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Evaluation of Groundwater Potential and Aquifer Protective Capacity Using Dar- Zar-rouk Parameters; A Case-Study f Kwara State Polytechnic, Kwara State, Nigeria.

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Competing Interests.

The authors declare no competing interests.

ABSTRACT

This research paper aims to determine the hydraulic properties of the water-bearing layer using parameters derived from the Dar-Zarrouk equation and characterize them into groundwater potential zones. The resistivity values of the weathered and slightly weathered layers which bearing water-bearing layers were added; an average was taken and used as the resistivity of the water-bearing formation in the computation of Dar-Zarrouk parameters in this study area. The curve types identified and the number of occurrences in parenthesis range from H(6), AH(4) and HAH(2). Five lithological layers were identified which are the Topsoil, laterite, weathered rock, fractured basement, and fresh basement. The data reveal generally three to four geo-electric layers, top layer with resistivity value of AB/2 = 1.2m to 3m ranging between 170 and 1322ohm-m. The middle layer has a resistivity value of AB/2 = 2.2m to 20m ranging between 66 and 1890ohm-m and the third geo-electric layer has resistivity values ranging between 100 and 1800ohm-m. The values of resistivity of water bearing formation ranged from 66 to 267 Ωm with an average resistivity value of 152Ωm and the thickness of the water bearing formation ranges from 5 to 61.6m with an average thickness of 17 m. The longitudinal conductance ranges from 0.030 to 0.616Ω^{-1}, the transverse resistance ranges from 830 to 6160 Ωm^2. The hydraulic conductivity and transmissivity values range from 1.62 to 33.2 m/day and 66.1 to 267m^2/day respectively with aquifer porosity values ranging from 1.2% - 23.6%. This study shows the importance of combination of different parameters for delineation of groundwater zones in a study area and also the advantage of surface geophysics in estimating hydraulic characteristics of an aquifer where pumping test data are not available and to determine its vulnerability to surface contaminants, also to correlate field/practical analysis in conjunction with theoretical mathematical calculations to delineate groundwater zones. This paper also suggests an imperativeness of not just focusing on the groundwater quantity (potential) but also its quality as it helps to avoid some water prone diseases in this study area.

Keywords: Groundwater, Dar-zarrouk, Electrical resistivity, Protective capacity

1. INTRODUCTION

Based on the correlation between hydraulic transmissivity and transverse resistance, the resistivity approach is applied to estimate water bearing formation (Kelly & Reiter, 1984). The concept of using rock thickness and resistivity to compute aquifer parameters using transverse resistance (R) and longitudinal conductance (S) was initially developed by (Maillet, 1947). Hydraulic conductivity is a crucial variable to consider when analyzing aquifer characteristics (Gemail et al., 2011). According to Chang et al. (2011), Dar-Zarrouk characteristics are crucial in understanding how groundwater flows through a porous geologic medium. Despite recent discoveries in alternate approach to estimating aquifer parameters and

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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 Soupious 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 formations 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 the 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 the parameters of the Dar-Zarrouk equation, and to determine the groundwater potential of the area using the electrical method in this study area within Kwara state polytechnic.

2. THE STUDY AREA

The study area is located within latitude $8^0$28'58.3''N, $4^0$31'35 and is located in Kwara state polytechnic, in the eastern part of Kwara State, in the Moro local government area of the state (Fig. 1). The study area is located geographically in a tropical climate area characterized by two distinct seasons; Dry/ Harmattan and Wet/Rainy season. The wet season last from April - October while the dry season last from November - March. The annual mean temperature of the area is between 32ºC to 35ºC. The study area falls under the tropical savannah region. The vegetation is characterized by leafy trees, thick bushes and grasses. Geologically, the area belongs to the southwestern Nigeria Precambrian basement complex. Locally, the study area is underlain by migmatite gneiss complex. These rocks were emplaced in Precambrian times and have been subjected to tectonic activities characterized by large changes in temperature and the pressure resulting in features like joints, faults and folds. Such fractures are those that influence the ground water in crystalline rocks especially, if they exist at depth and are over laid by a thick superficial cover (overburden) (Fig. 2).

2.1. Brief Geology of Kwara State Polytechnic

The study was carried out within the premises of Kwara State Polytechnic, Ilorin, Kwara State, Nigeria. The mapped area falls under the basement complex rock terrain of Nigeria. The basement complex is one of the three major litho-petrological components that make up the geology of Nigeria (Rahaman 1976). The Nigerian basement complex forms a part of the PanAfrican mobile belt and lies between the West African and Congo cratons and the Tuareg shield. Examples of rocks found in this area include schists, granite quartzite and gneiss. The geophysical survey was done to decipher the subsurface geology in respect to the depth to basement and also the aquifer zones with the major point of interest to be the geo-electrical investigation for groundwater in the area.

