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Estimation of Dar-Zarrouk parameters and delineation of groundwater potential zones in Karlahi, part of Adamawa Massif, Northeastern Nigeria

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Abstract: Karlahi is largely underlain by granites and migmatites gneiss of the Adamawa Massif. The area lies west of Benue Trough and east of Cameroon volcanic line. The aim of this paper is to determine hydraulic properties of water bearing layer using parameters derived from Dar-Zarrouk equation and characterized them into groundwater potential zones. The resistivity values of the weathered and slightly weathered layers which make up the water bearing layers were added and an average was taken and used as the resistivity of the water bearing formation in computation of Dar-Zarrouk parameters in Karlahi area. The values of resistivity of water bearing formation ranged from 18 to 4963 Ωm with an average resistivity value of 549 Ωm and the thickness of the water bearing formation ranges from 21 to 32 m with an average thickness of 24.5 m. Conductivity values range from 0.000201 to 0.05509 (σ) while the longitudinal conductance range from 0.00483 to 1.2363 Ω^{-1}, the transverse resistance ranges from 407 to 123504.3 Ωm^2. The hydraulic conductivity and transmissivity values range from 0.14 to 25.87 m/day and 3.28 to 580.4 m^2/day respectively. The longitudinal conductance values in Karlahi area revealed poor to good with an average longitudinal conductance value that is moderate. High transverse resistance values are located in the central and southern part of Karlahi area while low values are located in the eastern part. The spatial distribution map of transmissivity in the area revealed moderate to high transmissivity values in the north central part and a negligible to low transmissivity in southern part, extreme northeastern part. The groundwater potential map of Karlahi area shows negligible to weak potential groundwater zones in SW and SE, moderate potential in the central to northern part of Karlahi area.

Keywords: Dar-Zarrouk parameter, groundwater, hydraulic conductivity, transmissivity, transverse resistance, Adamawa

INTRODUCTION

The research was carried out within the Adamawa Massif which consists largely of granites and gneisses (NGSA, 2006). Karlahi is geographically located in between the Cretaceous Benue Trough to the west and the Cameroon volcanic chain to the east. To the north, it is bordered by Hawal Massif and to the south, by Oban Massif (Ferre *et al*., 1996). The three group of massifs run through the Republic of Cameroon and forms part of the north eastern Basement Complex of Nigeria which are classified as three major Basement Complexes in Nigeria (Baba, 2009). Rural and urban areas in Nigeria rely largely on groundwater supply from boreholes because the surface water systems are either not developed or are not even available in most cases, and for this reason communities and individual homes drill their own boreholes for water supply, this results into indiscriminate borehole drilling all over the country despite the fact that towns and rural communities are in need of portable water supply. Application of resistivity method for estimating water bearing formation is based on the relationship between hydraulic transmissivity and transverse resistance (Kelly & Reiter, 1984). (Maillet, 1947) was the first to develop the idea of using thickness and resistivities of rocks to calculate the aquifer parameters using transverse resistance (R) and longitudinal conductance (S). One very useful parameter in studying the aquifer characteristic is hydraulic conductivity (Gemail *et al*., 2011). Dar-Zarrouk parameters play a very important role in determining how groundwater flow within a porous geologic medium (Chang *et al*., 2011). Despite recent discoveries in alternate approach to estimating aquifer parameters and characteristics, the resistivity method remains one of the geophysical techniques widely used in Africa (Okiongbo & Akpofure, 2012), this is because the use of surface geophysics to estimate aquifer potential are effective and reliable (Soupius *et al*., 2007). According to Soupius *et al*. (2007) longitudinal conductance, transmissivity, hydraulic conductivity, transverse resistance and thickness of the aquifer are vital in determining groundwater flow in a given aquifer and how the medium will respond after withdrawal (Yadav, 1995). (Jones & Buford, 1951) revealed the relationship between electrical and aquifer properties of water bearing formation in basement complex terrain and discovered that as the rate of weathering increases flow rate of fluid increases in water bearing formation. (Chandra *et al*., 2008) studied hydraulic conductivity acquired from electrical resistivity with pumping test result, found that the result correlate and are reliable. Hydraulic conductivity is the most difficult to estimate due to high values or inappropriate laboratory analysis (Soupius *et al*., 2007). One reliable way of calculating hydraulic conductivity is by using pumping test results acquired at borehole locations but because of limited borehole data in the area, field resistivity data were used to achieve the objectives of this study. This paper is aimed at estimating parameters of Dar-Zarrouk equation in Karlahi area.

Karlahi area lies between latitudes 8˚48′ N to 8˚58′ N and longitudes 12˚30′ E to 12˚38′ E (Figure 1) in Fufore LGA, Adamawa State. The area has a total land mass of about 214 km^2. The area is characterized by rural setting and inhabited by the Chamba, Verre and Fulani speaking tribes. The area is drained largely by River Benue and Lake Pariya, Gobako, Gerwedi, Kapo with small rivers like Mayo-Ine.

