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Evaluation of Groundwater Potentials Using Dar Zarrouk Parameters in Mapeo and Environs, North-Eastern Nigeria

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Abstract
Groundwater is the safest and most reliable source of water in crystalline basement complex terrain especially those associated with semi-arid to arid regions. This research is aim at evaluating the groundwater potentials of Mapeo and its environs, The study area is located between latitudes 8° 37'and 8° 45' N and longitudes 12°21'and 12°32' E. Thirty-five Vertical Electrical Sounding (VES) points were surveyed using the Schlumberger array. The analysis of the VES conducted revealed four layered formations; Sandy clay to slightly weathered, fractured, and basement rocks. The aquifer units in the study area varied from highly weathered and fractured basement rocks. Dar-Zarrouk parameters such as the longitudinal conductance and transverse resistance revealed values that ranged from 0.0842 to 1.5926Ω with an average value of 0.5767Ω and 1107.235 to 8910.410Ωm² with an average value of 4167.902 Ωm² respectively. For the aquifer properties, empirical formulae based on grain size analysis were used to determine hydraulic conductivity which ranges from 1.01X 10⁻⁹ to 9.82X 10⁻⁶m/day with an average value of 2.176x10⁻³m/day, the hydraulic conductivity determined from geophysical method range from 1.833 to 17.525m/day with an average value of 7.2182x10⁻³m/day while transmissivity values range from 47.657 to 779.724 m²/day with an average of 289.113 m²/day. Groundwater potential zones were determined based on transmissivity values and classified the area into low, moderate, and high potentials.

Keywords: Aquifer, Groundwater, Dar-Zarrouk, geophysical, and transmissivity.

INTRODUCTION
The increasing demand for water in the Leko-Koma constituency particularly Mapeo and environs of the Jada Local government is becoming a difficult situation as a result of an increase in agricultural activities, a rapid increase in population, and as industries are beginning to reckon with the entire constituency due to abandoned natural resources in the area. Mapeo and the entire Leko-Koma constituency is an area situated in the cores of igneous and metamorphic rocks and this could be a strategic target terrain for tourism

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minerals and urbanization planning. Such terrains are commonly characterized by fractured and cracked rocks that can serve as a secondary porosity that can allow the flow of water as well as hold it in place. Due to the discontinuity characteristics of aquifers associated with basement rock areas, siting water boreholes and drilling them without proper guidance by experts may fail or achieve abortive water boreholes which could be waste of time, energy, and resources. This work is looking at the prospective locations that are feasible for water borehole exploration using the concept of Dar Zarrouk parameters. Fractures, fissures, intergranular porosities, and joints are associated with crystalline basement rocks which are technically termed secondary porosity (Ojo et al.,2015). Exploration of groundwater within the confines of the basement rock terrain is difficult to work to execute particularly when the potential aquifer areas for the groundwater investigation are associated with fissures and fractures. The reservoir capacity of fractured crystalline basement rocks is limited, and the conductivity and transmissivity of groundwater take place along cracks and planar breaks. The occurrences of groundwater in basement rocks usually take place in closely spaced cracks and other fracture patterns characterized by large openings generated by the effect of tectonism and other related geological events. The volume of water in the basement rock complexes largely depends on the sizes of the fractures and fissures (reservoir) connectivity. The porosity and permeability parameters of reservoirs within crystalline basement rocks are difficult to calculate compared to those related to sedimentary basins. The application of satellite data is important in identifying structural features such as lineaments and faults. This concept has been productively used (Lupker et al., 2012; Ndatuwong and Yadav, 2014; Badamasi et al., 2016). The application of hydro-geoelectrical resistivity techniques for groundwater exploration has been widely utilized by researchers, government, and industries, and this has solved a lot of exploration problems related to groundwater. (Zohdy et al., 1974; Hoekstra and Blohm, 1990; Mousa, 2003; Ibrahim et al., 2004; Nigm et al., 2008; Mohamaden et al., 2009; Araffa, 2013; Thabit and Al-hameedawie, 2014; Elbarbary et al., 2021). The aquifer medium, the pore spaces, the content of the fluids, the geometry, volume, and salinity have a substantial effect on the values related to electric resistivity (Cherry et al., 1996; Robain et al., 1996). The hydro-geoelectrical concept has been used to determine water content (Kesseles et al., 1985), and other parameters of hydrology (Frohlich and Kelly, 1988; Jackson et al., 1978; Troisi et al., 2000), however, the contaminated groundwater zone can affect the electrical resistivity techniques (Kelly, 1976; Karlik and Kaya, 2001). The availability and friendly nature of Vertical Electrical Sounding, numerical model techniques, and advances in computer software have become a common option and tool for groundwater exploration.