3. MATERIAL AND METHODS

Electrical sounding is the process by which depth investigations are made. If the ground is comprised of horizontal, homogenous, and isotropic layers, electrical sounding data represent only the variation of resistivity with depth. In practice, however, the electrical sounding data are influenced by both vertical and horizontal heterogeneities (Zohdy et al, 1980). Vertical Electrical Sounding (VES)

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Fig 1. Aerial map of study area

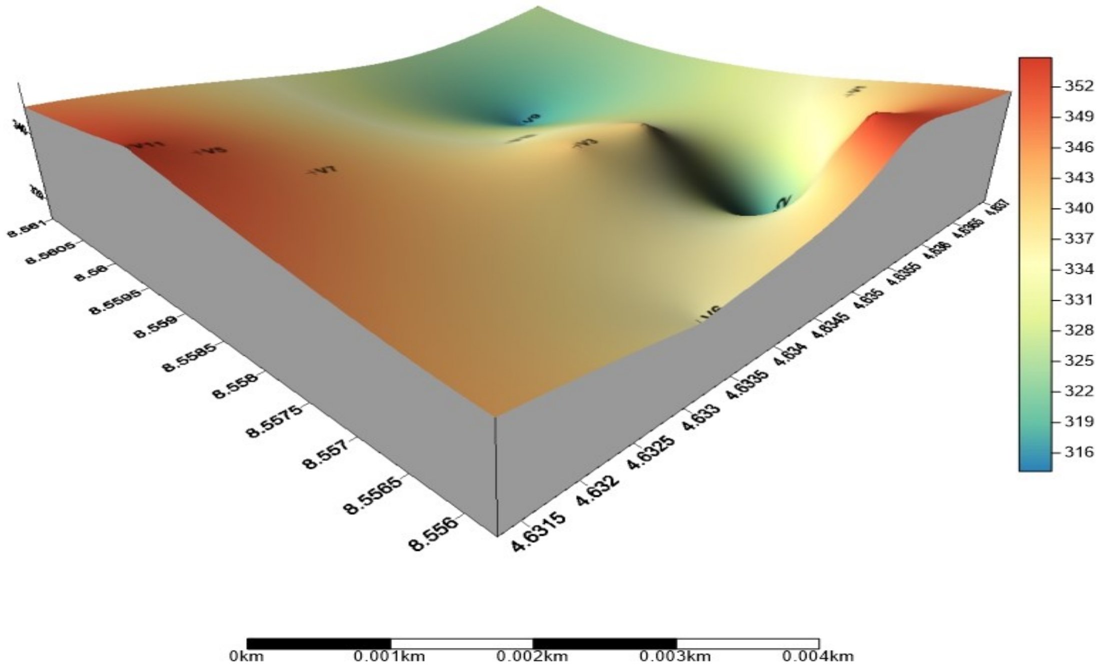

Fig 2. 3D view of study area

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collinear arrays designed to output a 1- D vertical apparent resistivity versus depth model of the subsurface at a specific observation point. Twelve (12) vertical electrical soundings were conducted using ABEM resistivity meter and data acquired were written down at the different meter. In Schlumberger array, the 5 to 1 ratio electrode spacing was considered so as to avoid error during the survey. Resistance value is then multiplied by the geometric factor to have the apparent resistivity. This apparent resistivity value is what is used to determine the types of materials we have in the subsurface and also use to know the number of layers in the subsurface.

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 geoelectric layer (Batte et al., 2010; Singh et al., 2004). The unit of longitudinal conductance (S) and transverse resistance (R) are given below as:

$$R = \Sigma n\ i = 1 \quad hi\rho i\ i = 1, 2, 3, \ldots\ldots.\ n \qquad 1$$

and

$$S = \Sigma ni = 1\ hi/\rho i \quad i = 1, 2, 3, \ldots.. n \qquad 2$$

Thereby ρ_i (electrical resistivities) and h_i (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

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

δ_i 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: $$Tri = Kihi \qquad 6$$

Where K_i is hydraulic conductivity of the i^{th} layer of thickness h_i 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:

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

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Detailed formulations were found in (Niwas & Singhal, 1981, 1985; Chandra et al., 2008 and Kosinski & Kelly, 1981). The values of the longitudinal conductance were used in evaluating the protective capacity of the aquifer. Mogaji *et al*., (2007) stated that the earth medium act as a natural filter for percolating fluid and that its ability to retard fluid is a measure of its protective capacity.

$P_c = \Sigma h_i / p_i$ (ΣS_L of the overburden layers).

where:

P_c= Protective capacity in mhos.

P_i = Resistivity of the overburden layer.

h_i = thickness of the overburden layer.

S_L = longitudinal conductance.

The rating of the Protective capacity of an aquifer was described by Fatoba *et.al*., (2014) as shown in Table 1 below.

Porosity and Formation factor

Archie's experiments revealed that the formation factor could be related to the porosity of an aquifer by the formula below.

$$F = a/\Phi m$$

Thus, $\Phi = [a/F]^{1/m}$

Senthil Kumar et al. (2001) relate the formation factor to the hydraulic conductivity by the formula below:

F = [k/a] 1/m

where:

F is the formation factor

K is the hydraulic conductivity (m/day)

Φ is the aquifer porosity

a = 0.62 (Tortousity factor for unconsolidated sands)

m = 2.15 (Cementation exponent)

DISCUSSION OF RESULTS

The data reveals generally three to four geo-electric layers, top layer with resistivity value of AB/2 = 1.2 m to 3 m ranging between 170 and 1322ohm-m. The middle layer has resistivity value of AB/2 = 2.2 m to 20 m ranging between 66 and 1890 ohm-m the third geo-electric layer has resistivity values ranging between 100 and 1800 ohm-m. The data for the twelve vertical electrical sounding (VES) are shown in Table 2. The curve types identified and the number of occurrence in parenthesis range from H (6), AH (4), HAH (2). Worthington (1977) show that field curves often reflect the character of the consecutive lithologic sequence in an area geo-electrically, and so can be used qualitatively to assess an area's groundwater potential. Five lithological layers were identified which are the Topsoil, lateritic zone, weathered basement, fairly weathered basement, and fresh basement (Fig. 3).

