried out using Schlumberger electrode configuration. The study aimed at estimating the aquifer hydraulic parameters in parts of Batagarawa area, Katsina state. Twenty four (24) VES were carried out. The interpreted and analyzed results reveal three to five geo-electric layers. The aquifer resistivity range from 0.274 to 2580 Ωm while aquifer thickness ranges between 1.25 to 29.5m. The transverse resistance ranges between 0 and 16583 Ωm^2. The range of hydraulic conductivity is 0.254 – 1292.767 m/day, while the range of transmissivity is 0 – 38,136.627 m^2/day from the estimated values. The contour maps were drawn using the electrical and hydraulic parameters, and the distribution of the aquifer hydraulic parameters was shown. Low spatial variability of hydraulic conductivity suggests strong homogeneity of the aquifer system. Based on the results, the assessment indicates that there is low groundwater potential in the greater part of the study area particularly western, eastern and slight northern part.
Keywords: Aquifer properties; basement terrain; geo-electrical method; hydraulic characteristics.

INTRODUCTION

Water is a critical natural resource upon which all social and economic activities and ecosystem functions depend (Biney, *et al.,* 2024). Groundwater is the main source of water which accounts for high proportion of the world's fresh water, as a result, the sustainable provision of groundwater supplies for current and future needs is of regional to global significance (Falowo, *et al.,* 2023). The importance of groundwater to the growth and health of people particularly in the developing world cannot be over emphasized (Salami, *et al.,* 2024). Hence, any assessment of a groundwater supply is considerably affected by geological factors that render the recharging process easier by linking surface discharge to the groundwater reservoir. In particular, the recharge process is controlled by geological features comprising faults, voids, fissures, fractures, crevices, solution cavities, and other structural geological characteristics (Abdelrahman, *et al.,* 2023).

The availability of groundwater depends on the presence and hydraulic properties of aquiferous (groundwater bearing) units; and its portability depends on its hydrogeochemical properties (Mgbolu, *et al.,* 2019). Aquifers of the crystalline basement, developed within crystalline rocks of igneous or metamorphic origin (Wright, 1992), are mostly developed within the weathered overburden and fractured bedrock of these crystalline rocks. Such aquifers typically have a fractured-weathered layer that has a fracture density that decreases with depth and controls most of the aquifer hydraulic parameters, including the aquifer storage properties (Muchingami, *et al.,* 2019).

About 95% of the population within the sudy area relied on groundwater as a result of scarce surface water resources in the area. Public water resources management infrastructures are inadequate or almost non-existent and where they exist cannot meet the needs of the growing population. Attempts to estimate aquifer hydraulic parameters from geophysical sounding method have not been carried out so far in the area. Therefore, estimation of aquifer hydraulic properties in the area is important in order to explore groundwater resources for different purposes. The goal of the study is to estimate aquifer hydraulic characteristics in order to enhance our understanding on groundwater availability in the area. Findings from this study will inform decision makers and general public on groundwater resource management.

MATERIALS AND METHODS

Location of the study area and geological setting

Batagarawa town is the study area which is located in the northern region of Nigeria's crystalline basement terrain. It is found between latitude 12º50' and 13º00' North of the equator, and longitude 07º20 and 07º40' East of the Greenwich meridian The landscape of the area is highly dominated by plain. The area is belongs to the tropical continental (wet and dry) climatic zone of northern Nigeria. It is characterized by short wet and long dry seasons, with very high annual temperature range. The study area receives few months of annual rainfall normally between June and October, having an annual average of about 650-700mm. (Hassan, and Maiwada, 2021). The study area compose of Sudan Savannah vegetation belt, with scanty trees, shrubs and short grasses. As per Abdulkadir, *et al.,* (2023) the soil of the study area is ferruginous tropical soil (undifferentiated). Geologically, about 80% of the state is underlined by the Basement Complex terrain which is characterized by nine geological formations consisting of biotite homeblend granite, coarse biotite homeblend granite, fine grained, granite gneiss, migmatite, porphyritic gneiss, ryolite, sandstone and Solicited sheared rock. The area considered in this research, Batagarawa town is underlain by coarse biotite homeblend granite and sandstone (Lawal and Usman, 2022).