Few or no research with such an approach has been carried out in the study area and coupled with the difficult conditions associated with increasing agricultural demands and growth in the population as stated earlier form the driving force behind this research.

Geology and Hydrogeologic Setting

The rocks in the study area are underlain Precambrian basement complex, these rocks are generally term as Adamawa Massif. The identified rocks are composed of fine, coarse to porphyritic granites. The older rocks are restricted to the central and northeastern part of the study area and other rocks observed are the migmatite gneisses and these are exposed in the northeastern and southwestern of the study area (Fig. 1). A geophysical survey revealed that the geology of the study area is characterized by four layers of rocks; clay topsoil with a thickness that ranges from 0 to 2 m, this is underlain by the second layer which is composed of highly weathered basement rocks with a thickness that ranges from

2 to 11 m, however, the third layer of the rocks is a fractured basement rock with a thickness that ranges from 7 to 25 m, and fresh basement rock characterizes the fourth layer of the strata of rocks in the study area. The aquifer unit of the rock is highly fractured crystalline basement rock with a total thickness of 36 m (Fig. 2).

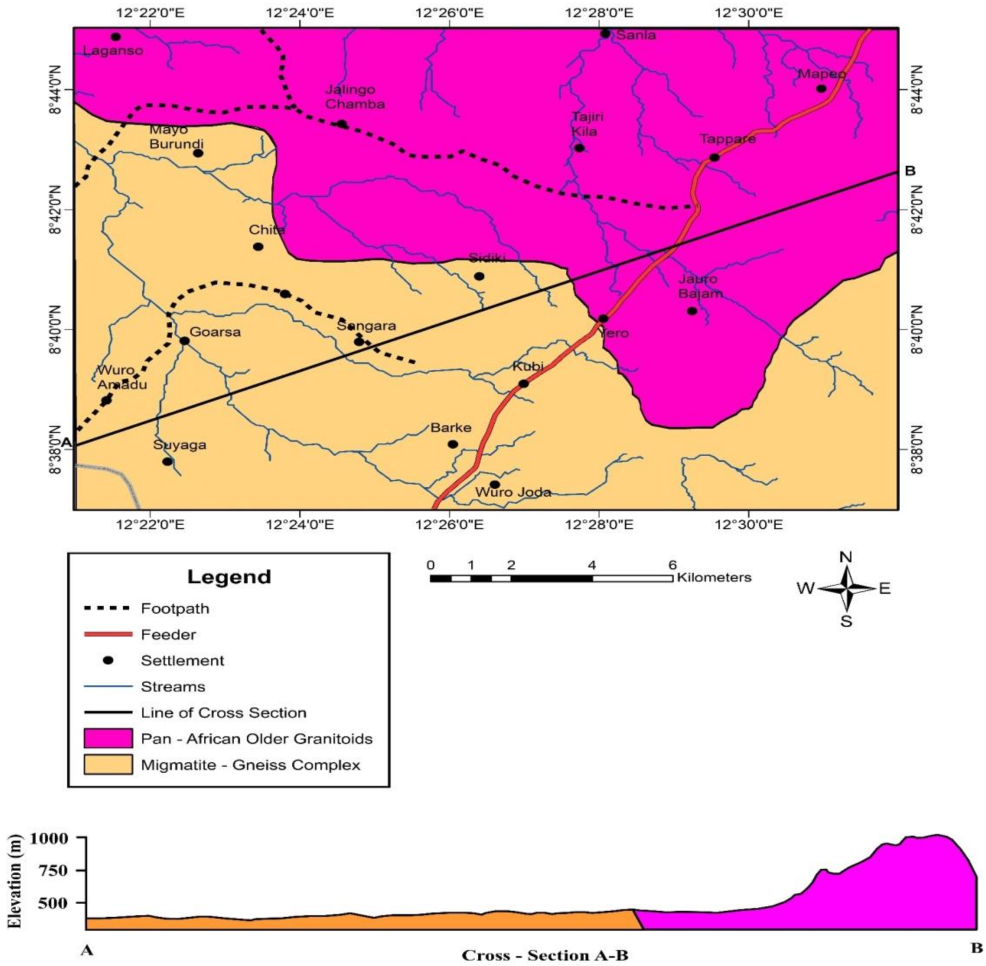

Figure 1. Geological map of the study area.