BRIEF GEOLOGY OF KARLAHI

Geological mapping which was done on a scale of 1:50,000 revealed Karlahi area being underlain by granites

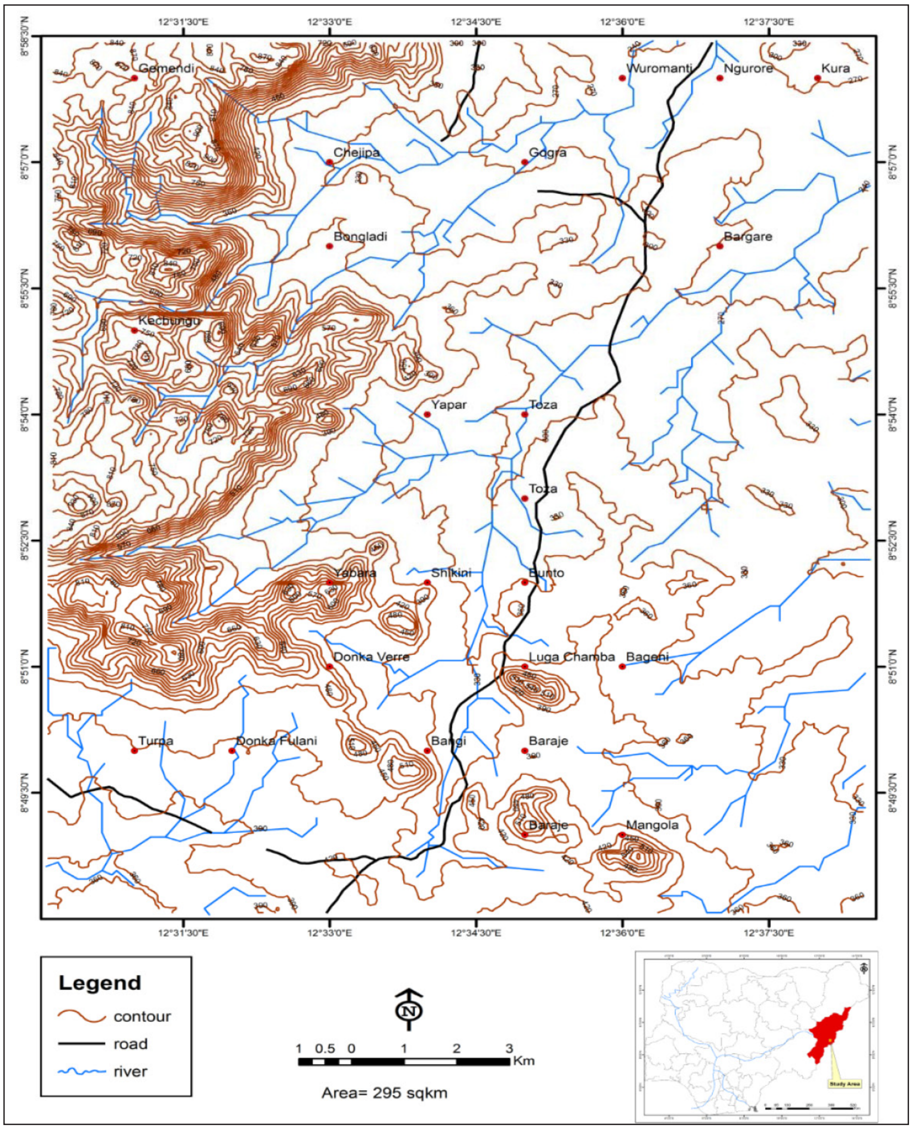

Figure 1: Topographic map of Karlahi and environs (GIS Analysis, 2020).

and metamorphic rocks. The granites are classified into coarse to medium grained size which are dominantly found in the western part of Karlahi (Figure 2). The Older Granites suite constitutes over 60% of outcrops in Karlahi (Rahaman, 1988). They form prominent features such as boulders, steep-sided craggy tors, sub-elliptical plutons to masses of batholithic dimensions as outcropped around Korkai, Lugga Chamba, Karlahi Chamba, Mamlaipa, Donrupa, Bongladi and Begni areas. Banded gneisses, quartz dyke and amphibolite form low-lying and in some places, flat outcrops especially around Baraje, Belwa Gite, Donkan Vera, Sabon Gari Koma and Kila Sarka. Banded gneiss occurs massively, low-lying and as short ridges constituting about 40% of the rock units in the area. Few boulders of about one to three meters in radius were also observed scattered around the base of medium-grained granite north of Jakada, Balwa Gite, Kila-Sakra and Rajiya localities respectively.

