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Aquifer Protective Capacity, Soil Corrosivity and Groundwater Potential Evaluation using Electrical Resistivity Method at Kwata-Zawan Area, Jos, Northcentral Nigeria

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ABSTRACT

Geophysical investigation involving electrical resistivity method was carried out to investigate the groundwater potential in Kwata-Zawan area, Jos, North central, Nigeria. Twenty (20) Vertical Electrical Sounding (VES) stations were occupied using Schlumberger configuration with current electrode separation (AB) varying from 1.5 to 125 m. The VES data was iteratively inverted using WINRESIST version 1.0 software to produce resistivity sounding curves.The qualitative interpretation of the curves showed HK, HA, KH, AA,AKQ, QH, HHK, HKQ, AAK, H, KHK, AK, AKH, K, and A type curves. Kwata-Zawan area showed three (3) to five (5) geo-electric layers; top-soil, laterite, clay, fracture/weathered basement and fresh basement. From the longitudinal conductance values, the aquifer protective capacity rating from poor to moderate, implying that the ground water of the study area is susceptible to surface contaminants. Soil corrosivity results reveals that soils with practically non-corrosive, slightly corrosive and moderately corrosive tendencies occupy top soil of the study area; with soils that are practically non-corrosive occupying greater part. The groundwater potential of Kwata-Zawan area is characterized as poor, low and good aquifer potential zones. The good groundwater potential rating is found at VESs 4, 6, 15, 16, 17, 19 and 20.

1. INTRODUCTION

Water is essential for the survival of living organisms. Groundwater occurs in the pores spaces of rocks and fractures within the basement rocks [1]. The groundwater availability is an environment is controlled by joints, faults and hydrogeological factors [2] [3]. The evaluation of groundwater resources and geoelectric properties using electrical resistivity method at BarakinRafin Gora area, Jos-Plateau, was carried out by [4] and [5] used the electrical resistivity method for the investigation of the axis of a small Earth Dam inAngwarearea of Jos Nigeria. An investigation of groundwater condition by geoelectric resistivity method with a case study in Korin aquifer, Southeast Iran was carried out by [6] while [7] mapped the Quaternary deposits in the El-Jufr playa (Southwestern Jordan plateau) using geoelectrical techniques with implications for geology and hydrogeology.

The geoelectric assessment of groundwater prospect a vulnerability of overburden aquifers at Idanre, southwestern Nigeria was reported by [8] and geoelectrical exploration for groundwater in crystalline basement rocks of Fobur and its environs in Jos-Plateau northcentral Nigeria was reported by [9]. The geoelectric sounding for groundwater exploration in the crystalline basement terrain around Onipe and adjoining areas, southwestern Nigeria was carried out by [10]. The resistivity method for groundwater prospecting with acase study of Army engineers quarters Zaria Road, Jos Nigeria was reported by [11] and hydrogeophysical investigation for groundwater development at Gbongudu area, Akobo Ojurin, Ibadan, southwestern Nigeria was reported by [12].

The appraisal of aquifer protective capacity and soil corrosivity using electrical resistivity method in Miango area, Jos, Plateau State, Nigeria [13] while [14] carried out hydrogeophysical investigation of groundwater potential in Emu kingdom, Ndokwa land of Delta State, Nigeria. The resistivity method for groundwater prospecting with a case study of EMI Block Industry Rafin Seyin Suleja, Niger State, Nigeria was reported by [15] and the 2-D electrical resistivity survey and heavy metal determination of water samples as

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indicators for groundwater Pollution at a waste dumpsite in Rock Haven area of Jos Nigeria [16] while [17] reported on soil and groundwater Contamination at an active mine Site in Kwang Rayfield Jos Nigeria using electrical resistivity and heavy metal analysis**.**

The population of Kwata-Zawan, Jos South has increased tremendously in the last two decades as Jos the capital of Plateau states expands. The increase in population of Kwata-Zawan area has also led to portable water demand for different purposes. Also, Kwata-Zawan area has experienced portable water scarcity as reflected in low yield boreholes and hand dug wells, which decreases domestic, agricultural and industrial activities in the area. Hence there was the need to determine ground water potential zones which can be assessed for portable ground water in the community. This research focuses on evaluation of Aquifer Protective Capacity, Soil Corrosivity and Groundwater Potential using Vertical Electric Sounding procedure with Schlumberger array.