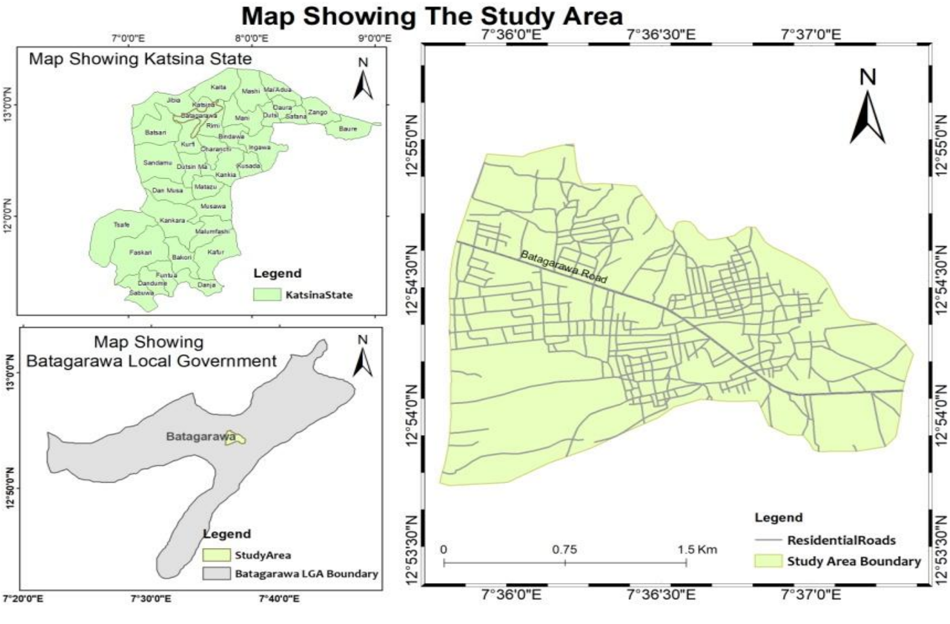

Figure 1: Map showing the study area

Methods

Vertical electrical sounding (VES) was carried out using ABEM Terrameter SAS 4000 in twenty-four (24) locations within the study area. The VES points were selected randomly based on the availability of space for spreading. Global Positioning System (GPS) was used to take the coordinate of each sounding point, Schlumberger electrode configuration was adopted with current electrode spacing (AB/2) ranging from 1m to 100 m while potential electrode spacing (MN/2) ranged from 0.5 m to 5 m. The values of resistance (R) were obtained directly from the resistivity meter, and the product of resistance (R) obtained and geometric factor (K) gives the apparent resistivity (ρ). The value of apparent resistivity (ρ) against half-electrode spacing (AB/2) was first plotted manually on a logarithmic graph, and the graphs were interpreted using master curves and auxiliary charts (Orellana and Mooney 1966). Output from the quantitative manual interpretation was modelled using computer software. The IPI2Win version 1.0 interpretation software was used for the iteration and presentation of the curve in order to generate the geoelectric parameters.

Estimation of aquifer hydraulic parameters

The transverse resistance R is given by:

$$\mathrm{R} = \sum_{i=1}^{n} hp \text{ ....i}$$

The longitudinal conductance S can be estimated using equation vi.

$$S = \sum_{i=1}^{n} h/p \text{ ....ii}$$

where h and ρ are respectively the thickness and resistivity of the ith layer in the section.

Hydraulic conductivity can be determined using:

$$K = 386.40 R_{rw}^{-0.93283} \text{ ....iii}$$

where K = hydraulic conductivity and R_{rw} = aquifer resistivity.

The aquifer transmissivity (Tr) was estimated using the relation (Niwas and Singhal, 1981):

Tr = $K\sigma T$ = KS/σ iv

where r is the electrical conductivity (inverse of resistivity), S is the longitudinal conductance and T is the transverse resistance. Equations (iii) and (iv) were used in this study to determine the hydraulic conductivity and transmissivity of aquifers.

RESULT AND DISCUSSION

The results of the geo-electric sounding data revealed three to five geo-electric layers with varying intrafacies and interfacies changes (Table 1). The third and fourth layers having the majority of the aquiferous zones. Seven geo-electric curve types were identified and grouped as: QH (41.67 %), 29.16 % of H, while 8.3 % represents A and Q, HK, KH and K having 4.16 % respectively.

The transverse resistance (R) of the study area ranged from 0 to 16,583.4 Ωm^2 with the mean value of 1650.72 Ωm^2. The spatial distribution of the transverse resistance is shown in Fig. 2. Highest value of transverse resistance was observed in the western part of the area and part of the north-eastern area. This indicates that the western and eastern part of the study area has high thickness as can be seen from the isopach map (Fig. 2), and it can be assumed that these areas may likely have high transmissivity and high yield of aquifer units. This result is in line with the findings of Ankidawa, *et al*., 2023.