MATERIAL AND METHODS

The instrument used for this work was SYSCAL JUNIOR Resistivity equipment, it is a signal averaging system which calculates the voltage by the current and multiplies it with the constant of the field configuration. The equipment is a complete transmitter/receiver system in a single box and it calculate the constant of every AB/2 spread which makes it very quick and easy resistivity meter to use. The machine automatically calculates the Ω (Rho) results and average are presented automatically on the display. The vertical electrical sounding surveys were done using field configuration of AB/2 = 1m and MN = 0.2m, spread was increased as the survey progresses. Potential distance MN were increased at particular cycles to give reliable reading from the resistivity meter. However, the condition of AB/2 ≥ 5MN has to be fulfilled. Readings of resistance is taken directly from the equipment, which is then multiplied by a K factor automatically by the

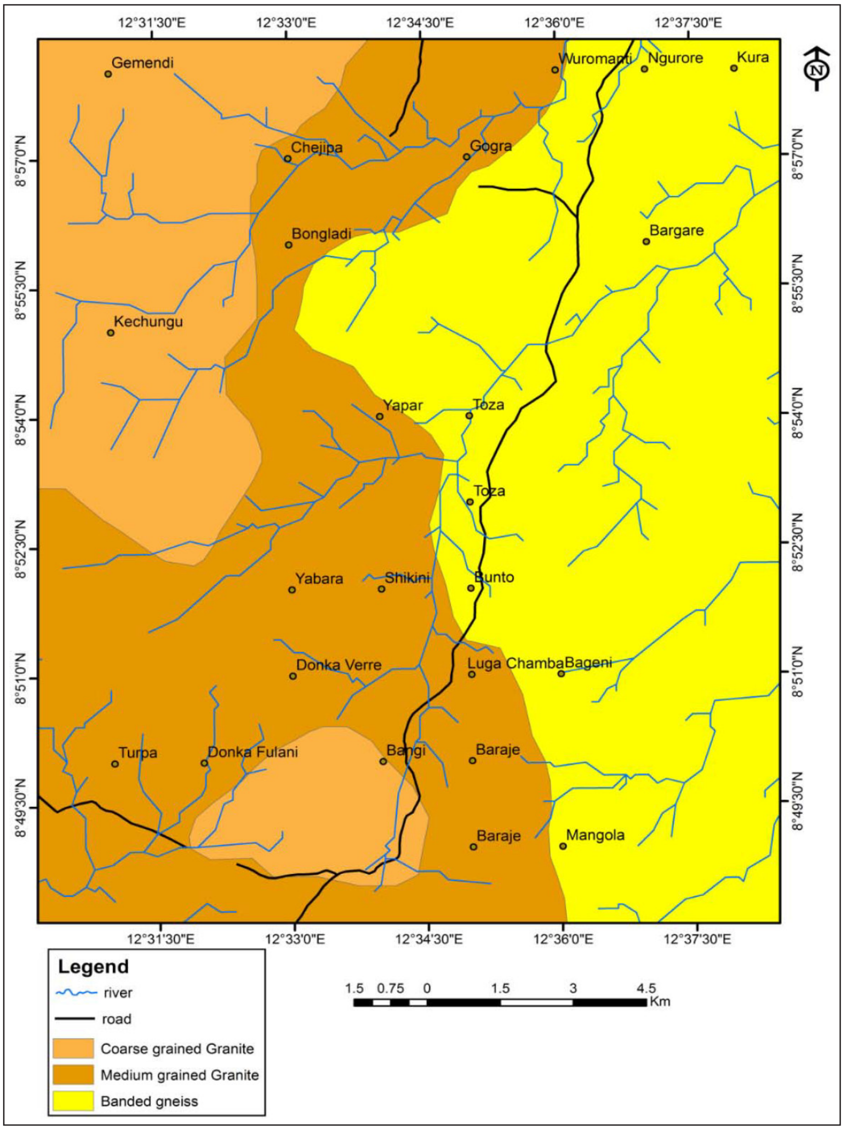

Figure 2: Geology of Karlahi and environs (Modified from NGSA Map, 1996).

machine to calculate the apparent resistivity. This was then plotted on a bi-logarithmic graph sheet, the distance AB/2 on the X axis against the resistivity values on the Y axis, resistivity models were then created and the data interpreted using (IX1D Interpex 2006) computer programme. The hydraulic parameters of each aquifer in Karlahi were calculated from the 30 Vertical electrical soundings data.

Dar-Zarrouk parameters

Theoretically, layered medium possesses good fundamental qualities that are important in interpretation of geoelectric layers (Braga *et al*., 2006), these important parameters are in combination of ρ and h for each geo-electric layer (Batte *et al*., 2010; Singh *et al*., 2004). The unit of longitudinal conductance (S) and transverse resistance (R) are given below as:

$$R= \Sigma^{n}_{i=1} hipi \qquad i = 1,2,3,.......n \qquad 1$$

and

$$S= \Sigma^{n}_{i=1} hi / pi \qquad i = 1,2,3,........n \qquad 2$$

Thereby ρi (electrical resistivities) and hi (thickness of i^{th} of a geologic layer).

