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Delineation of Groundwater Potential Zones of Girei and Environs, Adamawa State, North Eastern Nigeria

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Abstract

Evaluation of groundwater resources of Girei and environs is necessary in order to develop appropriate water supply scheme to the community. Cases of borehole failures have been on increase in the area due to a lack of knowledge of the aquifer geometry. The study is aimed at delineating the groundwater potential zones of Girei and environs with the objectives of delineating the different aquifer systems, estimating the aquifer characteristics such as transmissivity and hydraulic conductivity using the Dar Zarrouk parameter, determining groundwater flow direction, and identifying the recharged and discharged areas. Geological investigation indicates that the area underlain by Bima sandstone. Thirty profiles of Vertical Electrical Sounding using Schlunberger array method with the aid of ABEM signal averaging system (SAS 1000) was used to determine aquifer types and groundwater potential zones. Correlation between borehole lithological section and geoelectric section within the study area revealed a confineded aquifer type. The aquifer characteristics indicate that the transverse resistance ranged between 29.796 to 238000 Ωm^2, longitudinal conductance ranged between 0.0148 Ω^{-1} to 9.34 Ω^{-1}, hydraulic conductivity values range from 0.0014 to 5.865 m/s with an average value of 0.0355 m/s. Transmissivity values obtained from the various layers range from 237.6 m^2/day to 6324 m^2/day. Aquifer rating based on transmissivity values reveals that the aquifers in the study area have moderate to high potential.

1. INTRODUCTION

Water is a vital resource for human existence, and the growth of any community is a function of availability of basic infrastructures such as potable water, good road and industries. Evaluation of groundwater potentials and for its uses in terms of domestic, agricultural and industrial activities have not been given attention especially in developing countries like Nigeria. Groundwater is of significant importance to northern Nigeria where the amount of rainfall is limited to very few months of the year with annual rainfall of about 1,000 to 1,500 mm and surface water resources are usually inadequate. This concept of groundwater management centers on establishment of norms leading to optimization of factors necessary for economic utilization of the resources without disturbing the systems. In geophysical investigations for water, depth to bedrock determinations, sand and gravel are targeted etc., the electrical resistivity method can be used to obtain, details about the location, depth and resistivity of subsurface formations (Okolie, 2010; Ankidawa et al., 2018; Yusuf et al., 2021).

Recently, it has been proven that electrical resistivity is very reliable in determining the effectiveness of data interpretation for geophysical ground resistivity survey from the complexity between field and laboratory measurements. Jointly engaged both seismic refraction survey method and vertical electrical sounding for groundwater potential investigation. The degree of certainty of geoelectrical method over other methods in the search for groundwater was proven by the work of Pulowaski and Kurht (1977), while the work by Zodhy et al. (1974) shows the ability of the resistivity method to furnish information on the subsurface geology over the other methods of groundwater studies. Badmus and Olatinsu (2010) carried out research work on aquifer characteristics and groundwater recharge pattern in a typical basement complex in the south-western Nigeria. In their work, they used vertical electrical sounding using Schlumberger electrode array. It was revealed that Abeokuta has seven major litho stratigraphic sequences which are topsoil, shale or clay, sandy clay, clayey sand, sandstone, fractured basement and fresh basement. It was also discovered that the weathered and fractured basement constitutes the main aquiferous units in the area. They were

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able to discover that the reasons for borehole failure and poor recharge in the area is attributed to inadequate geophysical investigation, the depth at which drilling was terminated and the geological formation of the aquifers.

The electrical resistivity method has been recognized to be more suitable for hydrogeological survey than the other resistivity method (Ankidawa, 2014; Ankidawa et al., 2018). Seli et al. (2021) used Dar Zarrouk Parameters to delineate groundwater Potential zones using vertical electrical sounding. Nwosu et al. (2014) delineated the Aquifer Systems of Okigwe District Southeastern Nigeria Using Dar Zarrouk Parameters from Surface Geoelectric Survey, three aquifer systems were identified viz the Coastal plain sands aquifer, the Bende-Ameki sandstone/shale aquifer and the Ajali sandstone aquifer. Austin and Gabriel (2015) applied the concept of Dar Zarrouk parameters in predicting the aquifer protective capacity of Agbani Sandstone aquifer at Enugu State University of Science and Technology, Agbani campus, Enugu State.

Longitudinal conductance, longitudinal resistivity, transverse resistance and apparent resistivity data were computed from the interpreted vertical electrical sounding (VES) data. The longitudinal conductance data was used to predict the protective capacity of the Agbani Sandstone Aquifer. Three protective capacity zones were delineated, which include good, moderate and poor/weak protective zones. Obiora et al. (2016) evaluated the aquifer potential, geoelectric and hydraulic parameters in Ezza North, southeastern Nigeria, using geoelectric sounding. The result revealed that areas with high transverse resistance values may give high aquifer yield; the study area has good aquifer protective capacity due to the argillaceous overlying clay materials and also moderate-to-high aquifer potential. The results also show that the shallow aquifers characterized with wide ranges of hydraulic conductivity caused by heterogeneous facies change in the area can be located in the fine-sand facies underlying the clayey formation. The research is aimed at evaluating the groundwater potential zones of Girei and environs.

2. MATERIALS AND METHODS

2.1 The study area

The study area is Girei and environs, it is located within latitudes 9° 18′ N and 9° 26′ N and longitudes 12° 29′ E and 12° 37′ E and covers an area of about 164 km^2 (Figure 1). The study area is bounded by Song local government area to the north, Mubi to the south and Cameroon to the east. The main access roads to the study area are the Jimeta to Mubi road and some minor foot tracks. Sources of water supply are from hand dug wells, streams, boreholes and rivers. The population of Girei according to the Nigerian Population Census (2006) is 129,995 comprising of Male 67,403 and Female 62,592. The highest elevation in the area is 600 m and ranges from 180 to 600 meters above mean sea level (Figure 1). There are two climatic conditions existing in the area, the rainy season and the dry season. The rainy season is characterized by heavy rainfall that last from the months of June to October, the dry season extends from November to May with high temperature and dusty atmosphere. The study area falls within the humid tropics affected by the southwest rain bearing winds and by the northeast trades (harmattan) winds. The northeast winds blow from Sahara Desert from November to April, and the dry and dusty laden cloudiest monsoon, which comes from the southwest, dominates the month of May to September. The harmattan period which begins from November is generally characterized by low humidity due to the onset of the tropical continental air masses of the dry dust laden northeast trade wind while during rainy season the humidity is high. The temperature of the area varies from time to time, the minimum average for the year being 25°C while maximum is 40°C. The minimum rainfall is 418 mm and the maximum rainfall is 774.65 mm.