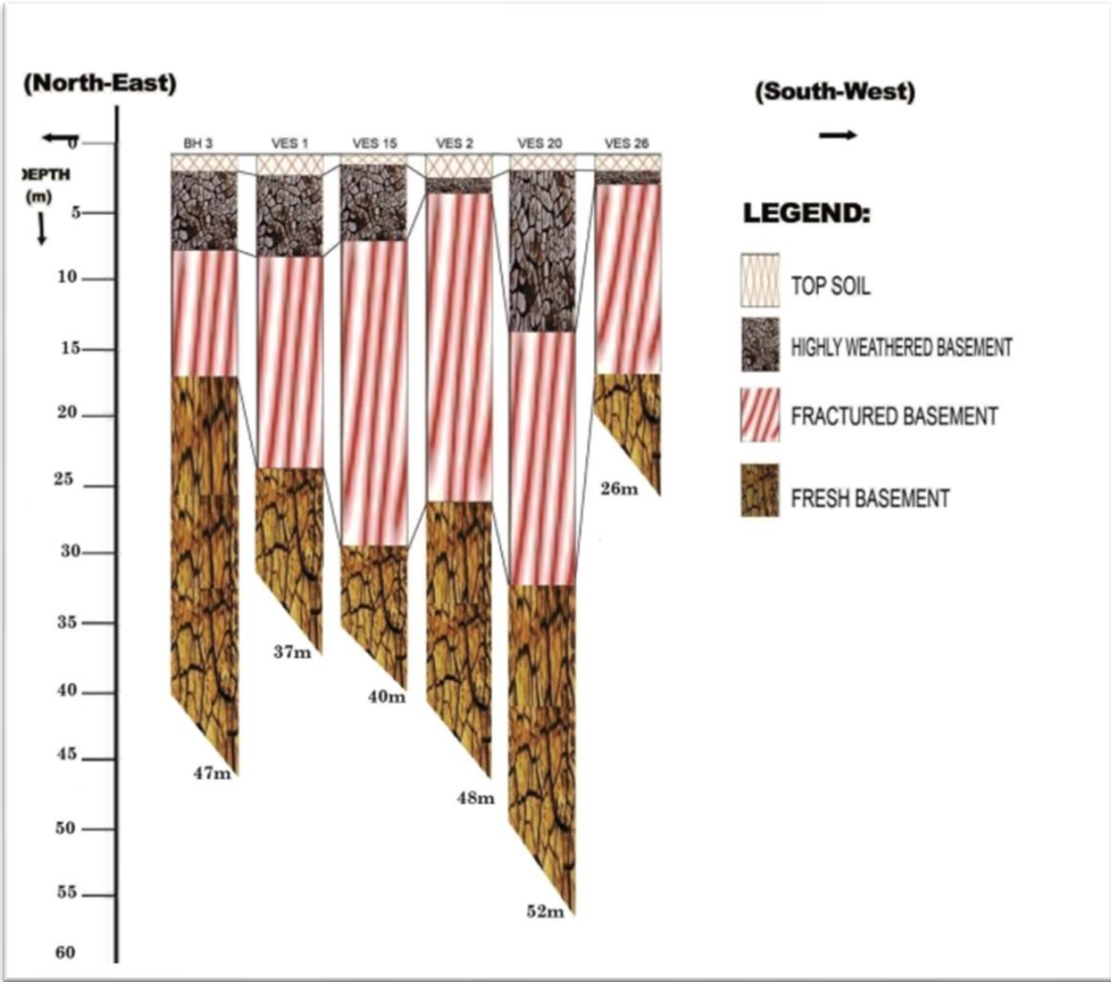

Figure 2. Correlation of borehole lithologic section and geoelectric sections from the study area

Location and Methodology

Location

The study falls within latitudes 8^0 37' and 8^0 45' N and longitudes 12^0 21' and 12^0 32' E with an aerial extent of 295km^2. It is bounded to the east by the Cameroun Republic and the west by Mayo Belwa. The northern boundary is demarcated by Fufore town and the southern boundary by Ganye town (Fig. 3).