The average longitudinal resistivity of a porous geologic layer given as,

$$\rho_L = H/S \qquad 3$$

the average transverse resistivity is presented as

$$\rho_t = R/H \qquad 4$$

The longitudinal conductance Si can also be represented as

$$Si = \delta ihi \qquad 5$$

δi is conductivity of the layer which is analogous to the transmissivity, Tr which is used in groundwater studies (Mbonu *et al*., 1991).

It is given by:

$$Tri = Ki\ hi \qquad 6$$

Where Ki is hydraulic conductivity of the i^{th} layer of thickness hi of the aquifer.

The analytic relationship between aquifer transmissivity, transverse resistance and longitudinal conductance demonstrated that in regions where the geologic condition and water quality don't differ significantly, the conductivity product of Kσ, remains consistent (Niwas & Lima, 2003). If the hydraulic conductivity K, of an existing groundwater wells and the electrical conductivity from surface resistivity results are accessible, at that point the transmissivity will be calculated by ascertaining the transverse resistance or longitudinal conductance for the water bearing layer (Niwas & Singhal, 1981).

The theoretical relationship between aquifer transmissivity (Tr) and transverse resistance (R) of water bearing formation and that of (S) were determined analytically by (Niwas & Singhal, 1981) and are given as:

$$Tr = K\delta R = KS/\sigma = Kh \qquad 7$$

Detailed formulations were found in (Niwas & Singhal, 1981, 1985; Chandra *et al*., 2008 and Kosinski & Kelly, 1981).

RESULTS

Aquifer characteristics using Dar-Zarrouk parameter

The calculated vertical electrical sounding (VES) results (thickness and resistivity of water bearing layer), aquifer parameters (transmissivity and hydraulic conductivity) were determined for all the 30 VES and are presented in Table 1, the resistivity estimations of the weathered and the slightly weathered layer which make up the water bearing formation of Karlahi area were added and their average taken and were used as the resistivity of the conductive layer in the computation of Dar-Zarrouk parameters. These parameters show the spatial distribution of longitudinal conductance, transverse resistance, hydraulic conductivity and transmissivity of the area. The values of longitudinal conductance estimated by Dar-Zarrouk equation shows values in Karlahi area with minimum and maximum longitudinal conductance values for Karlahi area as 0.00483 and 1.236 Ω^{-1} respectively with average value 0.306 Ω^{-1}. A spatial distribution map of longitudinal conductance presented in Figure 3 shows yellow and orange which indicate the zones with high longitudinal conductance values whereas the zones of low longitudinal conductance values are represented by shades of blue.

The values of transverse resistance from Dar-Zarrouk equation shows the distribution of transverse resistance data in Karlahi area. Minimum and maximum transverse resistance values of 407.29 and 123504.26 Ωm^2 with an average value of 12,912.66 Ωm^2. A spatial map of transverse resistance was generated and presented in Figure 4 showing very high values indicated in blue colours, green indicates low to moderate zones on the map. The transverse resistance is also used to determined potential zones of groundwater (Cassiani & Medina, 1997).

The values of hydraulic conductivity estimated by Dar-Zarrouk parameter shows the distribution of the hydraulic conductivity values in Karlahi area with minimum and maximum hydraulic conductivity values as 0.1379 and 25.87 m/day with an average value of 6.4208 m/day. A spatial map of hydraulic conductivity presented in Figure 5 shows blue colours indicating zones with high hydraulic conductivity values and zones of low hydraulic

Table 1: VES locations and their geo-electrical parameters computed using Dar-Zarrouk parameters.