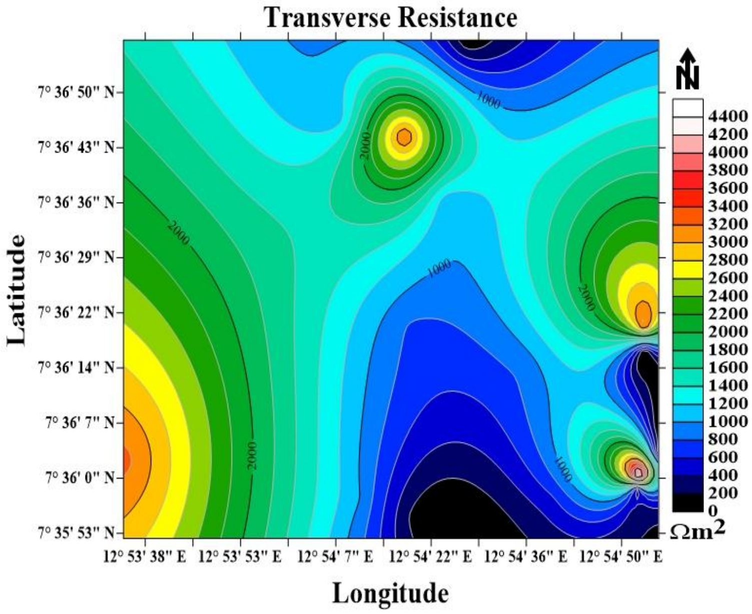

Figure 2: Spatial distribution of transverse resistance

Hydraulic conductivity is a measure of the ease with which a fluid will pass through a medium (Heigold, *et al.,* 1979). Hydraulic conductivity of the study area was shown in Fig. 3. The aquifer hydraulic conductivity (K) ranges from 0.254 – 1,292.767. m/day (Table 2). The high range of hydraulic conductivity of the aquifer may be due to the heterogeneity nature of the aquifer, a condition responsible for wide range in hydraulic conductivity (George *et al.,* 2015). The spatial distribution of hydraulic conductivity (Fig. 3) revealed low hydraulic conductivity values throughout the majority of the area, suggesting that the limited aquifers' geologic restrictions make groundwater flow in the area complex rather than simple.

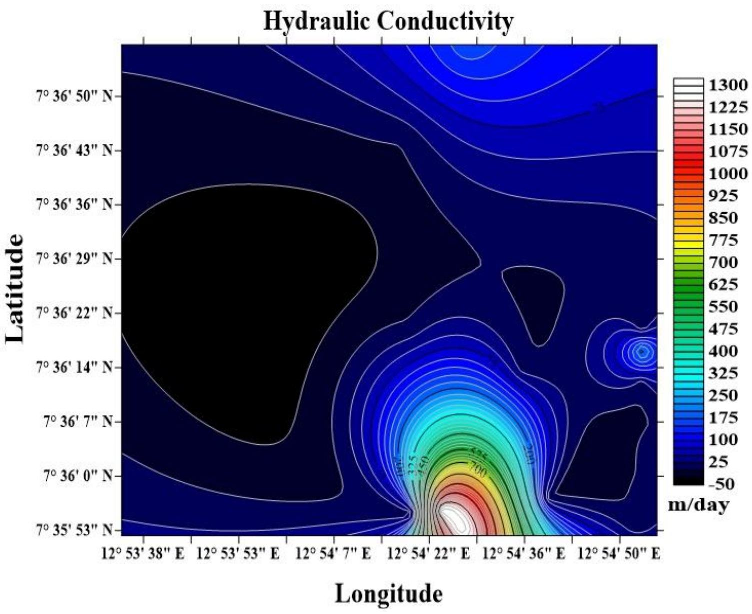

Figure 3: Spatial distribution of hydraulic conductivity

Table 1 Summary of result of interpreted parameters.