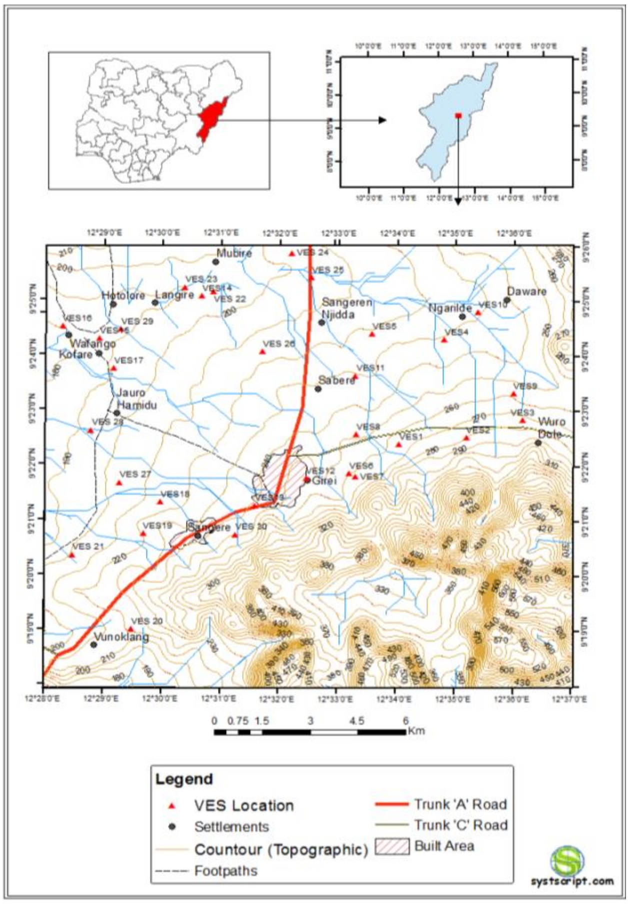

Figure 1: Topographical Map of the study area showing VES Points

2.2 Methodology

2.2.1 Geologic Field Mapping

The first stage of the field work started with a reconnaissance survey of the study area in the year 2020. Detailed geologic field mapping technique involved, traverses from outcrop to outcrops. GPS was used to locate outcrops on the base map and structures, dips and strikes were measured using compass clinometer (Ajayi et al., 2022).

2.2.2 Electrical Resistivity Survey

Vertical Electrical Sounding (VES) is one of the best DC methods that can be adapted to determine resistivity of layered rock with depth. Sedimentary rocks are deposited as flat-lying layered structures over one another, with the effect of high compaction resulting from the overlying weight of recent sediments over previously deposited sediments. This led to the reduction of the volume of pore spaces and subsequently reduces porosity. Layered sedimentary rock poses distinct characteristic properties from their composition. These differing materials cause them to show contrary electrical conductivity properties. The single VES method, which is best suited for horizontally layered rocks with very little lateral variation, can be interpreted using the 1D and 2D models and has been tested for its efficiency and accuracy (Kwami et al., 2019; Seli et al., 2021; Ajayi et al., 2022). The equipment used was the resistivity meter (ABEM SAS 1000) which has been tested for its ability to probe up to one Kilometre into the earth surface, provided the current and potential electrode followed spacing that prevents a faint detection of current by the inner potential electrode. The amount of current introduced was monitored and regulated throughout the field data acquisition. Stainless steel rods were used for both current and potential electrodes and good insulation of the cables was ensured in order to prevent leakages, measuring tape, hammer used in driving the metal electrodes into the ground, car battery was used in providing power source.

2.2.3 Field Procedure

An electrode made of stainless steel was driven into the soil at each end of the spread A and B. Both electrodes were then connected to the current sender of the Terrameter. The electrodes M and N were also driven into the soil and connected to the voltage receiver. At each position of A and B, the current was sent, and the potential difference between M and N was measured. Also, the distances AB and MN were measured. The aim was to determine the depth of current penetration as a function of current electrode spacing. The ABEM Terrameter SAS 1000 performs automatic recording of both voltage and current, stacks the results, computes the resistance in real time and digitally displays it. In this research study, vertical electrical sounding was carried out in the study area to establish the possible relationships between hydro-geophysical and hydrogeological aquifer parameter estimation (Seli et al., 2021; Castillo et al., 2022).

2.2.4 Data Interpretation

The qualitative interpretation is done by visual inspection of the curves obtained from the interpreted resistivity data and comparing with the standard curves that are used for apparent resistivity interpretation. The INTERPEX ID software was used for analyzing the raw data. The quantitative interpretation involves partial curve matching using two-layer Schlumberger master curves and the auxiliary K, Q, A and H curves. The output was modeled using computer iteration (Benson et al., 1997; Seli et al., 2021). The quantitative interpretation of the curves highlights the geological unit encountered, their various depths and thicknesses and the respective resistivity. The resistivity readings were processed to produce sections of the thickness and resistivity of subsurface electrical layers (Corriols and Dahlin, 2008).

2.2.5 Delineation of Aquifer Systems

Aquifer systems in the area were delineated using the interpreted result from the geophysical (Electrical Resistivity) survey. The VES method gives detailed information of vertical succession of individual thickness, resistivities and their different conducting zones. The interpreted VES results were used to prepared 2-D geo-electric sections which show respective layer resistivity values and thickness. The geo-electric sections were correlated with lithologic sections to reveal the aquifer type (Seli et al., 2021; Castillo et al., 2022; Ajayi et al., 2022).

2.2.6 Dar Zarrouk Parameters

The combination of thickness and resistivity of the overburden rock into single variables known as Dar Zarrouk parameters can be used as a plinth for a proper estimation of the safety condition of aquifers as well as the protection of groundwater resources in any environment. For the interpretation and understanding of the geologic model, some parameters related to different combination of thickness and resistivities of geoelectrical layer are necessary (Maillet, 1947; Zohdy et al., 1974; Ankidawa et al., 2019).