1.1. Location and Geology of the Study area

The study area is located at Kwata-Zawan area, Jos-Plateau, North Central Nigeria and covers longitude 8°49' 26"- 8°50' 17" E and latitude 9°45' 0"- 9° 45' 58" N. The area can be accessed through Zawan road and the location map of Kwata-Zawan area is shown in Figure 1. Geologically, the main rock types within the study area were observed to be the Jurassic Younger Granites [18]-[21]. The Jurassic Younger Granite Complexes which intruded the Crystalline Basement Rocks comprises Ngell biotite granite, Sabon Gida south biotite granite and biotite micro granite (Figure 2).

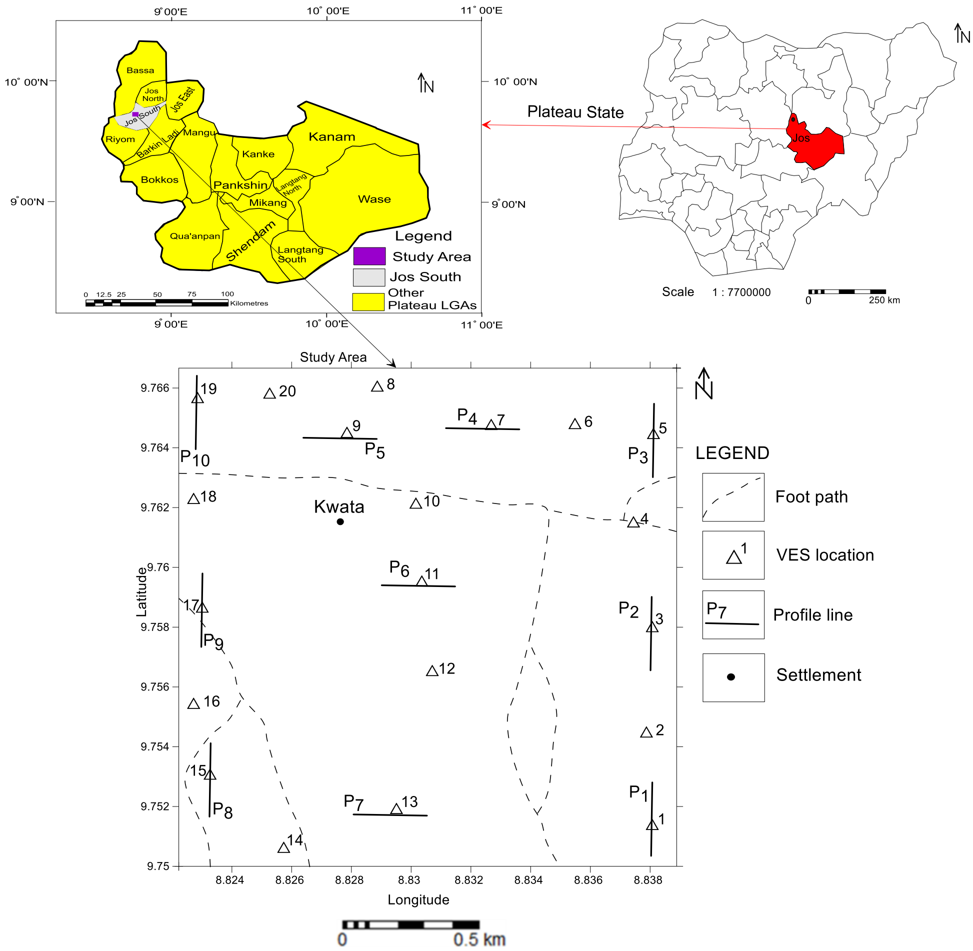

Fig. 1. Location map of the study area showing profile lines and VES points

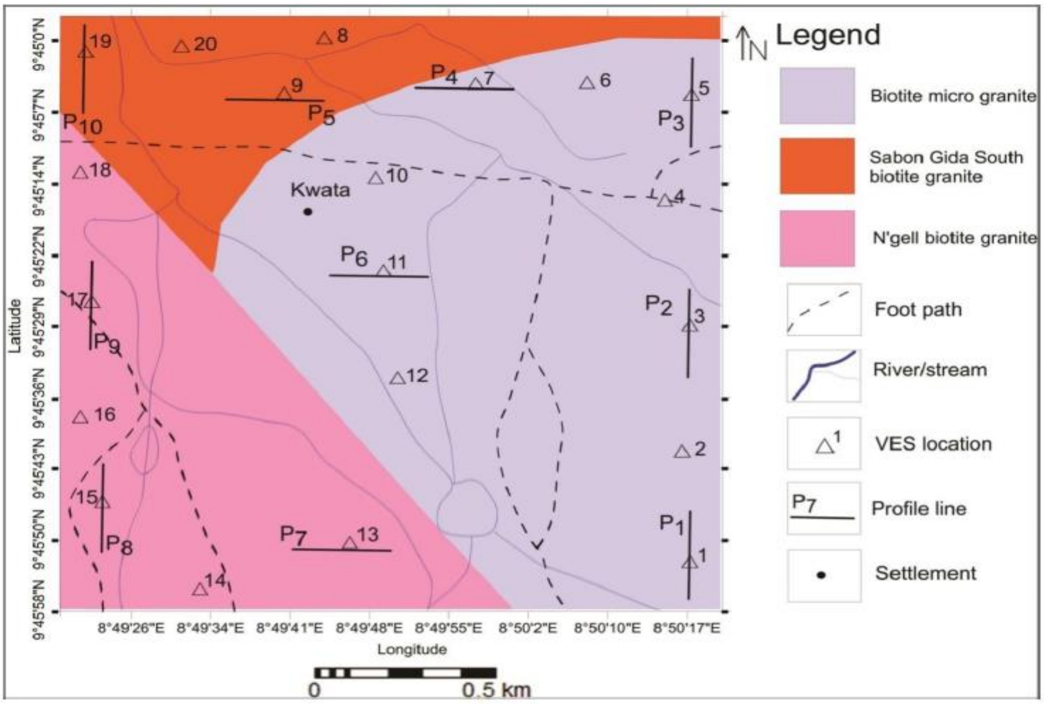

Fig. 2. Geological Map of Kwata-Zawan area

2. MATERIALS AND METHODS

For this study, Schlumberger electrode configuration was adopted and vertical electrical sounding (VES) technique was employed for data acquisition. All the four electrodes were arranged collinearly, while the distance between the inner electrodes was kept constant, the distance between the outer electrodes were varied for each measurement. Omega resistivity meter was used to acquire the VES data with half electrode spacing (AB/2) ranging between 1 and 125 m.

The data obtained on the field was resistance which was converted to apparent resistivity by using the appropriate geometric factor for twenty (20) VES locations. The VES survey data was iteratively inverted IX1D using WINRESIST version 1.0 software to produce resistivity sounding curves.