VES No	Location	Layer Resistivity (Ωm)	Layer Thickness (m)	Aquifer Conductivity (ohm)	Longitudinal Condutance (Ω)	Transverse Resistance (Ωm²)	Hydraulic Conductivity (m/day)	Transmissivity (m²/day)
1	Belwa Gite 1	56.54	23.05	0.0177	0.4077	1303.13	8.96	206.58
2	Belwa Gite 2	240.85	22.34	0.0042	0.0927	5379.27	2.32	51.79
3	Belwa Gite 3	73.85	22.85	0.0135	0.3094	1686.99	6.99	159.59
4	Dunkan Vera 1	207.07	29.55	0.0048	0.1427	6117.88	2.67	78.88
5	Dunkan Vera 2	122.23	26.65	0.0082	0.2180	3256.69	4.37	116.33
6	Dunkan Vera 3	138.87	22.97	0.0072	0.1654	3189.73	3.88	89.03
7	Kila Sakra 1	4963	24.89	0.0002	0.0050	123504.26	0.14	3.43
8	Kila Sakra 2	326.80	27.18	0.0031	0.0832	8880.65	1.74	47.40
9	Kila Sakra 3	842.39	20.48	0.0012	0.0243	17252.04	0.72	14.77
10	Baraje 1	162.14	23.97	0.0062	0.1478	3886.38	3.35	80.40
11	Baraje 2	173.83	25.51	0.0058	0.1467	4433.41	3.14	80.17
12	Baraje 3	4325.2	20.90	0.0002	0.0048	90375.05	0.16	3.28
13	Lugga Chamba 1	1072.9	24.33	0.0009	0.0227	26103.66	0.58	14.00
14	Lugga Chamba 2	175.78	23.44	0.0057	0.1334	4120.17	3.11	72.92
15	Lugga Chamba 3	146.54	27.44	0.0068	0.1873	4020.92	3.69	101.15
16	Bashinda 1	52.06	24.07	0.0192	0.4623	1252.82	9.68	232.93
17	Bashinda 2	61.21	22.49	0.0163	0.3674	1376.61	8.32	187.17
18	Bashinda 3	118.21	23.29	0.0085	0.1970	2752.52	4.50	104.88
19	Toza Gada 1	85.58	32	0.0117	0.3739	2738.40	6.09	194.82
20	Toza Gada 2	629.23	29.22	0.0016	0.0464	18382.81	0.95	27.66
21	Toza Gada 3	1844.81	22.35	0.0005	0.0121	41231.50	0.35	7.76
22	Alarba Gurigwa 1	19.49	23.91	0.0513	1.2268	466.01	24.20	578.68
23	Alarba Gurigwa 2	32.54	22.64	0.0307	0.6956	736.54	15.00	339.62
24	Alarba Gurigwa 3	26.75	23.20	0.0374	0.8673	620.35	18.02	417.88
25	Barkipa 1	31.68	23.71	0.0316	0.7485	751.01	15.39	364.80
26	Barkipa 2	18.15	22.44	0.0551	1.2364	407.29	25.87	580.42
27	Barkipa 3	90.12	22.93	0.0111	0.2544	2066.00	5.80	132.99
28	Gogra 1	93.83	24.81	0.0107	0.2644	2327.33	5.59	138.59
29	Gogra 2	122.18	25.15	0.0082	0.2058	3072.09	4.37	109.82
30	Gogra 3	204.66	27.80	0.0049	0.1358	5688.39	2.70	75.03
	Min	18.15	20.48	0.0002	0.0048	407.29	0.14	3.28
	Max	4963	32	0.0551	1.2364	123504.26	25.87	580.42
	Average	548.61	24.52	0.0128	0.3062	12912.66	6.42	153.76

conductivity values were represented by shades of green colours as shown on the map. Hydraulic conductivity provides an indication of the ease with which water moves through the subsurface; a higher value represents the ease with which that happens.

The values of transmissivity estimated by Dar-Zarrouk parameter showed the distribution of the transmissivity values in Karlahi area with an average value of 153.76 m²/day. A spatial distribution of transmissivity map generated from Dar-Zarrouk equation of VES results are presented in Figure 6. Sky blue and shades of blue colours indicate the zones with high transmissivity values whereas shades of green represent low transmissivity values. Transmissivity has high values in the north central