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 12 VES and are presented in Table 3, the resistivity estimations

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Table 1: Rating of Protective capacity (Fatoba, *et al*., 2014)

Protective capacity (mhos)	Rating
>10	Excellent
5 – 10	Very good
0.7 – 4.9	Good
0.2 – 0.69	Moderate
0.1 – 0.19	Weak
<0.1	Poor

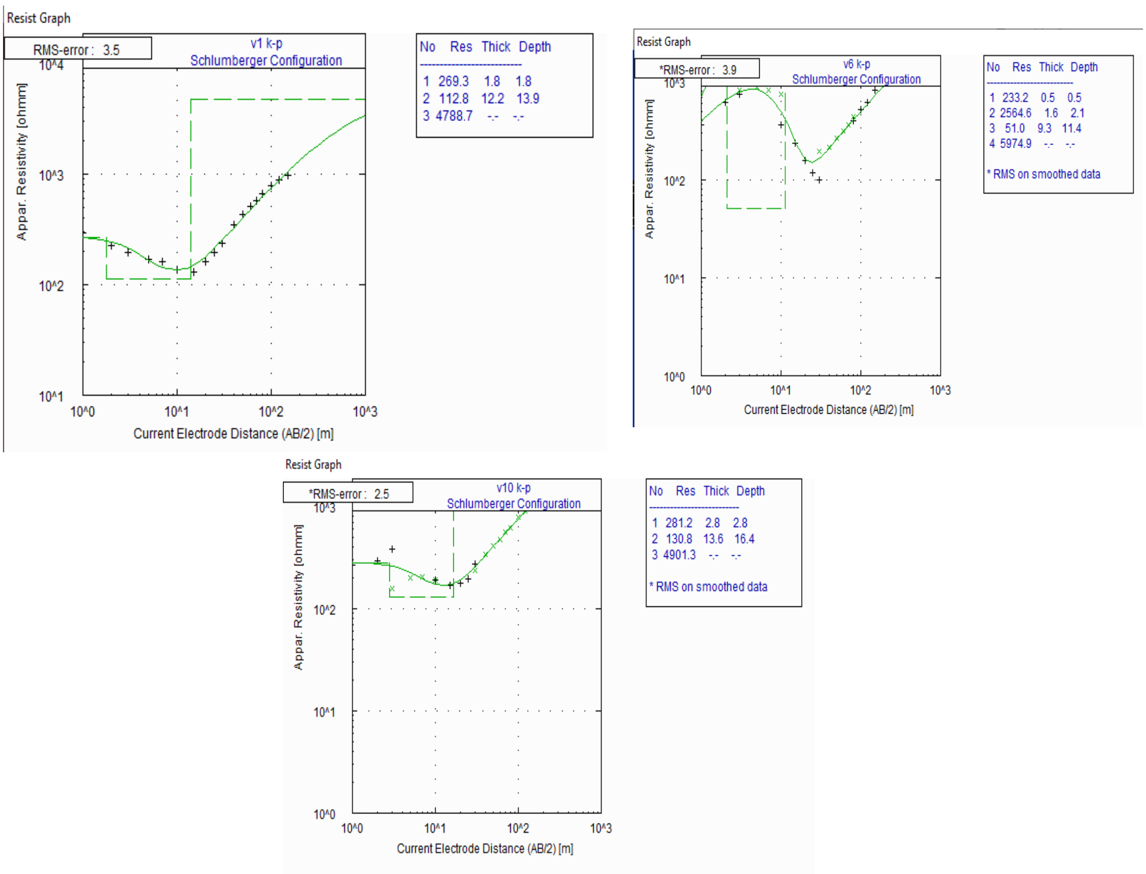

Fig 3; Sample of Resistivity graph

Table 2: VES locations and their geo-electrical parameters computed using Dar-Zarrouk parameters

Location	Layer thickness(m)	Layer resistivity (Ωm)	Aquifer conductivity (ohm)	Longitudinal conductance Ω	Transverse resistance Ωm^2	Hydraulic conductivity m/day	Transmissivity m^2/ day	Coefficient of Anisotropy	Rsistivity of formation	Porosity (%)
VES 1	9.6	172	0.0058	0.056	1651.2	17.916	172	1.01	2.55	2.5
VES 2	10.1	267	0.0037	0.038	2696.7	26.44	267	1.0	2.81	1.5
VES 3	11.2	220	0.0045	0.051	2464	19.64	219.9	1.3	3.37	2
VES 4	13.6	167	0.0059	0.081	2271.2	12.28	167.008	8.3	45	3
VES 5	20.4	66	0.015	0.309	1346.4	3.24	66.1	6.3	13.09	11.8
VES 6	61.6	100	0.01	0.616	6160	1.62	100	13.69	14.38	23.6
VES 7	10	100	0.01	0.1	1000	10	100	0.36	0.65	3.8
VES 8	20.8	81	0.012	0.26	1684.8	3.89	80.91	1.04	8.59	9.87
VES 9	12.2	101.1	0.009	0.121	1233.42	8.29	101.14	1	1.7	4.6
VES 10	9.6	245	0.004	0.0391	2352	25.52	245	1.15	2.99	1.5
VES 11	14.4	141	0.007	0.102	2630.4	9.79	140.976	1.12	1.90	3.93
VES 12	5	166	0.006	0.030	830	33.2	166	1.02	1.79	1.2

of the weathered and the slightly weathered layer which make up the water bearing formation of the study 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 in the area.