The apparent resistivity was computed using the equation:

$$\rho a = \pi\left(\frac{a^2}{b} - \frac{b}{4}\right)\frac{\Delta V}{I} \quad (1)$$

Where ρa is apparent resistivity,

$G = \pi\left(\frac{a^2}{b} - \frac{b}{4}\right)$ is geometrical factor, and

$\frac{\Delta V}{I}$ = R is the resistance

The apparent resistivity values gotten from equation (1) were plotted on log-log graph against the half current electrode separation spacing (AB/2). From these plots, qualitative deductions, such as the resistivity, thickness and depth of each layer were made with the curve types gotten from the primary electrical parameters. The resistivities and thicknesses of the various layers were enhanced by employing an automatic iterative computer program following the main concepts of [22].

The WINRESIST computer software was employed for carrying out the iteration and inversion processes. The root mean square (RMS) error of lower than 5% was obtained through the iteration process conducted for each sounding station in order to get a goodness of fit for the Computer-generated curves with the corresponding field curves data.

The Dar-Zarrouk parameters (Table 2) were obtained from the first order geoelectric parameters (layer resistivities and thicknesses) and these include the Total longitudinal unit conductance (**S**), Total transverse unit resistance (**T**) and coefficient of anisotropy (**λ**). These secondary geoelectric parameters are mainly significant when they are used to define a geoelectric section comprising of numerous layers [23].