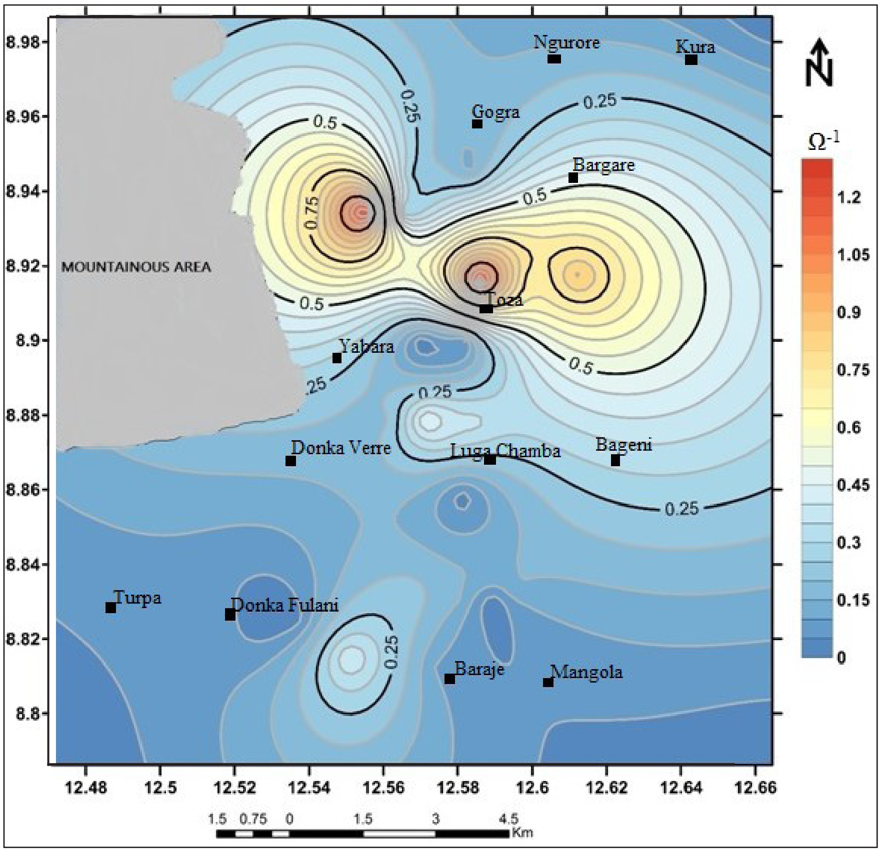

Figure 3: Longitudinal conductance distribution map over Karlahi area.

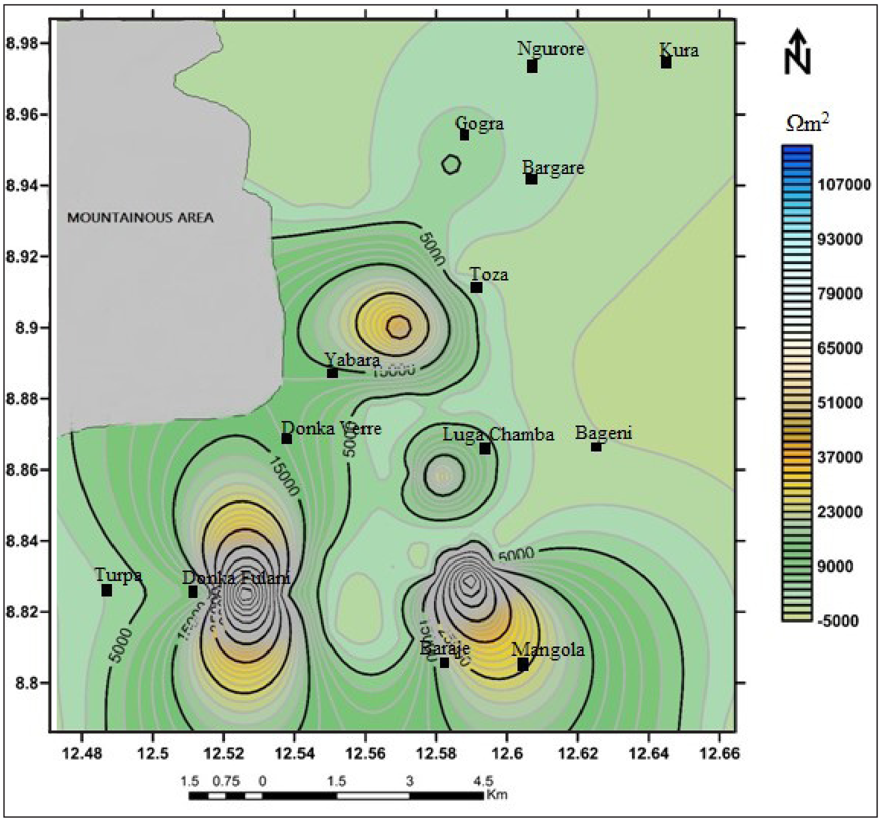

Figure 4: Transverse resistance over Karlahi area.