These are the Dar Zarrouk parameters: longitudinal conductance (S) and transverse resistance (R). The total transverse resistance (R) and total longitudinal conductance (S) can be used to define target areas for groundwater potential. The total transverse resistance has a direct relation with transmissivity and highest Tr values reflect most likely the highest transmissivity values of the aquifers or aquiferous zones and vice versa. The longitudinal conductance (S) can be expressed as.

$$S = {h}/{p} \quad (1)$$

Transverse Resistance Tr (Ωm^2) can be expressed as

$$R = hp \quad (2)$$

Where h and p are the thickness and resistivity of the saturated layers. The transmissivity for all the sounding location were determined by using the relationship

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between the Dar-Zarrouk parameter (transverse resistance) and transmissivity which is

$$T = \frac{K\sigma}{S} \quad (3)$$

Where T = Aquifer transmissivity, S= longitudinal Conductance of the aquifer (Ajayi et al., 2022).

3. RESULTS AND DISCUSSION

3.1 Geology of the Study Area

Girei, the study area form part of the Yola arm of the Upper Benue Trough. The area is underlain by the Bima Sandstone. Figure 2 shows the geology of the study area. Dip and strike were measured in the field and trend in the northwest and southwest direction. Litho sections of Bima Sandstone studied from three outcrop sections at Vunoklang, Modibbo Adama University, Yola, and Girei town all in Girei local government area indicates planar cross bedded sandstone underlain the formation.

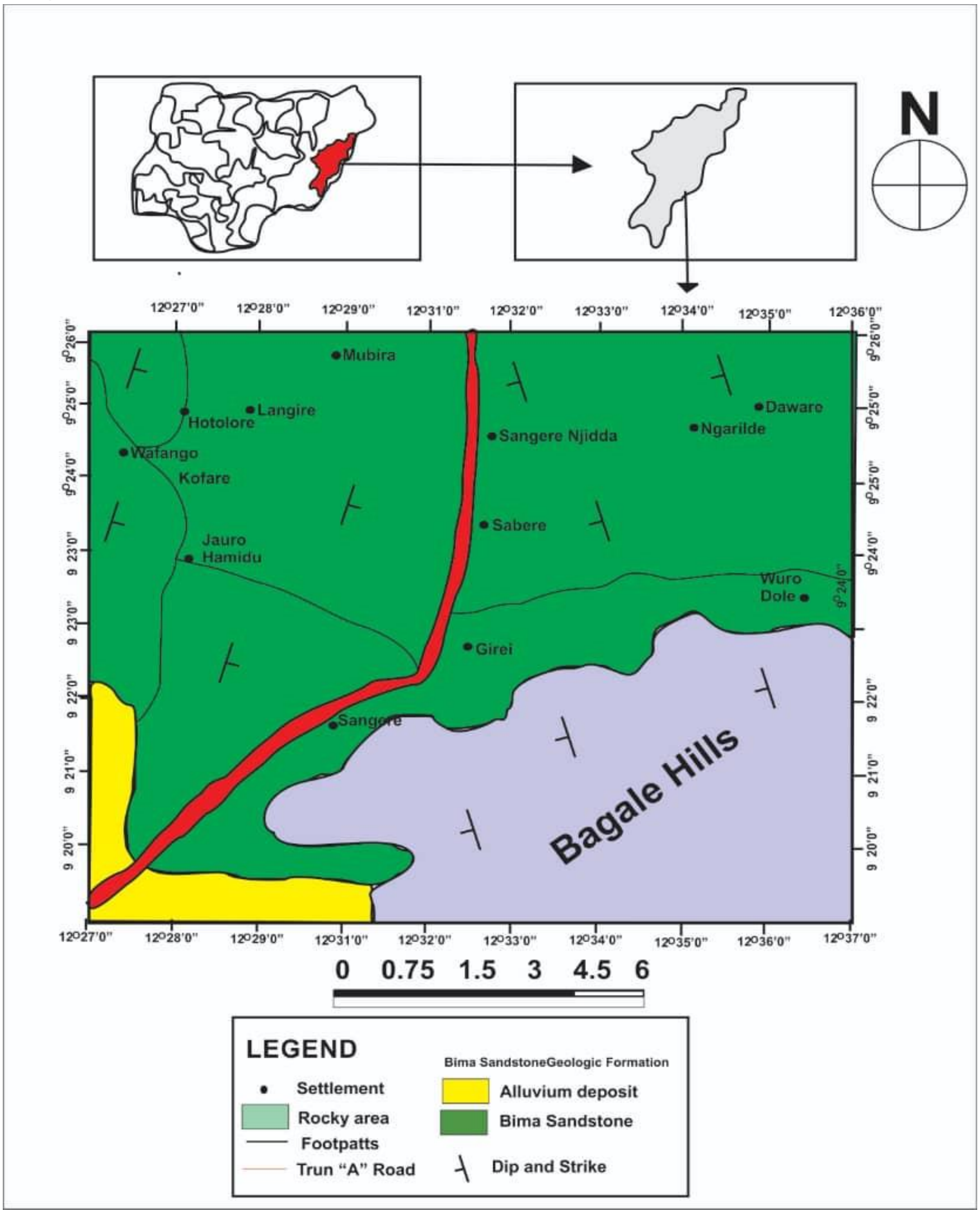

Figure 2: Geologic Map of the study area.

The litho section of Bima Sandstone exposed at Vunoklang along Yola-Mubi Road is composed of planar cross bedded sandstone which is the common primary depositional structure that the sedimentary outcrop is composed. The thickness of the individual cross beds range from 0.5 cm to 1.5 cm and the total thickness of the section is about 15 m. From the bottom of the section, the sandstone is very coarse grained in texture, it is brownish in colour, the nature of the grain sizes gradually reduce from very coarse to medium grain towards the topmost part of the section, however, at the lower most part of the litho section, thin lenses of conglomerates were very common which could probably be an erosional surface. At the bounding erosional surfaces, occasional intra-formational conglomerates were observed, these are in form of mudclast. Another primary depositional structure of parallel bedded sandstone were also observed at the middle of this section, this passes up into inter bedded clay stone sandstone intercalation, ranging in thickness from 0.03 cm to 0.04 cm, which marked the end of the first depositional cycle. The upper part of the section, which marks the last depositional cycle, is composed of light brown-milky colour sandstone inter bedded with thin layers of brown to reddish, medium to coarse grained iron concretion that ranges in thickness from 1 cm to 2 cm. The entire section generally shows fining upward facies sequence. The azimuth data of the individual beds were plotted in a form of rose diagram which show bimodal paleocurrent flow pattern in a northwest and southeastern direction (Figure 3).