For 'n' layers, the total longitudinal unit conductance is:

$$\mathbf{S} = \sum_{i=1}^{n}\left(\frac{hi}{\rho i}\right) \quad (2)$$

$$\mathbf{T} = \sum_{i=1}^{n} \rho i hi \quad (3)$$

$$\lambda = \left(\frac{\rho T}{\rho L}\right)^{\frac{1}{2}} \quad (4)$$

where ***hi*** is the layer thickness, ***Pi*** is layer resistivity while the number of layers from the surface to the top of aquifer, (*i*) varies from 1 to n.

Electrical anisotropy is a measure of the degree of in homogeneity in a basement terrain; which increases the near surface effects, variable degree of weathering and structural features such as faults, fractures, joints, foliations and beddings [24] [25]. These in turn are responsible for producing secondary porosity (Φs) and hence effective porosity (Φe).

3. Results and Discussions

The qualitative interpretation of curve types carried out for the twenty (20) VES points is presented in Table 1. Fifteen resistivity sounding curves types were obtained namely HK, HA, KH, AA, AKQ, QH, HHK, HKQ, AAK, H, KHK, AK, AKH, K, and A type curves (Table 1). The sounding curve for VES 1 is shown in Figure 3 while Figure 4 shows the sounding curve for VES 2. Bar chat representation of the qualitative analysis is shown in Figure 5 with HK, HA, HKQ, H, and AK curve types being the most dominant.

Quantitative VES interpretation involves curve matching and computer iteration using computer program WINRES32IST version 1.0. The result of quantitative interpretation is presented in Table 2 with the values of resistivity, thickness, depth, Thickness of Overburden, Longitudinal Conductance, Transverse Resistance and Electrical Anisotropy/Coefficient of Anisotropy.