Geophysical survey

The measurement of resistivity parameters was carried out based on Vertical Electrical Sounding (VES) approach, this is aimed at understanding the geology of the study area. The voltage of the electric field induced into the sub-surface with the aid of two pegged, separate, and distant current electrodes (A, B) connected to a source of the current coupled with closely fixed potential electrodes (M, N) were measured. A total of 35 VES points were carried out using the Schlumberger array with 200 VP spacing of the electrodes in the study area. The Schlumberger array is a reliable method for delineating horizontal layers of rocks with adequate depth sensitivity, however, this method commonly adjoins a high signal noise ratio (Hoekstra and Blohm, 1990). The depth that can be penetrated by resistivity survey is roughly 1/3 of the total current electrode distance (Maiti et al., 2011). The measurement of the resistivity values was conducted with the aid of a set of equipment known as terameter with a model label "ABEM SAS 4000 terameter ". Apparent resistivity values versus AB/2 have been plotted on a logarithmic sheet of paper to obtain the apparent field curves. The field data were converted to apparent resistivity (ρa) in ohm-meter by multiplying with Schlumberger geometric factor (k). The data were interpreted qualitatively and quantitatively through a computer program with the aid of (IX1D interpex 2006) computer software. Distortion due to lateral inhomogeneity of the lithology of the rocks is commonly visible in the plotted curve and probably as a result of errors or failure of the equipment (Zohdy et al., 1974) and this has been corrected by employing smoothening techniques. An experimental data curve was used as it is sub-divided into many minor curves and each represents a geoelectric of resistivity (Ω.m) that is known and it also represents the thicknesses (m) of a peculiar geologic layer and its geophysical properties and making it unique from the layers below and above.

Dar-Zarrouk Parameter

The conceptualized medium that is layered commonly exhibits excellent characteristics that are important when interpreting geoelectric layers (Braga et al., 2006), and the composition of parameters such as ρ and h for every single geoelectric layer is important (Batte et al., 2010; Singh et al., 2004). For a sequence of n horizontal, homogenous, and isotropic layers of resistivity ρ_i and thickness h_i. The DZ parameters (longitudinal conductance (**S)** and transverse resistance (**T**)) are defined respectively.

$$S_i = \sum_{i=1}^{n} \frac{h_i}{p_i} (Seimens) \qquad 1$$

S_i represents longitudinal conductance; h is thickness and ρ_i is the apparent resistivity of the aquiferous layer.

(Tr) represent transverse resistance which is a product of the aquifer's apparent resistivity and the aquifer thickness. Thus: $T_i = \sum_{i=1}^{n} \rho_{i\, *h_i}\ (ohm.m^2)$ 2

T_i symbolizes transverse resistance, i thickness while p_i is the apparent resistivity of the aquiferous layer. The highest borehole yields usually come from the zone with the highest transverse value (Opara et al., 2012). A target area of good groundwater potential zone can be defined using transverse resistance (Tr) due to its direct relationship with transmissivity, highest transmissivity value can as well be predicted by highest Tr values of water bearing rocks (aquifer).

to note that horizontal groundwater flow is governed by transmissivity (T). Transmissivity can be connected to transverse resistance and/or longitudinal conductance, however, this can be dependent on the geological conditions. The transmissivity (T) of the aquifer is linked to the field hydraulic conductivity (K) by equation.