The values of longitudinal conductance estimated by Dar-Zarrouk equation shows the values in the study area having a minimum of $0.030\Omega^{-1}$ and maximum of $0.616\Omega^{-1}$, with average value of $0.1503\Omega^{-1}$. A spatial distribution map of longitudinal conductance presented in Figure 4 shows the southwestern part of the study area having a moderate value compared to the other part of the map which showed poor values taking up to 75% of the whole area. The values of transverse resistance from Dar-Zarrouk equation show the distribution of transverse resistance data with Minimum and maximum values of 830 and 6160 Ωm^2 respectively, with an average value of 2193.276 Ωm^2. A spatial map of transverse resistance is presented in Figure 5. The transverse resistance is also used to determined potential zones of groundwater (Cassiani & Medina, 1997). The values calculated of hydraulic conductivity estimated by Dar-Zarrouk parameter shows the distribution of the hydraulic conductivity values in the area with minimum and maximum hydraulic conductivity values as 1.62 and 33.2 m/day with an average value of 14.318m/day. Presented in Figure 6 is a spatial map of hydraulic conductivity in the study area. A spatial distribution of transmissivity map generated from Dar-Zarrouk equation of VES result is presented in Figure 7 with a range of transmissivity values of minimum and maximum of 66.1 and 267 m^2/day respectively.

I. Aquifer Protective Capacity:

When interpreting aquifer protective capacity; Greater than 10 is Excellent, 5 to 10 is Very Good, 0.2 to 4.9 is Moderate, 0.1 to 0.19 is Weak, Less than 0.1 Poor (Olusegun et al., 2016). The aquifer protective capacity was determined using the parameters of longitudinal conductance presented in Table 2 and the aquifer protective Capacity Rating presented in Table 1. The results showed that all the aquifers in VES 1, VES 2, VES 3, VES 4, VES 10 and VES 12 showed poor aquifer protective capacity having longitudinal conductance values ranging from 0.030 to 0.081. VES 7, VES 9 and VES 11 showed weak aquifer protective capacity while VES 5, VES 6 and VES 8 showed moderate aquifer protective with values ranging from 0.26 to 0.616. Longitudinal conductance map presented in Figure 4 also gives more details about the aquifer protective capacity as they are codependent .Usually, groundwater is protected by sufficient protective layers. Groundwater is given adequate protection if silt and clay are found as thick layers above the aquifer.

II. Low values of the coefficient of anisotropy (λ) may be indicating high density water – filled aquifer usually determined for a basement complex. Its determination in this work was to see if it can also provide insight into groundwater potential in the study area. In this work, the values of coefficient of anisotropy

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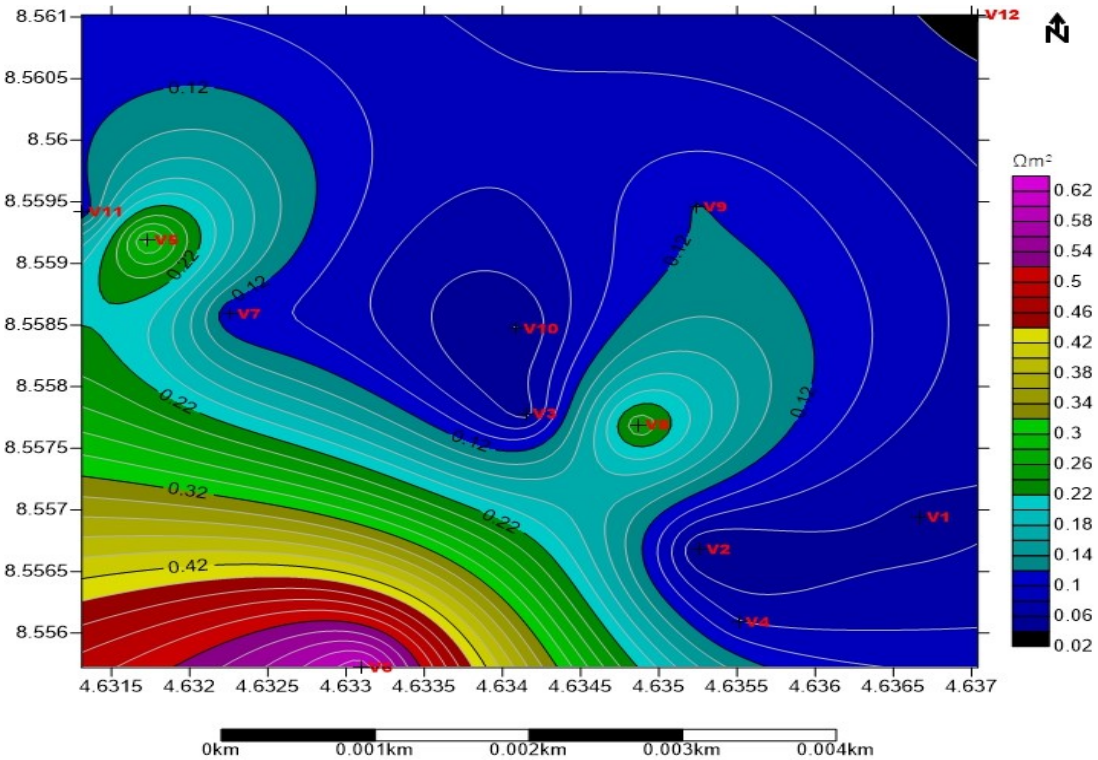