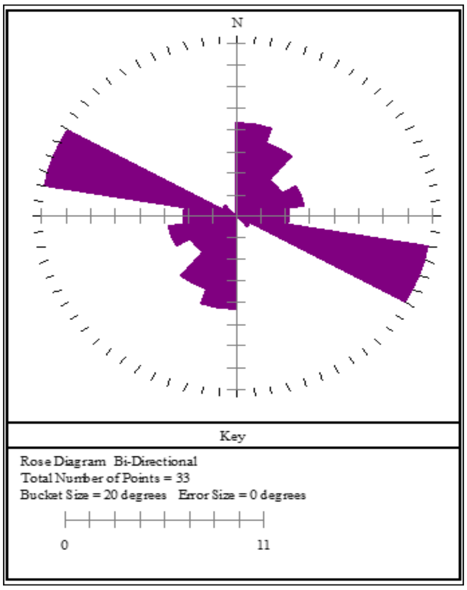

Figure 3: Rose Diagram showing Paleocurrent direction within Bima Sandstone at Vunoklang. By implication, the flow direction is in Northwest and Southeastern direction

The litho section of Bima sandstone at MAU, Yola is composed of amalgamated planar cross beds. From the bottom of the section, the sandstone is very coarse-grained in texture and it passes up into medium to coarse grained sandstone, and this becomes finer towards the topmost part of the litho section which is composed of parallel cross lamination, amalgamated small scale planar cross bedded sandstone which is the common primary depositional structure of the sedimentary rock in this part of the study area. The bedding units of the studied section are separated by sharp contacts, thickness of the individual cross beds ranges from 0.9 cm to 1.2 cm and 0.9 cm on average scale with total thickness of about 6.71 m. The azimuth data of each individual bed was taken, and the result showed bimodal flow direction in northwest and southeastern direction (Figure 4). The sandstone is generally light brown in color and the litho facies are generally fining upward.

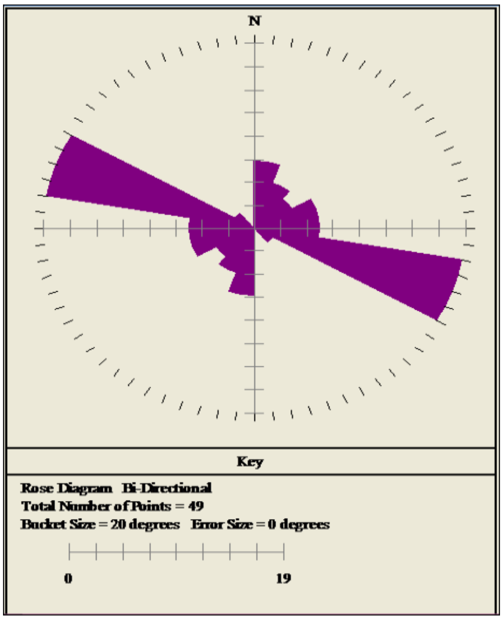

Figure 4: Rose Diagram showing Paleocurrent direction within Bima Sandstone at MAU, Yola. By implication, the flow direction is in Northwest and Southeastern direction.

The litho section of Bima sandstone at Girei is composed of amalgamated planar cross beds overlain by parallel bedded sandstone at the middle of the section. The planar cross bedded sandstones are the common primary depositional structure in this part of the study area. The thickness of the individual cross beds ranges from 1 cm to 1.1 cm with an average of 1 cm with total thickness of 13.49 m. From the bottom of the section, the sandstone is coarse grained in texture and reduces from the coarse grained to fine and medium grained in texture towards the top of the section. The azimuth data of each individual bed was taken, and the result showed bimodal flow in the northwest and southeast direction (Figure 5). The section in this location has no exposure of mudstone litho facies. The bounding surfaces of this section are sharp and it equally shows some occasional erosional surfaces that are characterized by mudclast intra-formational conglomerates. The sandstone is light brown to milky in color, with small scale planar cross bedded sandstone. This section is generally fining upward.

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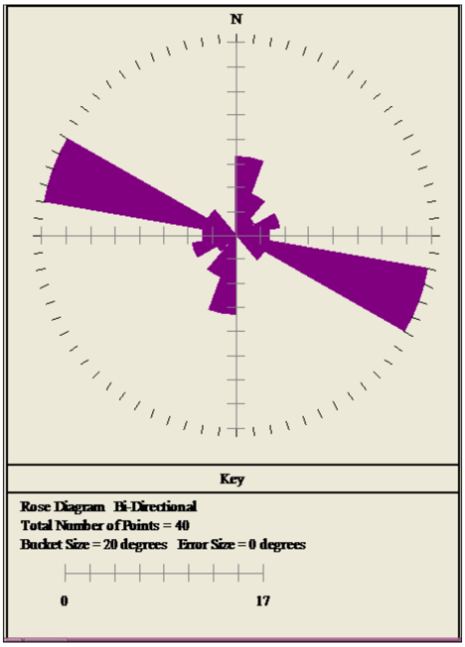

Figure 5: Rose Diagram showing Paleocurrent direction within Bima Sandstone at Girei. By implication, the flow direction is in Northwest and Southeastern direction.