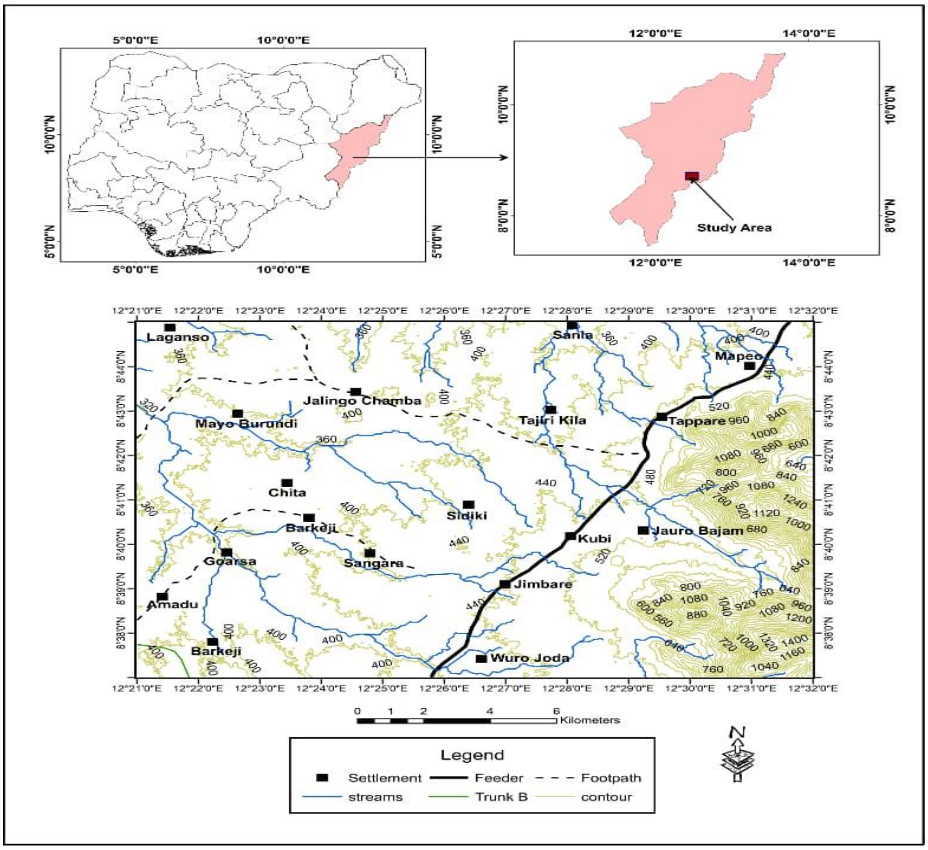

Figure 3: Topographic map of the study area

T = Kh (m^2/day) (Daniel *et al.*, 2015) (3)
Hence, K = Tb^{-1} (m/day), h = Aquifer thickness (m).

Results and Discussion

Aquifer Characteristics Using Dar Zarrouk Parameters

The interpretation of the data identified aquifer layers at various sounding points showing the variation of aquifer resistivity and thickness due to lithologic composition from which the longitudinal conductance and transmissivity were computed. The layer having low resistivity with high thickness was used in the computation of the Dar-Zarrouk parameters. (Table 1) gives the result of transmissivity (T), Transverse resistance (Tr), and Longitudinal conductance (S).

A spatial distribution map of longitudinal conductance (Fig. 4) shows Dark and Light Blue which indicate the zones with high longitudinal conductance values (central part) whereas the zones of low longitudinal conductance values range from Yellow to Green as shown on the map. The values obtained

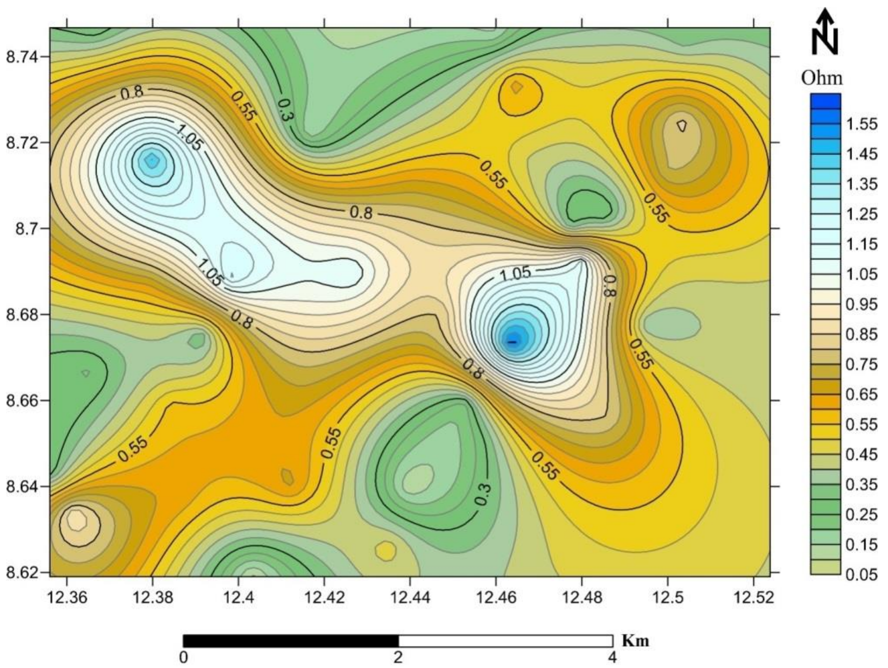

Figure 4: Spatial Distribution of Longitudinal Conductance over the study area

Table 1: Summary of aquifer characteristics and Dar Zarrouk Parameters using the geophysical survey