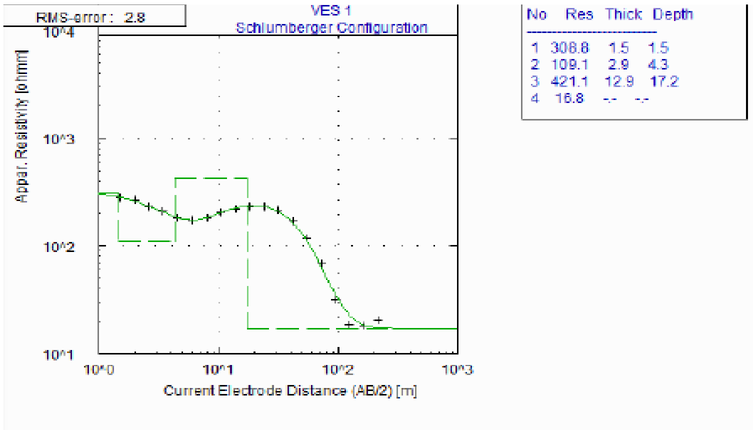

Fig. 3. Resistivity sounding curve for VES 1

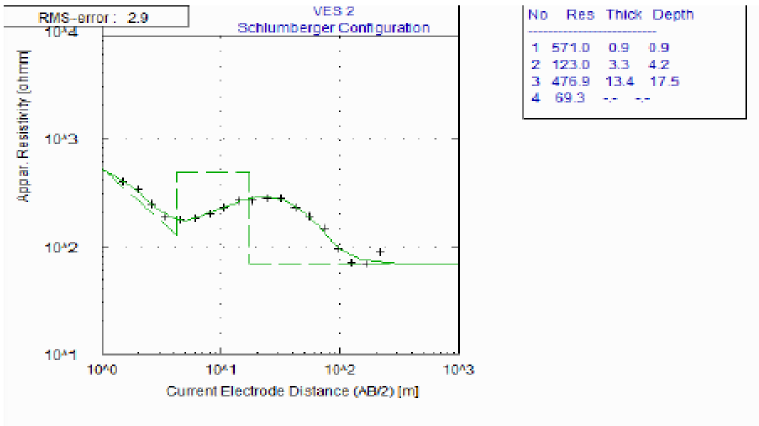

Fig. 4. Resistivity sounding curve for VES 2

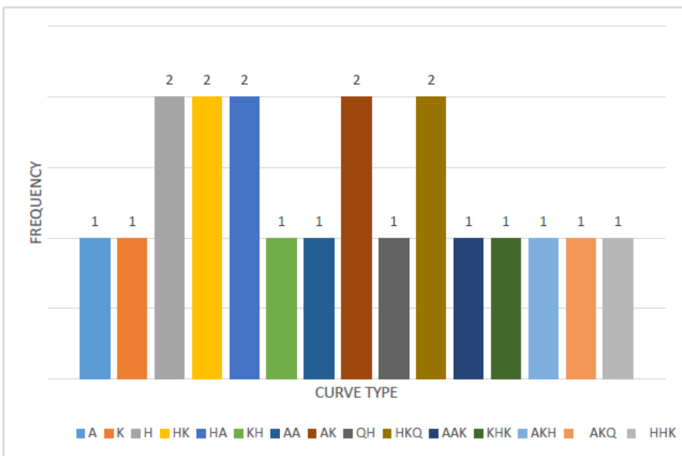

Fig. 5. Curve Types in Kwata-Zawan area

Table 1. Qualitative VES Curve interpretation

S/N	Curve type	Frequency	Layers Resistivity relationship	Number of geoelectric layers
1	A	1	ρ1<ρ2<ρ3	3
2	K	1	ρ<ρ2>ρ3	3
3	H	2	ρ1>ρ2<ρ3	3
4	HK	2	ρ1>ρ2<ρ3>ρ4	4
5	HA	2	ρ1>ρ2<ρ3<ρ4	4
6	KH	1	ρ1<ρ2>ρ3<ρ4	4
7	AA	1	ρ1<ρ2<ρ3<ρ4	4
8	AK	2	ρ1<ρ2<ρ3>ρ4	4
9	QH	1	ρ1>ρ2>ρ3<ρ4	4
10	HKQ	2	ρ1>ρ2<ρ3>ρ4>ρ5	5
11	AAK	1	ρ1<ρ2<ρ3<ρ4>ρ5	5
12	KHK	1	ρ1<ρ2>ρ3<ρ4>ρ5	5
13	AKH	1	ρ1<ρ2<ρ3>ρ4<ρ5	5
14	AKQ	1	$\rho_{2<}\rho_2 < \rho_3 > \rho_4 > \rho_5$	5
15	HHK	1	$\rho_{2>}\rho_2 < \rho_3 < \rho_4 > \rho_5$	5
	Total	20		

Table 2. Quantitative VES Curve Interpretation (Summary of Geo-electric Parameters