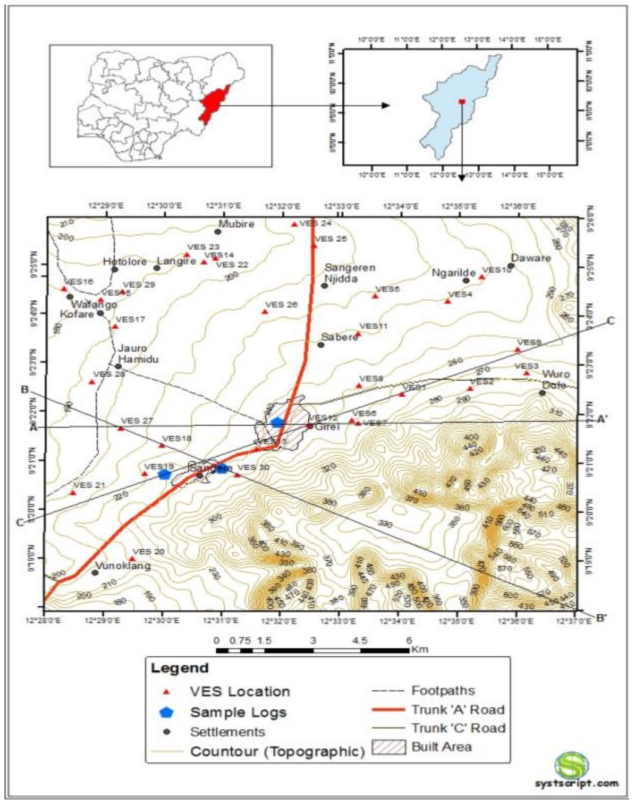

Figure 6: Map of the study area showing borehole locations and VES points

3.2 Delineation of Aquifer System

The key to the success of any geophysical data is the hydrogeological and geological information (Lashkaropour and Nakhaei, 2005). The delineation of the aquifer system in the area was done through the correlation of geo-electric and lithologic sections. The geo-electric sections show vertical and lateral variations in layer resistivity and thickness, which is a revelation of the lateral and vertical lithological changes in the study area. Profiles were taken along A-A′, B-B′ and C-C′ (Figure 6). To assess the accuracy of the VES interpretations, down hole lithologic logging was carried out during borehole drilling in the research area. The lithologic section, were produced from the down hole lithologic logging.

The geo-electric sections were correlated with the borehole lithologic section along A-A′ which connects VES 27, BH1 with VES12 and VES7 respectively (Figure 7). VES 27 have 3 layers, VES 12 has 4 layers and VES 7 has 5 layers. The lithological section is characterized by lithology of top soil, brown medium to coarse grained sand, clayey sandstone and medium to coarse grain sandstone with total depth of 90 m. Profile along A-A′ vertical electrical sounding data interpretation results obtained from the area showed five to six geoelectrical layers and has been interpreted as top soil, brown medium to coarse grained sandstone, reddish brown fine sandstone, clayey sandstone, medium to coarse grained sandstone and fresh basement. The upper most layers which is the topsoil has a resistivity value of 260 Ωm to 1900 Ωm and thickness values ranging from 4 m to 6.29 m respectively.

The second layer consists of brown medium to coarse grained sandstone with resistivity values ranges from 38.116 Ωm to 1300 Ωm and thickness of 4 m to 69.742 m. The third layer consists of reddish-brown fine-grained sandstone and medium to coarse grained sandstone in VES 27 and 7 with resistivity values of 983.64 Ωm and 150 Ωm. While VES 12 has clayey sandstone and resistivity of 3400 Ωm and thickness of 70 m. The fourth layer in VES 27 composed of the bed rock while VES 12 composed of medium to coarse grained sandstone having resistivity value of 6000 Ωm, VES 7 composed of clayey sandstone of resistivity value 650 Ωm. The last layer is composed of bed rock. The correlation between geoelectrical section along AA' reveals that the aquifer type is unconfined to semi confined aquifer (Figure 7).

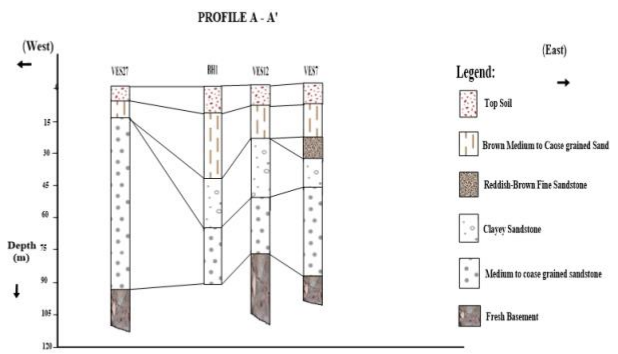

Figure 7: Correlation between borehole lithological section and geo-electric section along A-A′

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Section along B-B′ links VES 27, VES 30, BH 2 and VES 18 (Figure 8). VES points 27 and 18 have three layers while VES 30 have 5 layers consisting of overburden top soil. Profile along BB', has a maximum of five geologic section, the first layer with resistivity values ranging from 2.6197 Ωm to 1900 Ωm and thickness value ranging from 1.7619 m to 6.2871 m, represent the top soil formation. The second layer consists of brown medium to coarse grained sandstone with resistivity values of 35.518 Ωm to 90 Ωm and thickness values of 4 m to 69.741 m. The third layer vary across the entire profile, it is clayey sandstone in VES 18, reddish brown fine sandstone in VES 20 and medium to coarse grained sandstone in VES 27. The fourth layer consists of medium to coarse grained sandstone with resistivity value of 110 Ωm and thickness of 56 m. The last layer is the fresh basement with resistivity values of 2.8152 Ωm to 983.64 Ωm and infinite thickness. The correlation between geoelectric section and lithologic section along B-B' revealed aquifer system of unconfined to semi confined (Figure 8).

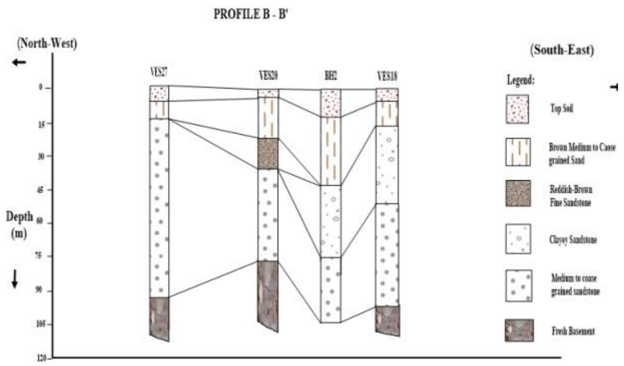

Figure 8: Correlation between borehole lithological section and geo-electric section along B-B′

Section along C-C′ which connects BH 3,VES 12,VES 1 and VES 9 respectively (Figure 9). VES 12, VES 1 and VES 9 have 3 layers. VES 1 and VES 9 both have four layers and VES 12 have 5 layers consisting of top soil with resistivity values ranging from 800 Ωm to 1958 Ωm and thickness of 1.94 m to 5 m. The second layer consists of brown medium to coarse grained sandstone across the entire profile with resistivity value of 600 Ωm to 1360 Ωm and thickness value of 9 m to 38.44 m. The aquifereous zone across CC' is medium to coarse grained sandstone with resistivity ranging from 140 Ωm to 6000 Ωm and thickness of 47 m to 70 m. The aquifer system along C-C′ revealed unconfined to semi confined aquifer type (Figure 9).