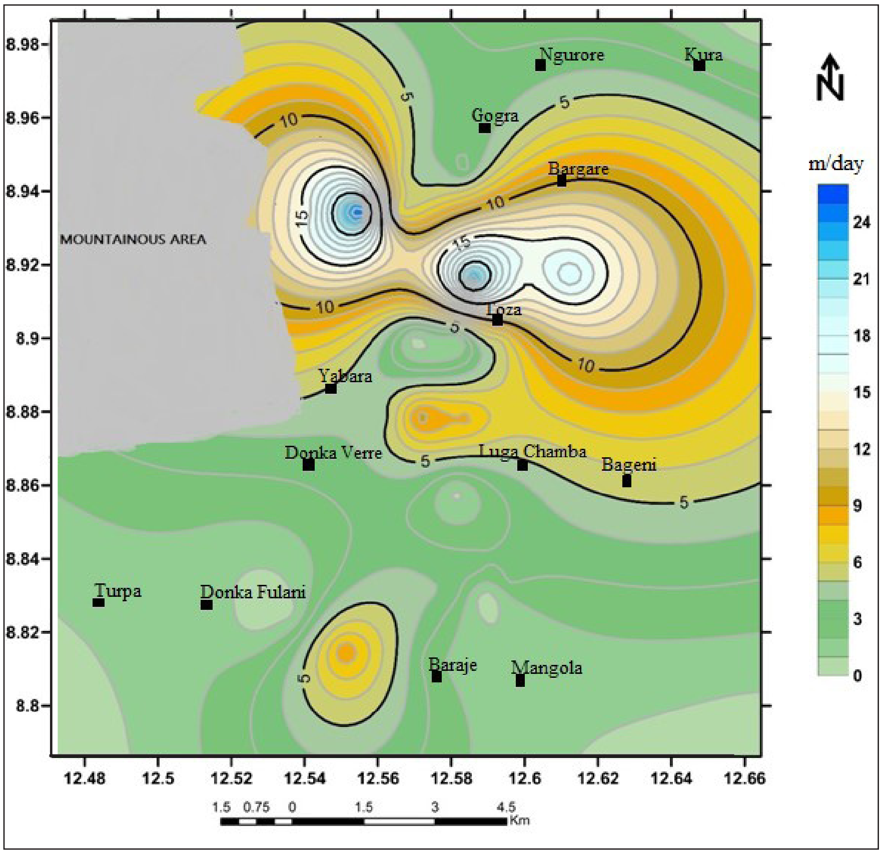

Figure 5: Spatial distribution of hydraulic conductivity over Karlahi area.

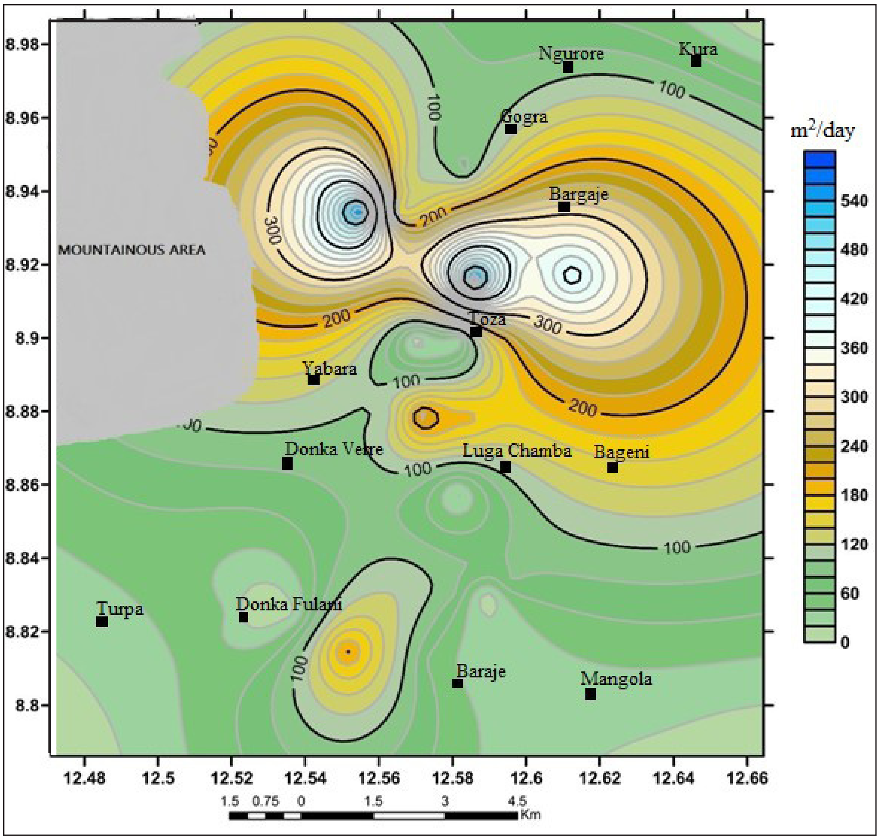

Figure 6: Spatial distribution of transmissivity over Karlahi area.

part of Karlahi area and are low in southern part and extreme northeastern part.

Zones of groundwater potential in Karlahi area

The values of the transmissivity over Karlahi area and the numerical boundary given by (De Wiest, 1965) was modified by grouping all values < 50 together and having three range values of < 50 as negligible and weak, between 50 -500 as moderate and > 500 as high. These standards are used to determine the potential groundwater zones in the area. High transmissivity values correspond to high groundwater potential. The groundwater potential map of Karlahi area presented in Figure 7 shows a negligible to weak groundwater potential zone represented by yellow colours covering 23.3% of Karlahi area, moderate groundwater potential zone represented by green colours covering about 70% of Karlahi area and high groundwater potential zone represented by red colours covering 6.7% of Karlahi area. These moderate zones are mostly concentrated in the central to the northern part of Karlahi. The southern part is characterized by negligible to weak zones and the high zones are concentrated in pockets.

DISCUSSION OF RESULTS

According to (Oladapo & Akintorinwa, 2007) standard, protective capacity value of >10 is excellent, between 5 -10 is very good, 0.7 - 4.9 is good, 0.2-0.69 is moderate, 0.1 - 0.19 is weak and < 0.1 is poor. By this standard, the longitudinal conductance values in Karlahi area revealed poor to good with the average longitudinal conductance as moderate. This analysis revealed Toza and northwestern part of Toza to have moderate protective capacity and are considered to have moderate yield of groundwater. The values of transverse resistance in Karlahi area revealed low to moderate groundwater yield according to (Cassiani & Medina, 1997). In hydrogeological studies, transverse resistance has been discovered to function analogous to transmissivity (Singh & Singh, 2016). These high transverse resistance values are located in Donka Fulani, Baraje, Mangola and Yabara communities while low values are located in Gogra, Bargare, Ngurore and Kura, all situated in the north eastern area corresponding to areas underlain by banded gneiss.