Fig 4. Longitudinal conductance distribution map over the study area

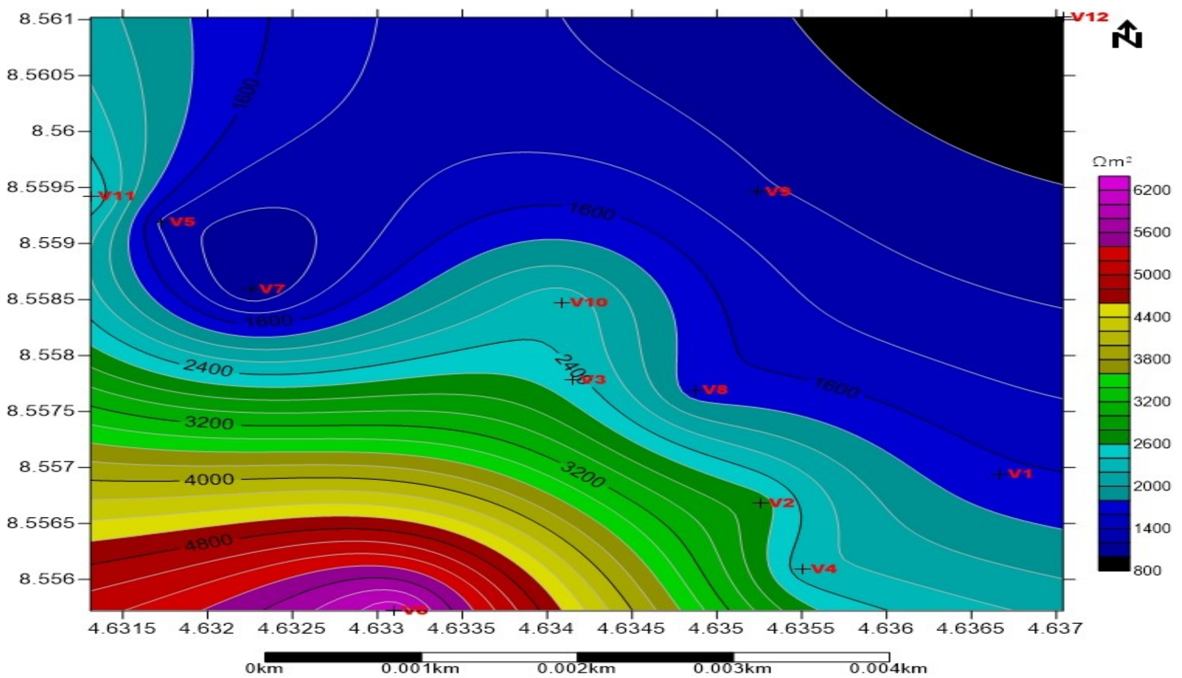

Fig 5. Transverse resistance over the study area

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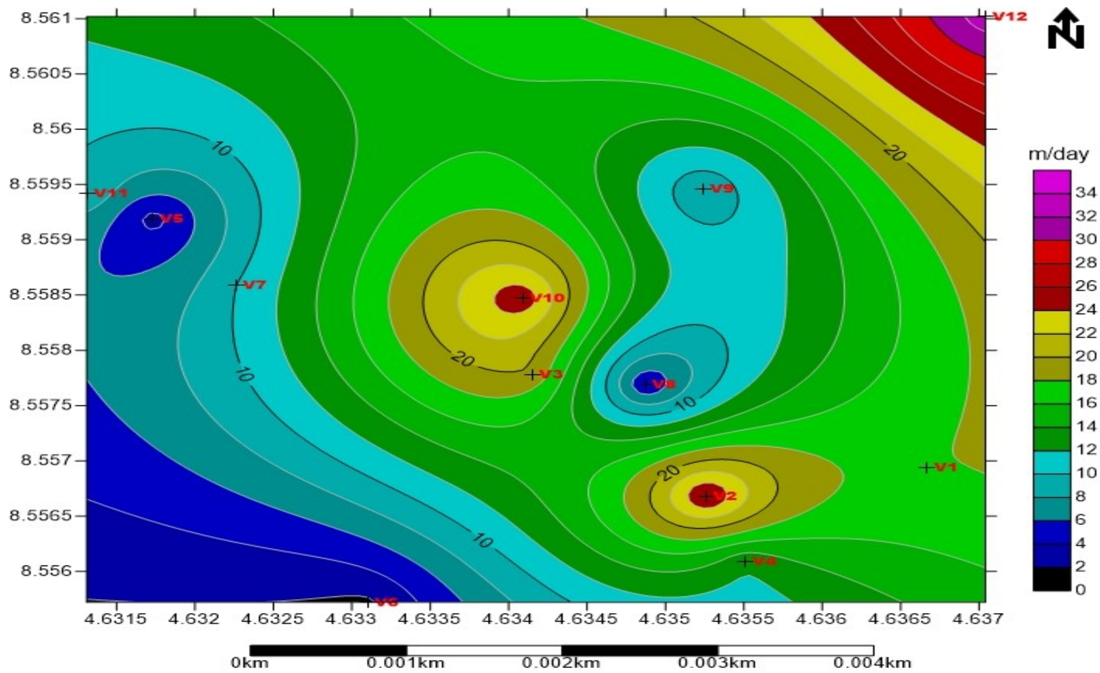