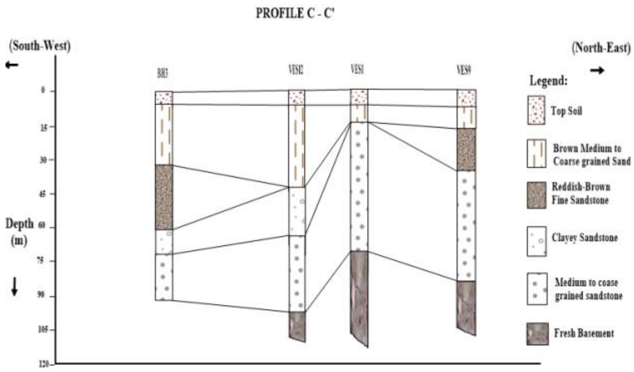

Figure 9: Correlation between borehole lithological section and geo-electric section along C-C′.

3.3 Estimation of Aquifer Parameters

Table 1 shows the analysis of resistivity values and Table 2 shows the estimated aquifer parameters derived from Dar Zarrouk parameters for the study area.

The longitudinal conductance in the research area ranges from 0.1117 Ω^{-1} at VES 2 to 7.53 Ω^{-1} at VES 6. The maximum value of longitudinal conductance was recorded in the eastern part of the study area (Ngarilde) and pockets around Girei with decrease towards the eastern and western parts of the study area and some pockets in Sangere Njidda (Figure 10). A marked increase in longitudinal conductance may correspond to an average increase in clay content and consequently a decrease in transmissivity (Khalil, 2009; Ankidawa et al., 2019; Yusuf et al., 2021).

According to Oladapo and Akintorinwa (2007), longitudinal conductance >10 Ω^{-1} (Excellent), 5 to 10 Ω^{-1} (Very good), 0.7 to 4.9 Ω^{-1} (Good), 0.2 to 0.69 Ω^{-1} (Moderate), 0.1 to 0.19 Ω^{-1} (Weak) and <0.1 Ω^{-1} (Poor). The total longitudinal conductance values can also be utilized in evaluating overburden protective capacity in an area Abiola et al. (2009). This is because the earth acts as a natural filter to percolating fluid and is a measure of its protective capacity (Olorunfemi et al., 1999; Abiola et al., 2009). Based on Oladapo and Akintorinwa (2007) classification of longitudinal conductance, the overburden materials of the study area have very good to poor protective capacity.

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Table 1: Analysis of curve shows resistivity types (p of the curve layers)

S/No	Curve Type	Geo electric layer	Resistivity Values (Ωm)					Thickness Value (m)					Fitting Error
			ρ1	ρ2	ρ3	ρ4	ρ5	h1	h2	h3	h4	h5	
VES 1	QH	4	1958.3	1360.3	39.187	1026	-	1.9443	38.433	95.93	-	-	1.6
VES 2	A	3	824.58	516.56	1375	-	-	4.685	57.679	-	-	-	3
VES 3	AH	3	1075.5	64.12	755.22	-	-	4.0697	85.83	-	-	-	0.38
VES 4	HK	4	244.71	45.229	6.288	137.26	-	3.1199	9	46	-	-	1.11
VES 5	HH	5	320	15	70	22	50	3	1	26	84	-	0.72
VES 6	QH	4	160	50	6	40	-	3	12.3	45.18	-	-	1.1
VES 7	QA	5	260	200	150	650	200	4	4	22	120	-	1.2
VES 8	KA	5	130	74	50	150	500	3	3.38	14.154	40.812	-	1.17
VES 9	QH	4	1000	600	130	400	-	4	9	47	-	-	0.94
VES10	AK	4	120	210	400	700	-	4	16	80	-	-	2.92
VE 11	KH	4	220	500	100	380	-	5	9	96	-	-	0.89
VES12	AK	4	800	1300	3400	6000	-	5	25	70	-	-	1.27
VES13	KQ	5	153.2	4062.8	3809.5	139.77	123.6	1180	1.5224	35.1	101.32	-	0.85
VE 14	HH	5	120.52	20.938	147.77	162.98	174.7	5.0196	3.5992	16.388	84.415	-	0.8
VES15	HK	5	32.064	6.3477	21.817	78.022	72.982	5.3235	8.1949	12.576	39.696	-	0.988
VES16	QA	5	50	23	14	30	53	2	1	17	40	-	0.99
VES17	QA	5	1020	300	43	200	800	3	6	14	60	-	1.82
VES18	QA	5	180	90	34	110	300	3	4	17	56	-	1.04
VES19	K	3	2040	3080	1070	-	-	3	97	-	-	-	0.72
VES20	K	4	2.6197	35.518	18.663	2.8152	-	1.7676	24.859	61.579	-	-	0.69
VES 21	K	4	4.253	76.192	12.692	4.0996	-	1.3506	15.341	44.656	-	-	0.76
VES 22	H	4	153.61	106.57	73.55	21506	-	9.7196	24.84	30.077	-	-	0.97
VES 23	H	3	1899.5	39.836	5420	-	-	3.2708	38.946	-	-	-	1.86
VES 24	K	3	150.41	36.5	112.13	-	-	1.0446	63.125	-	-	-	2.46
VES 25	H	3	151.85	15.965	11382	-	-	3.7482	85.956	-	-	-	1.19
VES 26	K	3	114.62	36.166	235.58	-	-	4.0472	64.452	-	-	-	0.96
VES 27	H	3	1900	38.166	983.64	-	-	6.2871	69.741	-	-	-	2.56
VES 28	H	3	1075.3	64.116	755.22	-	-	6.28	85.83	-	-	-	2.5
VES 29	H	3	32.034	19.6521	65.023	-	-	4.0697	62.102	-	-	-	1.07
VES 30	H	3	204.08	14.372	565.96	-	-	5.321	61.07	-	-	-	2.85