	Resistivity (Ohm-m)					**Thickness (m)**				**Depth (m)**				**OBT**	**S (mhos)**	**T (Ωm²)**	**λ**
VES	***ρ1***	***ρ2***	***ρ3***	***ρ4***	***ρ5***	***h1***	***h2***	***h3***	***h4***	***d1***	***d2***	***d3***	***d4***				
1	308.8	109.1	421.1	16.8	-	1.5	2.9	12.9	-	1.5	4.3	17.2	-	17.2	0.062073	6211.78	1.135
2	571.0	123.0	476.9	69.3	-	0.9	3.3	13.4	-	0.9	4.2	17.5	-	17.5	0.056504	7310.26	1.155
3	667.3	249.5	1035.8	1491.2	-	2.5	6.9	13.9	-	2.5	9.5	23.4	-	23.4	0.044821	17787.42	1.212
4	404.4	954.3	574.2	2767.7	-	1.6	2.8	24.1	-	1.6	4.3	28.4	-	28.4	0.048862	17157.30	1.016
5	622.3	590.1	695.6	772.3	-	1.5	4.4	13.4	-	1.5	5.9	19.3	-	19.3	0.029131	12850.93	1.003
6	209.8	298.2	774.4	968.5	-	1.3	1.7	28.6	-	1.3	3.0	31.6	-	31.6	0.048829	22927.52	1.059
7	81.9	498.8	3650.1	1894.1	127.0	0.9	1.0	8.3	13.8	0.9	1.9	10.2	23.9	23.9	0.022500	30868.38	1.099
8	417.9	346.4	149.9	1132.1	-	1.2	2.5	13.8	-	1.2	3.7	17.5		17.5	0.102150	3436.10	1.071
9	554.0	139.2	318.6	470.3	62.9	1.2	1.8	4.7	13.9	1.2	3.0	7.7	21.5	21.5	0.059400	2412.78	0.554
10	209.6	193.4	219.5	195.4	4.6	0.9	1.2	4.7	16.7	0.9	2.1	6.7	23.4	23.4	0.117300	1452.37	0.556
11	27.4	254.6	1448.3	5856.7	186.5	0.7	0.7	2.1	17.6	0.7	1.4	3.5	21.2	21.2	0.032700	3238.83	0.488
12	557.6	364.0	1552.8	-	-	2.4	13.6	-	-	2.4	16.0	-	-	16.0	0.041667	6288.64	1.012
13	471.3	254.2	239.2	433.3	303.3	1.2	1.5	8.1	14.1	1.2	2.7	10.8	24.8	24.8	0.074851	2884.38	0.590
14	666.0	592.4	659.6	-	-	2.0	12.0	-	-	2.0	14.0	-	-	14.0	0.023260	8440.80	1.001
15	212.8	326.2	3125.1	927.8	-	1.9	2.9	17.6	-	1.9	4.9	22.5	-	22.5	0.023451	56352.06	1.623
16	293.2	543.3	616.2	225.2	-	1.2	2.5	45.7	-	1.2	3.7	49.4	-	49.4	0.082859	29870.43	1.007
17	344.7	583.7	710.4	597.9	2488.3	1.1	1.5	5.6	19.0	1.1	2.7	8.3	27.4	27.4	0.075496	2239.25	0.478
18	112.3	1276.1	277.5	-	-	1.4	19.4	-	-	1.4	20.8	-	-	20.8	0.027669	24913.56	1.262
19	41.0	53.8	1687.7	-	-	0.9	27.0	-	-	0.9	27.9	-	-	27.9	0.523810	1489.50	1.001
20	529.0	194.0	507.4	271.2	22.0	1.0	3.1	14.2	20.2	1.0	4.1	18.3	38.5	38.5	0.120339	8335.48	0.823

OBT**:** Overburden Thickness (m);**S**.: Longitudinal Conductance**; T:** Transverse Resistance; **λ**: Electrical Anisotropy/Coefficient of Anisotropy.

3.1. Subsurface Geo-Electric Layers

The geoelectric sections are shown in Figures 6, 7 and 8. The Profile A-A' geo-electric section is shown in Figure 6 with five (5) geologic layers. The topsoil has resistivity values of 41 to 666 Ω-m and thickness of 0.9 to 2 m. The second layer consists of laterite having resistivity of 1276.1 Ω-m and thickness of 1.5 to 20.0 m. The third layer consists of clayey soil with resistivity of 53.8 Ω-m and depth of 1.5 to 27.0 m The fourth layer weathered basement with resistivity of 277.5 to 3125.1 Ω-m and thickness of 5.6 to 45.7 m. The fifth layer is fresh basement having resistivity 225.2 to 927.8 Ω-m and thickness of 19 to 20.2 m.

The Profile B-B' geo-electric section is shown in Figure 7 with three (3) distinct geoelectric layers. The topsoil resistivity ranges from 27.4 to 557.6 Ωm with thickness of 0.7 to 2.4 m. The second layer has weathered basement at all the VES points with resistivity of 139.2 to 364 Ω-m and thickness of 0.7 to 13.6m. The fresh basement has resistivity values of 149.9 to 1552.8 Ω-m and thickness of 2.1 to 13.8 m.The Profile C-C' geo-electric section is shown in Figure 8 with four (4) geoelectric layers namely: topsoil layer with resistivity of 81.9 - 667.3 Ω-m and thickness of 0.9 - 2.5 m. The second layer is laterite with resistivity of 109.1 to 954.3 Ω-m and thickness of 1.0 to 6.9 m. Weathered basement is the third layer with resistivity of 95.1 to 4030.5 Ω-m and thickness of 11.5 to 26 m. The fourth is fresh basement with resistivity ranging from 536.5 to 2670.0 Ω-m having an infinite thickness.