VES No.	**Coordi-nates**	**Layer Resistivity (ohm-m)**					**Layer thickmess (m)**				**Lithological description**	**Erro r %**	**Curve type**
		p_1	p_2	p_3	p_4	p_5	h_1	h_2	h_3	h_4			
1.	12º91'48" 07º59'82"	2470	84.7	71198	∞	∞	2.31	3.43	∞	∞	Top laterite soil, aquiferous layer, weathered basement.	5.71	H
2.	12º91'71" 07º59'86"	1700	98.6	150000	∞	∞	1.82	2.56	∞	∞	Top laterite soil, aquiferous layer, weathered basement.	5.11	H
3.	12º91'14" 07º59'90"	10177	1385	106	84570	∞	0.492	0.954	4.27	∞	Top soil, sandy clay, weathered sandstone, weathered basement	3.25	H
4.	12º91'95" 07º59'96"	596.2	22534	115.8	62267	∞	0.324	0.955	2.267	∞	Top soil, sandy clay, weathered sandstone, weathered basement	1.21	KH
5.	12º91'98" 07º60'01"	4992	1391	335	480000	∞	0.525	2.03	14.8	∞	Top soil, sandy clay, weathered sandstone, weathered basement	2.94	H
6.	12º91'93" 07º60'09"	751	470000	18.4	∞	∞	0.36	1.3	∞	∞	Top laterite soil, aquiferous layer, weathered basement.	9.39	K
7..	12º91'44" 07º60'18"	223	40938	1494	80000	∞	0.472	0.741	11.1	∞	Top soil, sandy clay, weathered sandstone, weathered basement	4.63	A
8.	12º91'54" 07º60'34"	1814	485.3	132.3	48.62	93133	0.315	1.175	4.999	4.943	Top laterite, dry sandy + laterite, saturated laterite, aquifer, weathered basement	1.94	H
9.	12º91'69" 07º60'40"	1748	61.1	3.31	3492	∞	0.388	1.12	9.23	∞	Top soil, sandy clay, weathered sandstone, weathered basement	8.5	QH
10.	12º91'98" 07º60'46"	385	97.1	1141	1.81	∞	0.325	4.73	18	∞	Top soil, sandy clay, weathered sandstone, weathered basement	2.46	HK
11	12º91'66" 07º60'55"	4157	764	192	67057	∞	0.578	1.46	17.2	∞	Top soil, sandy clay, weathered sandstone, weathered basement	4.04	QH
12	12º90'80" 07º59'78"	290.1	43.35	3.729	0.6483	0.2976	0.5582	1.539	4.763	20.27	Top laterite, dry sandy + laterite, saturated laterite, aquifer, weathered basement	1.81	Q
13	12º90'73" 07º59'79"	163	6.05	0.754	0.274	950000	0.51	1.2	8.43	29.5	Top laterite, dry sandy + laterite, saturated laterite, aquifer, weathered basement	2.73	Q
14	12º90'64" 07º59'87"	155	31.6	1.51	0.272	167	0.553	1.6	5.18	7.87	Top laterite, dry sandy + laterite, saturated laterite, aquifer, weathered basement	8.72	QH
15	12º90'52" 07º59'86"	1340	395	42.6	46306	∞	0.543	2.32	2.94	∞	Top soil, sandy clay, aquiferous, weathered basemsnt	9.38	H
16	12º90'51" 07º60'84"	1618	65.7	28174	∞	∞	1.1	11.6	∞	∞	Top soil, sandy clay, aquiferous, weathered basemsnt	9.98	QH

Table 1. *Continued ....*

17	12º89'30" 07º60'06"	16063	2103	325	230000	∞	0.64	1.87	10.1	∞	Top soil, sandy clay, aquiferous layer, weathered basement	8.51	QH
18	12º90'48" 07º61'23"	17637	1112	179	91641	∞	0.542	1.76	18.3	∞	Top soil, sandy clay, aquiferous layer, weathered basement	7.85	QH
19	12º90'75" 07º61'59"	2.41	2580	51819	∞	∞	0.316	2.3	∞	∞	Top soil + aquiferous layer, sandy clay, weathered basement	5.42	A
20	12º90'75" 07º61'59"	2893	514	142	9641	∞	0.656	2.01	7.41	∞	Top soil, sandy clay, aquiferous layer, weathered basement	2.99	H
21	12º90'28" 07º59'92"	3753	434	96.5	49453	∞	0.598	1.94	10.9	∞	Top soil, sandy clay, aquiferous layer, weathered basement	5.51	QH
22	12º90'66" 07º61'00"	5802	1328	112	8450	∞	0.356	1.08	9.18	∞	Top soil, sandy clay, aquiferous layer, weathered basement	3.34	QH
23	12º90'99" 07º60'39"	2289	202	44	13702	∞	0.493	1.25	19.6	∞	Top soil, sandy clay, aquiferous layer, weathered basement	2.21	QH
24	12º91'10" 07º59'92"	12971	2420	274	101	106517	0.3555	1.068	4.928	5.394	Top soil, sandy clay, aquiferous layer, weathered basement	2.99	QH

The transmissivity (Tr) value ranges from 0 – 38,136.627 m^2/day with an average value of 1698.34 m^2/day (Table 2), Area with high transmissivity values can be identified as area of high water bearing potential and aquifer materials are known to be relatively permeable to fluid movement. The spatial distribution of transmissivity was shown in Fig. 4. The greater part of the study area has low trasmissivity. Thus, indicating that the area is of low groundwater potential.