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Table 2: Aquifer parameters estimated from geophysical data

VES NO	Resistivity (Ωm)	Thickness (m)	Aquifer Conductivity (ohm)	Transverse Resistance (Ωm^2)	Longitudinal conductance (Ω^{-1})	Transmissivity (m^2/day)	Aquifer Rating
1	39.187	95.93	0.0255	3756.3	2.4352	294.6	moderate potential
2	516.6	57.679	0.002	29.796	0.1117	480.9	moderate potential
3	64.12	85.83	0.001	5503.4	1.3386	327.8	moderate potential
4	6.288	46	0.159	289.48	7.3155	611.4	High potential
5	22	84	0.0455	1848	3.818	363.3	moderate potential
6	6	45.18	0.1667	271.08	7.53	622.9	High potential
7	650	120	0.002	78000	0.1846	304.9	moderate potential
8	150	40.812	0.007	6121.8	0.272	723.9	High potential
9	130	47	0.008	6110	0.361	623.4	High potential
10	400	80	0.0003	32000	0.2	351.6	moderate potential
11	100	96	0.001	9600	0.96	293.0	moderate potential
12	3400	70	0.001	238000	0.0206	409.7	moderate potential
13	139.77	73.32	0.0071	10247	0.524	381.2	moderate potential
14	162.98	84.415	0.0061	13757	0.517	331.9	moderate potential
15	78.022	39.696	0.0128	3097	0.5087	707.9	moderate potential
16	30	40	0.0333	1200	1.333	702.8	High Potential
17	200	60	0.005	12000	0.3	468.9	moderate potential
18	110	56	0.0091	6160	0.509	502.9	High Potential
19	3080	97	0.0003	298760	0.0315	267.9	moderate potential
20	18.66	61.58	0.0536	1149.1	3.3	456.9	moderate potential
21	12.69	44.65	0.0787	566.6	3.52	628.9	moderate potential
22	73.55	309.08	0.0136	2212.3	0.41	933.2	High Potential
23	39.836	38.95	0.0251	5439.6	1.004	703.3	High potential
24	36.5	63.129	0.0274	2304.2	1.73	445.5	moderate potential
25	15.965	85.96	0.0626	1372.3	5.384	327.1	moderate potential
26	36.2	64.452	0.0276	2333.1	1.78	436.2	moderate potential
27	38.17	69.742	0.0262	2662.1	1.82	404.9	moderate potential
28	64.116	85.83	0.0156	5503.4	1.34	327.5	moderate potential
29	19.6521	62.102	0.1503	12204	3.1601	453.1	moderate potential
30	14.372	61.076	0.0692	877.8	4.25	458.1	moderate potential

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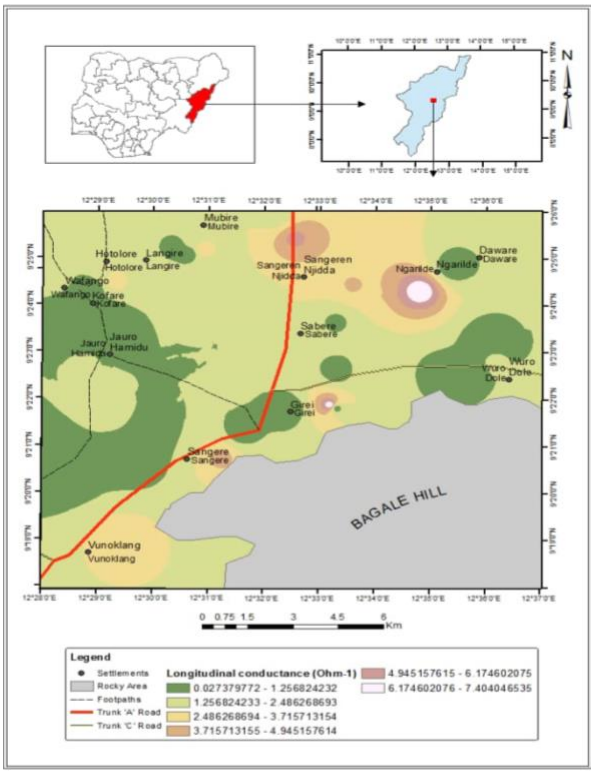

Figure 10: Spatial distribution of longitudinal conductance in the study area

The transverse resistance (T) is one of the parameters used to define target areas of good groundwater potential. It has a direct relation with transmissivity and the highest values reflect most likely the highest transmissivity values of the aquifers or aquiferous zones. The transverse resistance ranges between 271 Ωm^2 at VES 6 to 298760 Ωm^2 at VES 19. Figure 11 shows the spatial distribution of transverse resistance values of the study area. Areas of high transverse resistance occurred in the Central part (Girei town) and toward the Southwest part (Federal Housing Estate) and low transverse resistance was recorded in the northeast and southern parts of the study area. Transverse resistance map has been used in the determination of zones with high ground water potential (Nafez et al., 2010). According to Braga et al. (2006) high values of Transverse resistance can be associated with the zones of high transmissivity.

The ranges for transmissivity according to Offodile (1983) is that, transmissivity value >500 m^2/day (High potential), 50 to 500 m^2/day (Moderate potential), 5 to 50 m^2/day (Low potential), 0.5 to 5 m^2/day (Very low potential), <0.5 m^2/day (Negligible potential). The transmissivity values in the study area range from Tmin= 267.9 m^2/day and Tmax = 933.2 m^2/day. The southwestern parts of the study area have high transmissivity (Federal Housing Estate) with pockets around the central area and northwestern and low transmissivity occur around north, northeast and southern parts of the study area (Figure 12). The classification of groundwater potential based on transmissivity values by Offodile (1983) reveal aquifer of High potential to Moderate potential, 27% constitute high potential while 73% constitute moderate potential.