Fig 6. Spatial distribution of hydraulic conductivity over the study area

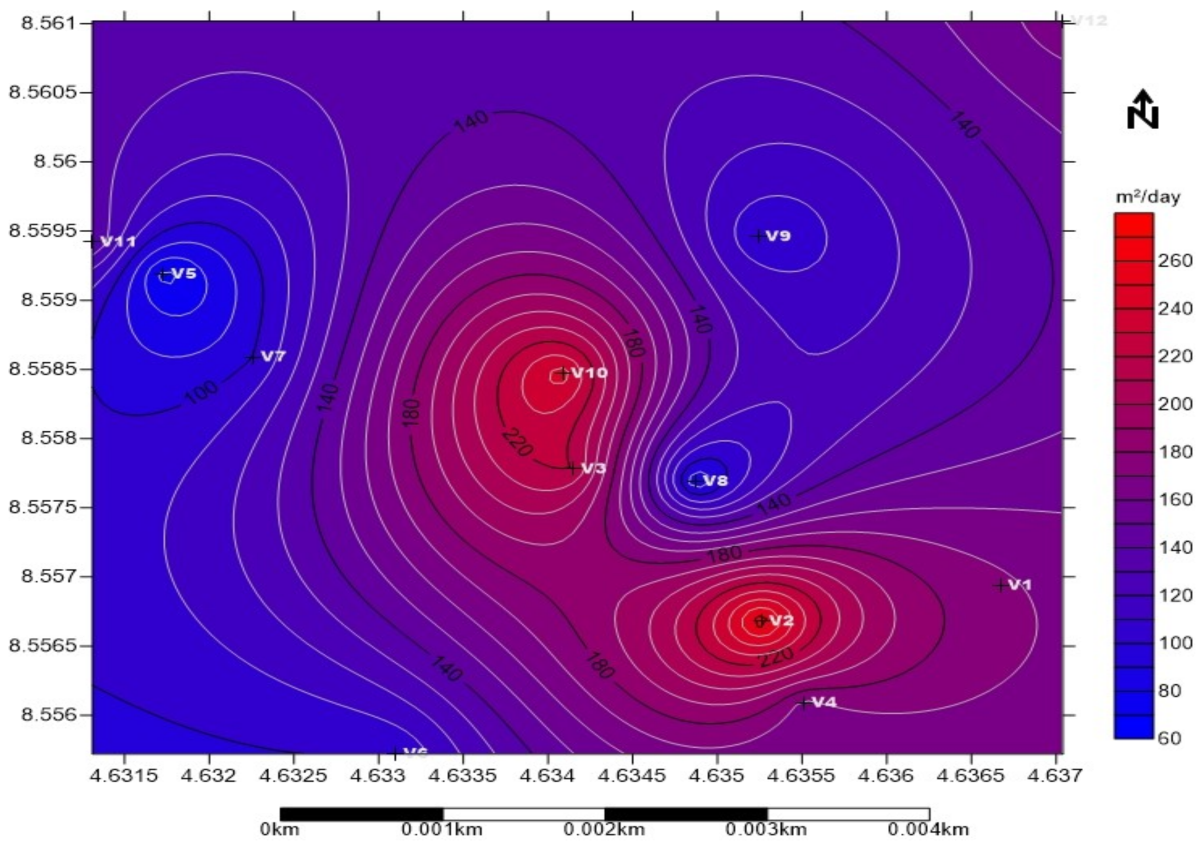

Fig 7. Transmissivity over the study area

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III. In hydrogeological studies, transverse resistance has been discovered to function analogous to transmissivity (Singh & Singh, 2016). Transverse resistance values in this study area revealed low to moderate data values ranging from 830 (VES 12) to 6160 (VES 6).

IV. Hydraulic conductivity provides an indication of the effortless flow of water in the subsurface (Ezema et al., 2020); a higher value represents the ease with which that happens. High permeability will be observed in aquifer zones with high hydraulic conductivity (Niwas & Singhal, 1985). From the spatial map, Hydraulic conductivity is high throughout the whole study area while low value is seen in the pocket located in the southwestern part of the study area showing VES 6 and is also is seen at VES 8 and VES 5.

V. Transmissivity values in the study area revealed moderate to high groundwater potential based on data reported by (Kransy, 1993.). Logically, high transmissivity values imply high groundwater potentials and this study area correspond to high hydraulic conductive zones.