Hydraulic conductivity provides an indication of the effortless flow of water in the subsurface (Ezema *et al*., 2020), higher value represents the ease with which that

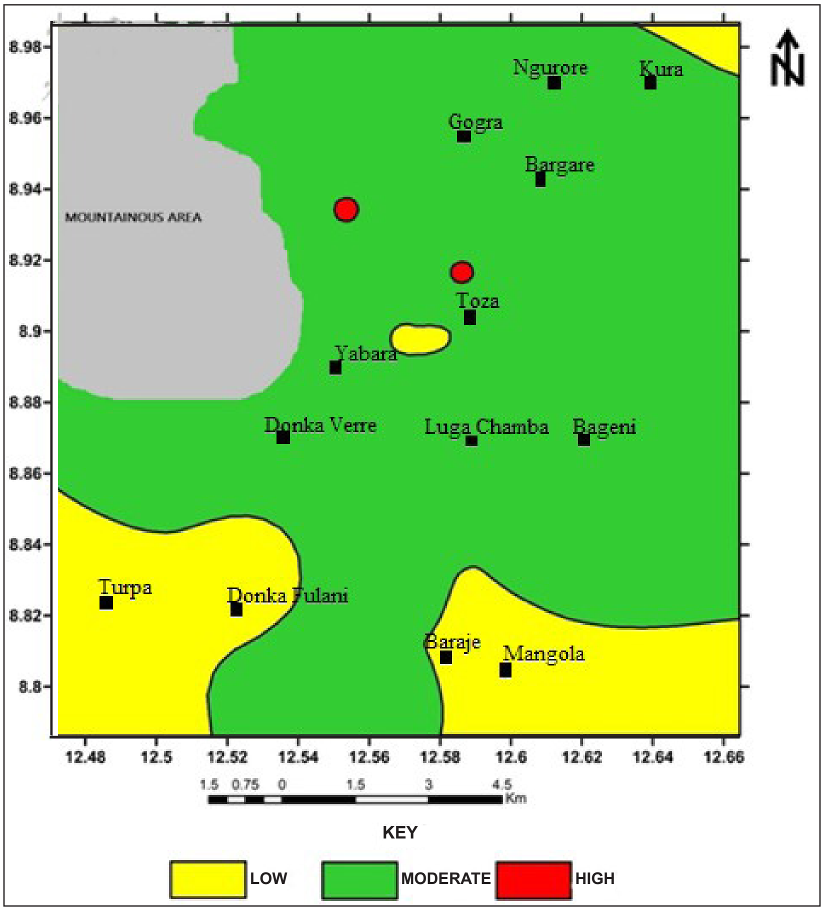

Figure 7: Groundwater potential zones using transmissivity values in Karlahi area.

happens. High permeability will be observed in aquifer zones with high hydraulic conductivity (Niwas & Singhal, 1985). Hydraulic conductivity is high in Yabara, Luga Chamba, Bageni, Toza, Bargare communities all in north central area of Karlahi area with pocket of high hydraulic conductivity on the western part of Baraje while low values are predominantly located in the southern part covering Turpa, Donka Fulani, Baraje and Mangola and also on the extreme part of the northen part of the study area covering Gogra, Ngurore and Kura which are predominantly underlain by coarse to medium grained granite and banded gneiss. Transmissivity values in Karlahi area revealed negligible to moderate groundwater potential based on data reported by (De Wiest, 1976). The spatial distribution map of transmissivity in Karlahi area revealed areas with moderate to high transmissivity values in the north central to northern parts and a negligible to low transmissivity in southern part. Logically, high transmissivity values imply high groundwater potentials and these areas corresponds to high hydraulic conductive zones. Pockets of high groundwater potential zone is observed north of Toza and directly below the mountainous area. The mountainous area characterized by lineaments with high interconnectivity structures for easy flow of groundwater in to weathered geologic materials, these may be the possible reason for moderate groundwater potentials in the area.

CONCLUSION

Dar – Zarrouk parameters proved useful for delineating zones of groundwater potentials in a complex basement terrain. The groundwater potential map delineated central to northern part of Karlahi area with moderate to high groundwater potential and low groundwater potential zones in the southwest and southeastern areas. Low groundwater potential zones in southwest and southeastern area and are attributed to limited or no weathered material in the area. Other low groundwater potential areas are in the extreme northeastern and central parts of Karlahi area. The mountainous areas are serving as possible recharge zones to faults, fissures and weathered basement in the area.

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