VES No	Location	Layer Resistivity (Ωm)	Layer Thickness (m)	Aquifer Conductivity (ohm) (σ)	Longitudinal Conductance (Ω)	Transverse Resistance (Ωm²)	Hydraulic Conductivity (m/day)	Transmissivity (m²/day)
1	Tappare	49.91	37.38	0.0200360	0.7489	1865.636	10.067	376.304
2	Sidiki	59.34	47.81	0.0168520	0.8057	2837.045	8.567	409.588
3	Inusa	39.19	32.06	0.0255167	0.8181	1256.431	12.615	404.437
4	Mapeo	101.67	42.91	0.0098357	0.4221	4362.659	5.184	222.445
5	Malope	48.54	32.97	0.0206016	0.6792	1600.364	10.332	340.646
6	Vanbei	45.00	50.00	0.022222	1.1111	2250.00	11.088	554.4
7	Laganso	182.37	44.82	0.0054834	0.2458	8173.823	3.011	134.953
8	Kubi	121.32	36.29	0.0082427	0.2991	4402.703	4.396	159.531
9	JalingoCha	161.96	45.65	0.0061744	0.1584	4154.274	12.358	564.143
10	Chita	47.68	57.56	0.0209732	1.2072	2744.461	10.506	604.725
11	Barkeji	81.86	25.34	0.0122159	0.3096	2074.332	6.346	160.808
12	Mayo Kila	175.54	50.76	0.0056967	0.2892	8910.410	3.124	158.574
13	TappareJan	310.0	68.58	0.0032258	0.2212	21259.8	1.832	125.639
14	Goreldo	47.49	31.44	0.0210570	0.6620	1493.086	10.545	331.535
15	Lengdo	157.78	39.96	0.0063379	0.2533	6304.889	3.441	137.502
16	WuroJoda	123.46	53.38	0.0080998	0.4324	6590.295	4.325	230.869
17	Wanlu	46.07	36.72	0.0217061	0.7970	1691.690	10.848	398.339
18	Jimbare	92.13	44.07	0.0108542	0.4783	4060.169	5.683	250.449
19	Mayo	64.71	41.16	0.0154536	0.6361	2663.464	7.901	325.205
20	Sangara	72.70	51.53	0.0137552	0.7088	3746.231	7.088	365.245
21	Dabega	41.39	45.60	0.0241604	1.1017	1887.384	11.988	546.653
22	Sanla	188.16	45.23	0.0053146	0.1447	5123.597	13.500	610.605
23	Rigaji	95.45	31.61	0.0104767	0.3312	3017.175	5.498	173.792

24	Jirani	57.44	38.76	0.0174095	0.6748	2226.37	8.831	342.289
25	Dekbara	291.30	24.54	0.0034329	0.0842	7148.502	1.942	47.657
26	Suyaga	49.68	45.09	0.0201288	0.9076086	2240.071	10.111	455.905
27	Mayo	27.55	40.19	0.0362976	1.4588	1107.235	17.525	704.329
28	JauroBajam	109.10	42.89	0.0091659	0.3565	4242.899	11.612	498.039
29	Mari	69.48	43.47	0.0143926	0.6256	3020.296	7.394	321.417
30	Goarsa	46.56	26.16	0.0214777	0.5619	1218.009	10.741	280.985
31	Barke	121.55	13.16	0.0082271	0.1083	1599.598	4.388	57.746
32	WuroAma	170.50	44.42	0.0058651	0.2605	7573.61	3.2	142.144
33	Kwasara	165.96	40.37	0.0060255	0.2432	6699.805	3.282	132.494
34	TajiraKila	100.00	50.00	0.01000	0.45	4500.00	12.450	622.500
35	Yero	33.90	53.99	0.0294985	1.5926	1830.261	14.442	779.724
	Min	27.55	13.16	0.0032258	0.0842	1107.235	1.833	47.657
	Max	291.30	68.58	0.053937	1.5926	8910.410	17.525	779.724
	Average	102.764	40.25342	0.0141775	0.5767187	4167.902	7.2182	293.3612286

from the Dar Zarrouk parameters ranges from 0.0842 to 1.5926Ω with an average value of 0.5767Ω. It can be inferred that the zones with low longitudinal conductance values are vulnerable to contamination and thus are highly conductive as a result of seepage of contaminant fluid into the groundwater system.

A spatial distribution map of transverse resistance generated (Fig. 5) shows a Dark and Light Blue very high area (southwards) and Green to Yellow indicates low areas on the map. The values obtained from the Dar Zarrouk parameters ranges from 1107.235 to 8910.410Ωm^2 with an average value of 4167.902 Ωm^2. The transverse resistance is also used to define target areas of good groundwater potential. It has a direct relationship with transmissivity and the highest values reflect most likely the highest transmissivity values of the aquifers or aquiferous zones. The transverse resistance is one of the parameters used to define target areas of good groundwater potential. In hydrogeological investigations, transverse resistance has been found to be functionally analogous to transmissivity (Cassiani and Medina, 1997).