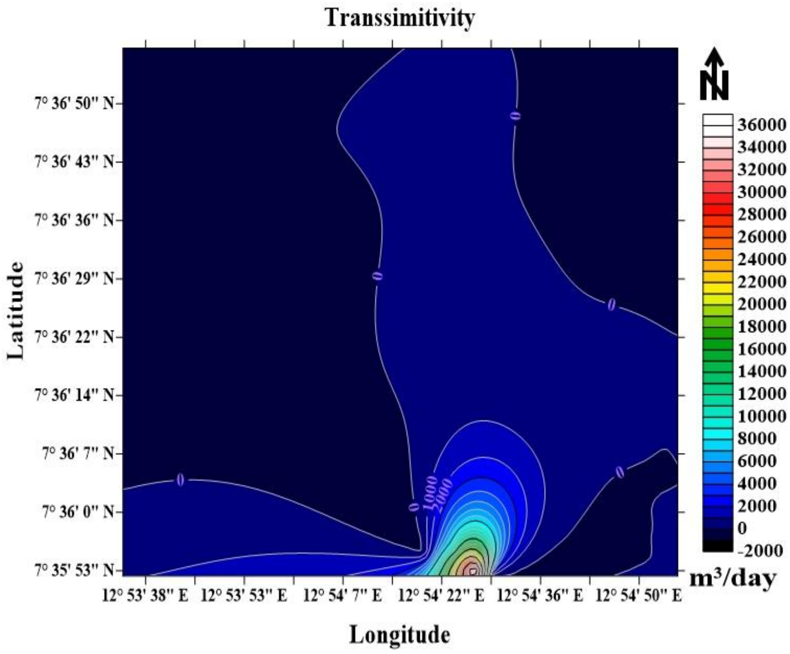

Figure 4: Spatial distribution of transmissivity

Table 2 Summary of hydraulic parameters of the study area

VES No.	ρ (Ωm)	h (m)	R = hρ	S = h/ρ	K = (m/d)	Tr = Kh (m^2/d)
1	84.7	3.43	290.521	0.041	6.149	21.090
2	98.6	2.56	252.416	0.026	5.334	13.656
3	106	4.27	452.62	0.040	4.986	21.291
4	115.8	2.267	262.519	0.020	4.591	10.409
5	335	14.8	4,958	0.044	1.705	25.227
6	18.4	∞	0	0	25.537	0
7	1494	11.1	16,583.4	0.007	0.423	4.691
8	132.3	4.999	661.368	0.038	4.055	20.270
9	3.31	9.23	30.551	2.789	126.510	1,167.690
10	97.1	4.732	459.283	0.049	5.411	25.595
11	192	17.2	3,302.4	0.090	2.865	49.276
12	0.2976	∞	0	0	1,196.873	0
13	0.274	29.5	8.083	107.66	1,292.767	38,136.627
14	167	∞	0	0	3.263	0
15	42.6	2.94	125.244	0.069	11.670	34.310
16	65.7	11.6	762.12	0.177	7.790	511.829
17	325	10.1	3,282.5	0.031	1.753	17.709
18	179	18.3	3,275.7	0.102	3.059	55.971
19	2580	2.3	5934	0.0009	0.254	0.584
20	142	7.41	1,052.22	0.052	3.796	28.128
21	96.5	10.9	1,051.85	0.113	5.443	59.325
22	112	9.18	1,028.16	0.082	4.737	43.482

23	202	1.25	252.5	0.006	2.605	3.256
24	101	5.394	544.794	0.0534	5.216	28.136
Average	280.24	7.64	1,650.72		113.62	1,698.34

ρ = Aquifer resistivity, h = Aquifer thickness, R = Transverse resistance, S = Longitudinal conductance, K = Hydraulic conductivity, Tr = Transmissivity,

CONCLUSION

Geo-electrical sounding method was used in this study to evaluate the aquifer hydraulic parameters. The results provide information on aquifer hydraulic parameters which included the hydraulic conductivity and transmissivity. These parameters were used to generate different contour maps. The result revealed that areas with high transverse resistance values may give high aquifer yield; it also show that the aquifers characterized with low hydraulic conductivity indicating complexity of groundwater flow in the area and transmissivity revealed the area is of low groundwater potential.

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