Zones of groundwater potential in the study area

The values of the transmissivity over the 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 range of transmissivity values is 66.1 – 267m^2/day. According to the numerical boundary classification for transmissivity proposed by Kransy (1993) in Table 3, high transmissivity values equate to high groundwater potential. The majority of the study area falls under the high transmissivity range while VES 5 and VES 8 fall under the intermediate transmissivity range; thus, the aquifer of the area can yield sufficient water for the polytechnic community, though from interpretation of the direct electrical resistivity data on the bi-log graph, VES 1, 5, 6, 7 and 11 shows more evidently good aquifer properties including thick overburden layers making both the practical and theoretical analysis and survey done in this area in concordance with each other.

The Dar-Zarroukk parameter, hydraulic characteristics of the aquifer was calculated and shows that the aquifer has porosity ranges from 1.2% - 23.6%. According to the numerical boundary for porosity of consolidated material, it is noticed that the values from VES 1,2,3,4,7,8,9,10,11,12 falls under the fractured intrusive igneous and metamorphic rocks and from the geology of the area, the predominant rock type in the area is granite gneiss and migmatite. Further probing should be done in these areas. VES 5 and 6 shows an uncomformity of permeable basalt as the numerical boundary

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Table 4: Standard for Transmissivity Classification (Kransy 1993)

T (m/day)	Designation	Groundwater supply potential
>1000	Very high	Withdrawal of great regional importance
100 – 1000	High	Withdrawal of lesser regional importance
10 – 100	Intermediate	Withdrawal from local water supply (small community)
1 – 10	Low	Local water supply. For private uses.
0.1 – 1.0	Very low	Withdrawal for local water supply with limited use.
<0.1	Impermeable	Water withdrawal is difficult

falls within 10-25 %. The Da-Zarroukk parameters, the VES validates the results gotten from the porosity calculations.

GEO-ELECTRIC DATA INTERPRETATION OF PROFILES

Geo-electric method was used in delineating groundwater potential of kwara state polytechnic and the interpreted results of the 12 VES data points revealed 3 to 4 lithological layers (Topsoil, lateritic zones, fairly weathered zone, weathered basement and fresh basement), with depth to basement ranging from 6 to 62 and 3 profiles are seen. The results and interpretation of this research work has been compared and therefore shows correspondence of the electrical resistivity in estimating ground water potential of the study area.

The geo-electric sections in Figs 8a-c reveal the variations of resistivity and thickness values of layers within the depth penetrated. The profiles were taken along the SE and NW directions. Generally, the profiles revealed the lithology as it changes with depth as it progresses towards the fresh basement.

In profile 1(Figure. 8**a**), the thickness of the topsoil varies from 1.2-3 m with variable resistivity. The thickness of the weathered basement varies from 2.4-20.4 m with resistivity values ranging from 66Ωm to 100Ωm. Fresh basement with a resistivity value of 810 – 1520Ωm and depth to basement values ranging from 8.7-11.1 m while overburden thickness has values varying from