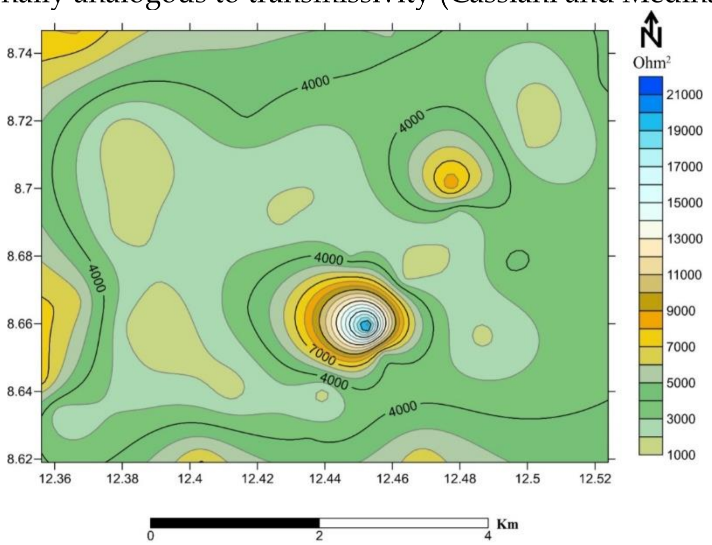

Figure 5: Spatial Distribution of Transverse Resistance over the study area

For characterization of rocks as a water conducting media, transmissivity is a major property(Fatoba et al., 2014). The spatial map of transmissivity (Fig. 6) shows that high transmissivity is obtainable in the central part of the study area and decreases northwards and southwards across the study area. It is also deduced that groundwater flow potential increases as transmissivity and longitudinal conductance increases. Transmissivity values ranges from 47.657 to 779.724 m^2/day, the average value been 293.361 m^2/day. The values of transmissivity in the study area revealed low to high potential based on (Offodile, 1976) standards.

A spatial distribution map of hydraulic conductivity generated from Dar Zarrouk equation (Fig. 7) is presented with red and purple colors which indicate zones with high hydraulic conductivity values (central part) and zones of low hydraulic conductivity values which are represented by shades of blue color as shown on 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. Hydraulic conductivity is high in the central part of the study area and has low values in the southern and northern part of the study area. The hydraulic conductivity value ranges from 1.833 to 17.525 m/day with an average value of 7.2182 x 10^{-3}m/day. The values of hydraulic conductivity in the study area revealed the hydraulic conductivity of silty sand to clean sand (Freeze and Cherry, 1979).

Groundwater Potential Zones of The Study Area

(Offodile, 1976) classified transmissivity values as <50 as Low potential, between 50-500 as Moderate and >500 as High which are used to delineate the potential groundwater zones. High transmissivity values correspond to areas of high groundwater potential. The groundwater potential map of the study area (Fig. 8) shows three zones which are the low, moderate and high zones.