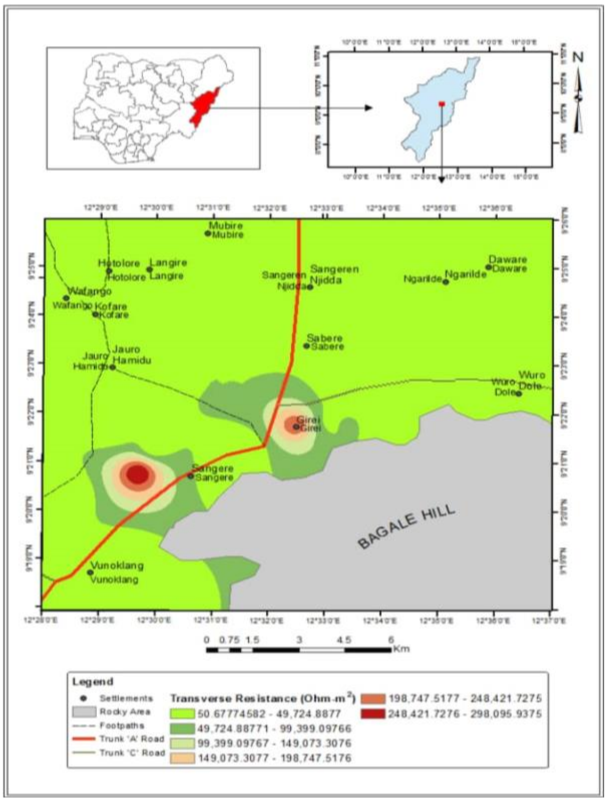

Figure 11: Spatial distribution of Transverse Resistance in the study area

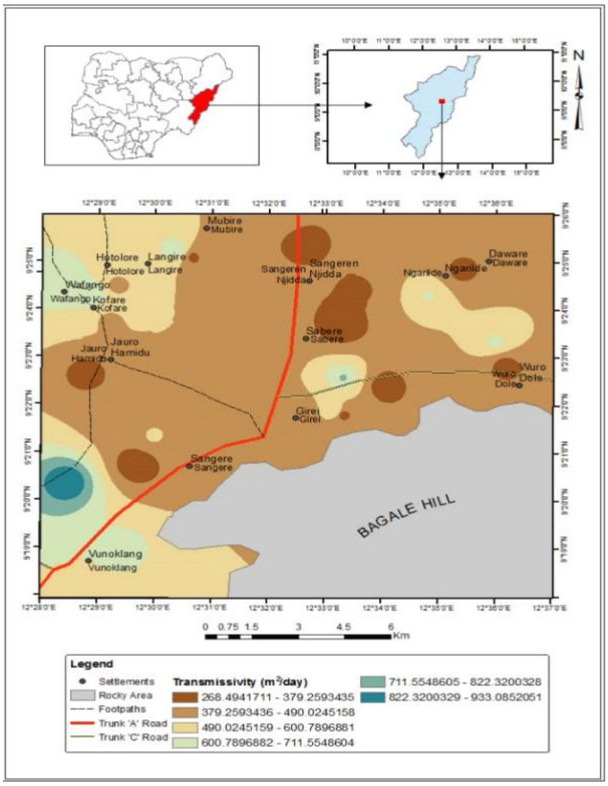

Figure 12: Spatial distribution of Transmissivity in the study area

3.4 Hydraulic head distribution

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Figure 13 shows the hydraulic head distribution in the study area. The eastern and central parts of the study area constitute the recharge areas from Wuro Dole and Girei while the southwest and north east towards the north constitute the discharge areas around Vunoklang, Daware and Sangeren Njidda (Figure 13). The flow is from the eastern part around Wuro dole towards the central part of Girei and from the central part towards Sabere and Sangeren Njidda at the northern part of the study area. Another flow occurs from the central part towards Sangere, Vunoklang and Federal Housing at the southwestern part of the research area. A similar finding was obtained by Ofomola et al. (2022) in Ogbeje and Umeghe in Abraka, Delta State Nigeria.

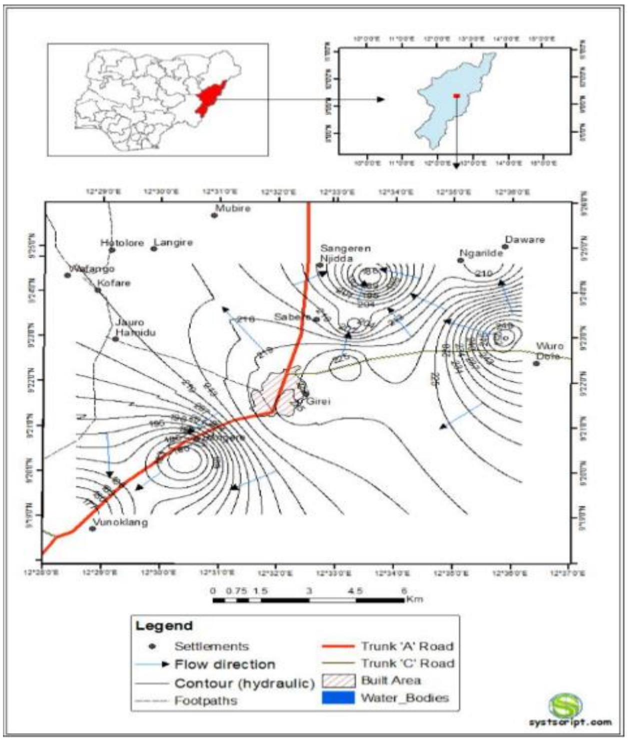

Figure 13: Hydraulic Head Distribution map of the study area showing flow direction

4. CONCLUSIONS

The groundwater flow direction is the northwest and southeast of the area. The area is characterized by unconfined to semi confined aquifer system. The vertical electrical soundings characterize aquifer parameters such as longitudinal conductance, transverse resistance, and transmisivity indicating aquifers of moderate to high performance. Spatial distribution maps were produced and it shows that the longitudinal conductance values where high in the north western and northern part of the recharge area with decrease towards the south east and eastern parts of the study area, transverse resistance values where high at the Southwestern, central and northeast parts of the study area. The transmissivity values where high at the south western parts of the study area with decrease towards the Northwestern and Eastern parts of the study area. The transmissivity values classified the area into moderate to high potentials. The Hydraulic distribution map revealed that the flow direction is from the eastern part towards the central part and from the central parts towards the northern part of the study area. The eastern and central parts constitute the recharge area while the southern and north east towards the north constitutes the discharge area.

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