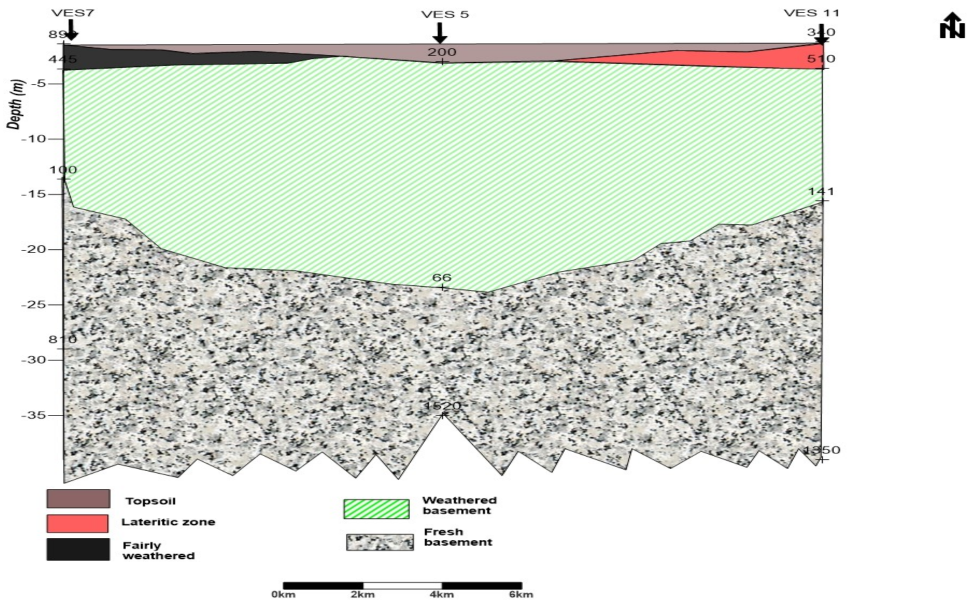

Figure 8(a) Geo-electric section of profile 1

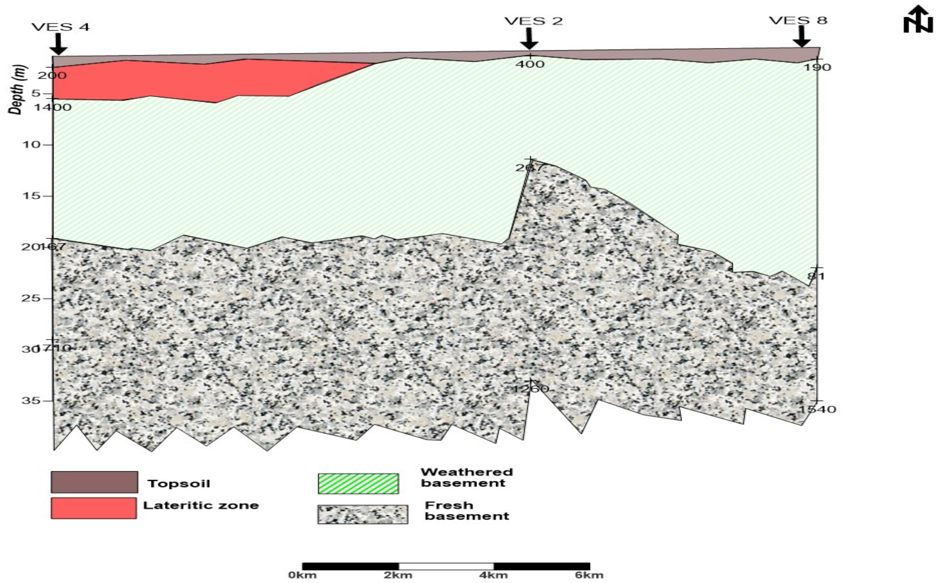

Figure 8(b) Geo-electric section of profile 2

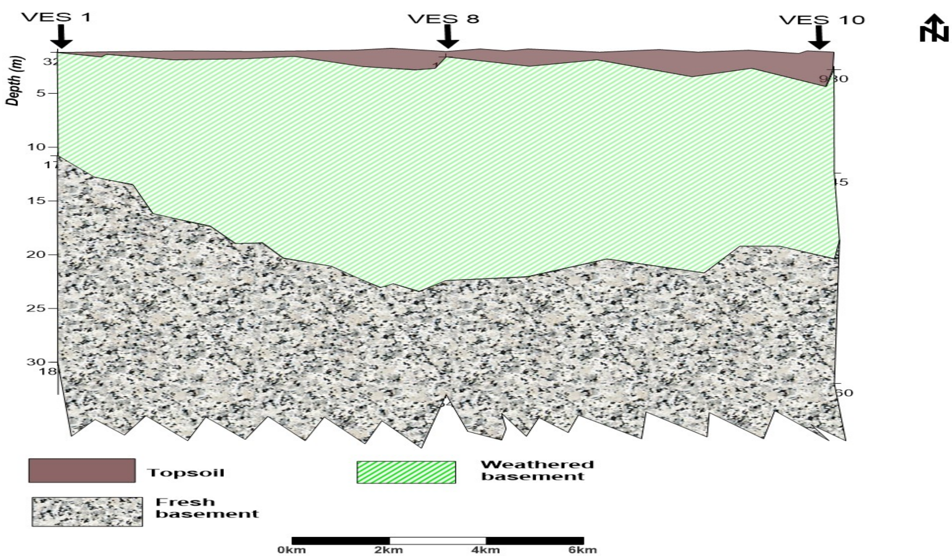

Figure 8(b) Geo-electric section of profile 2

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from 14-24 m.

In profile 2 (**Fig. 8b**), the thickness of the topsoil ranges from 1.3-2.4 m with variable resistivity values. The thickness of the weathered basement ranges between 10.1-20.4 m with resistivity values ranging from 81-267 Ωm. The fresh basement is ≥ 9 with a resistivity value 1260 – 1710 Ωm while overburden thickness has values varying from 20-23 m.

Profile 3(Fig. 8c), running through VES 1,8 and 10, shows the following geo-electric units: topsoil, weathered basement, fairly weathered and fresh basement. The thickness of the topsoil and weathered basement ranges from 1.2-2 m, 9.6-20.8 m. Depth to basement values between 9.3-116.4 m with a resistivity value between 1260 - 1800 Ωm. Overburden thickness value ranges from 11-23 m.

Conclusion

This study aim to determine the hydraulic properties of the water-bearing layer using parameters derived from the Dar-Zarrouk equation and characterize them into groundwater potential zones.. The Dar-Zarrouk parameters calculated in correlation with geo-electric section revealed the following lithology namely topsoil, lateritic zones and fairly weathered basement. The study shows the area around profile 2 having the most groundwater potential with an overburden thickness ranging from 20 to 23 m and thickness of weathered basement ranging from 10.1 to 20.4 m with resistivity values ranging from 81-267 Ωm and transmissivity value ranging from 81 to 267 m^2/day. The aquifer protective capacity values calculated revealed poor to moderate zone as observed in the study area, with VES 12 having the lowest value of aquifer conductivity of 0.030 per Ωm and VES 6 with the highest value of aquifer conductivity of 0.616 per Ωm and it is located at the northeastern and southwestern part of the study area. The study suggests that VES 5, 6 and 8 in this study area is very viable for groundwater exploration and exploitation having high porosity value, high transmissivity value, and overburden thickness of 62 m.

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