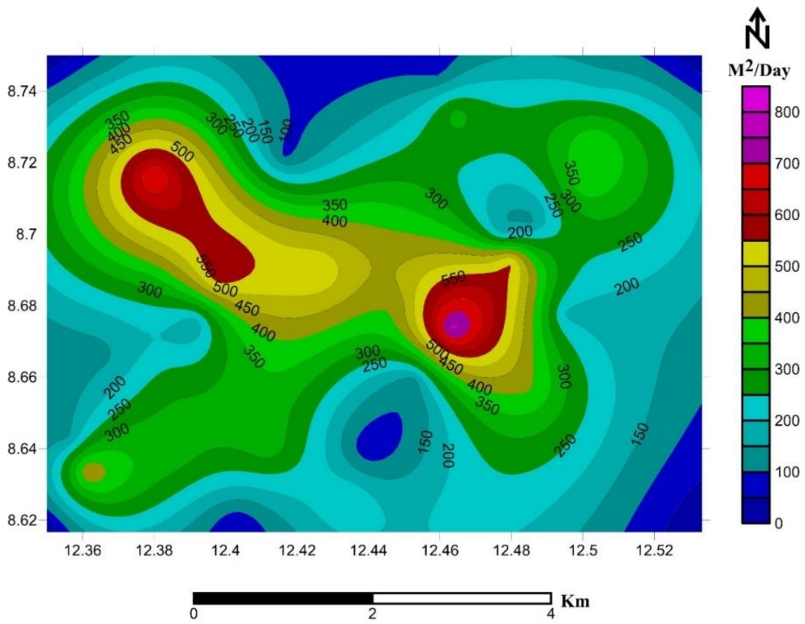

Figure 6: Spatial Distribution of Transmissivity over the study area

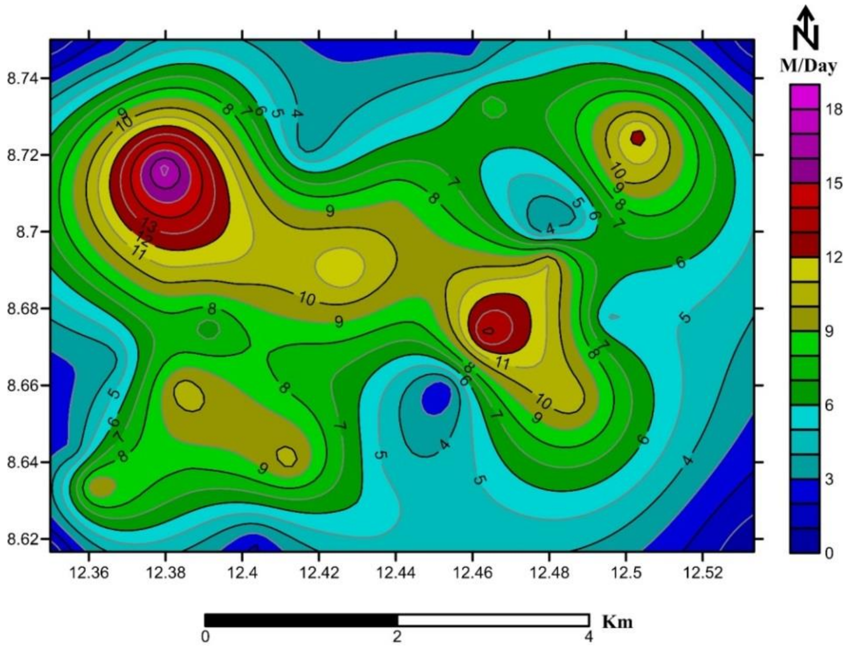

Figure 7: Spatial Distribution of Hydraulic Conductivity over the study area

The low potential zone has a little concentration at the southeastern, Northeastern, Southwestern, and Northwestern parts which is indicated with purple color, it covers about 9.5% of the study area. A moderate zone which is light green in color covers the dominant part of the study area. High groundwater potential is represented by red color and is concentrated in the northern, southeastern, northwestern and central part of the study area.

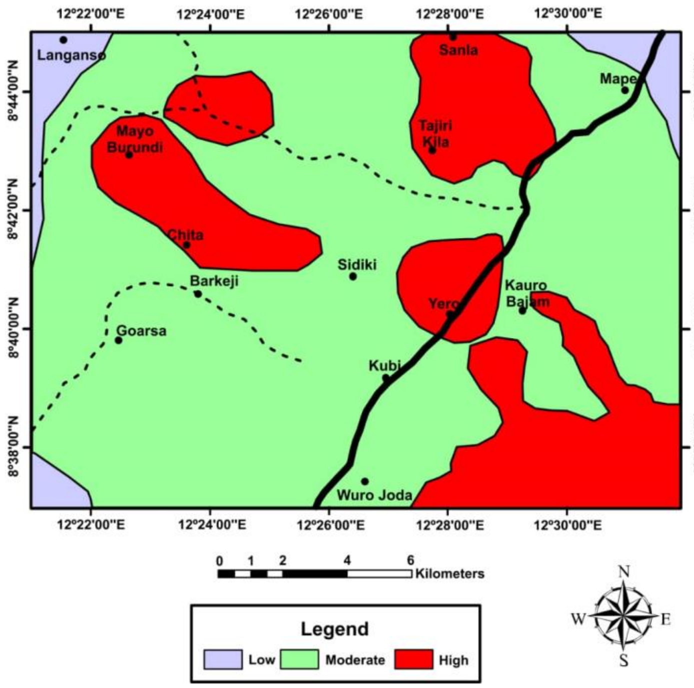

Figure 8: Map showing groundwater potential zones over the study area.

Conclusion

Exploration of groundwater particularly in complex and complicated areas such as crystalline basement settings requires a careful and special approach, therefore, the application of the hydro-geoelectric method Dar- zarrouk parameters are a reliable tool for mapping out groundwater potential areas in a geological setting that is composed of a crystalline basement complex, these concepts had proven useful in highlighting the groundwater potentials zones in the study area. The groundwater map of the potential zones in the study area shows that the north and southeastern parts of the study are characterized by groundwater potential while moderate groundwater potentials are restricted to the central part of the study area, however, the fringes of the groundwater potential map shows that the NW, NE and SW part of the map have low groundwater potentials. The high relief provided by the mountainous areas within the study area may serve as the recharge zones for the aquifer system in the study area.

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