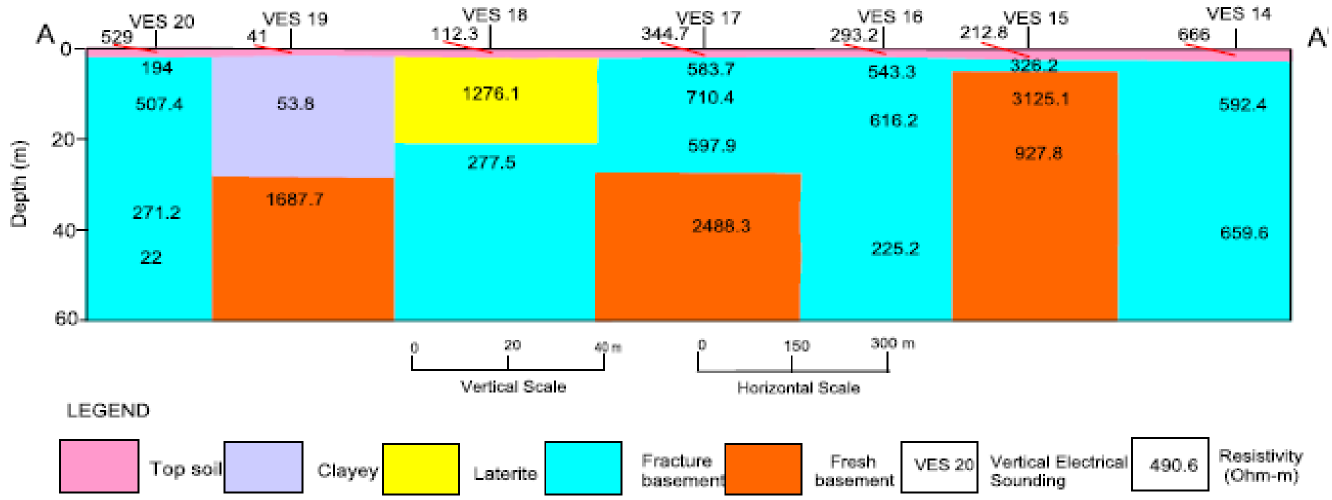

Fig. 6. Geo-electric section along A-A' Profile

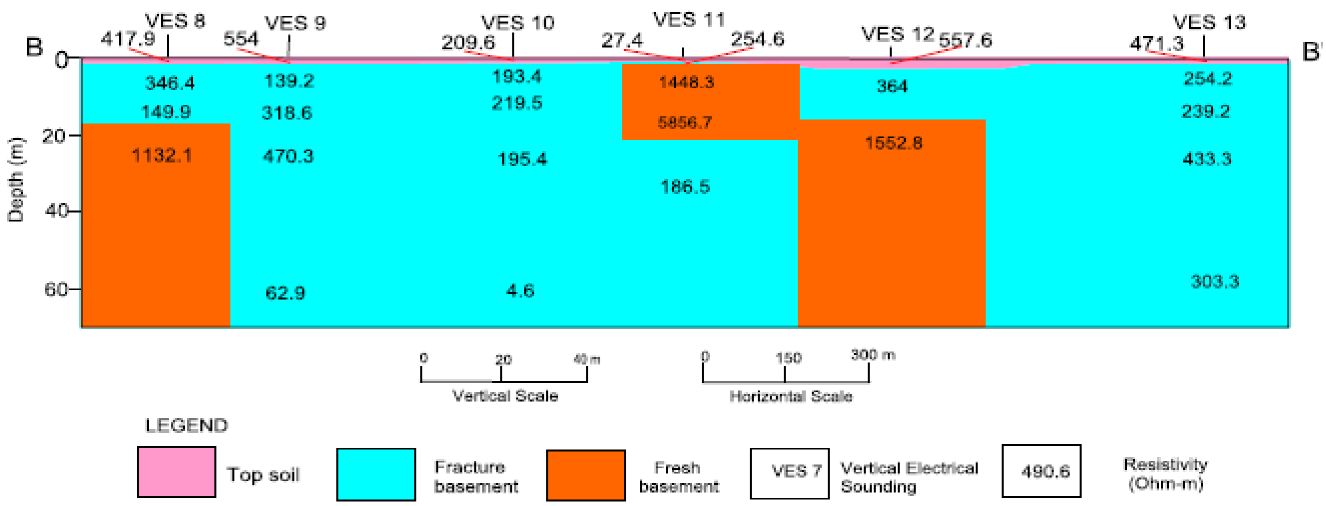

Fig. 7. Geo-electric section along B-B' Profile

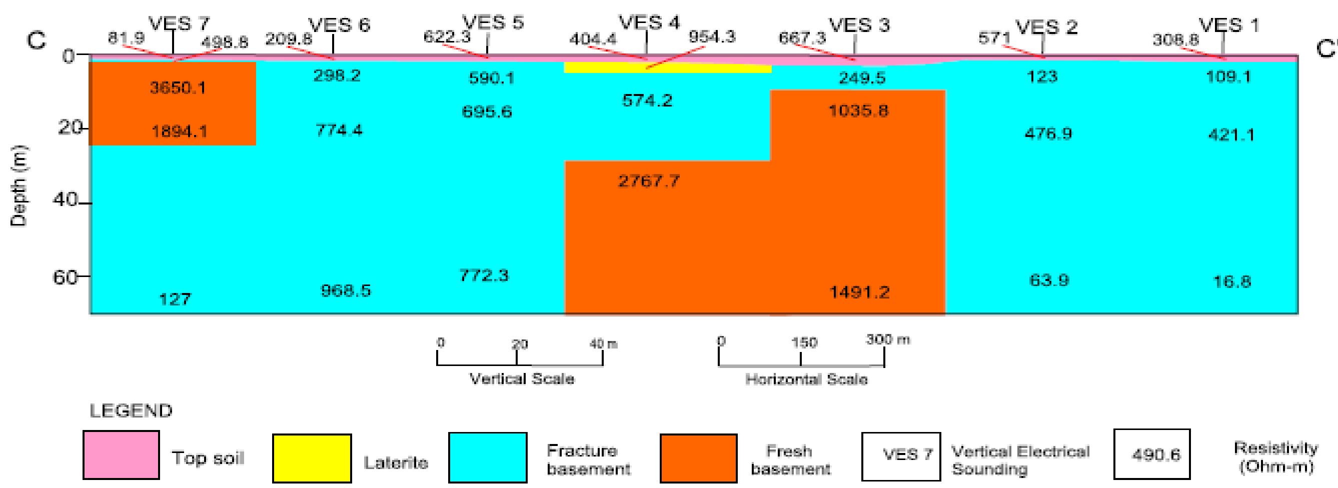

Fig. 8. Geo-electric section along C-C' Profile

3.2. Total Transverse Resistance

The total transverse resistance obtained from Equation 3 [26] is shown in Figure 9 for all VES locations and ranges from 1452.37 to 56352.06 Ωm^2. According to Freeze and Cherry (1979, it can be classified as poor with transverse resistance value of <400 Ωm^2(negligible transmissivity); weak with transverse resistance value of 400 to 1000 Ωm^2 (weak transmissivity); moderate with transverse resistance value of 1000 to 2000 Ωm^2 (moderate transmissivity) and very good with transverse resistance value of >2000 Ωm^2 (good aquifer transmissivity). In Figure 9, approximately 90% of Kwata-Zawan area has good aquifer transmissivity and is shown by green, cyan, purple and orange colour zones. Figure 9 also shows that approximately 10% of Kwata-Zawan area has moderate aquifer transmissivity as shown by yellow colour.

3.3 Total Longitudinal Conductance

The characteristic longitudinal conductance map is shown in Figure 10 while Table 2 shows the longitudinal conductance for the various VES locations across Kwata-Zawan area with value of 0.0225 to 0.52381mhos. The clay overburden is highly impervious and protects the underlying aquifer with the extreme northwestern flank has weak to moderate protective capacity, this covers about 15% of Kwata-Zawan area. About 85 % of the overburden materials have poor protective capacity rating. This suggests that the study area is largely underlain by overburden of poor protective capacity and indicates zones susceptible to surface contaminants

3.4 Soil Corrosivity

A corrosive material is that which has the quality of eating away or consuming another material. After drilling a borehole, pipes are laid in soils and connected to buildings, hence, it becomes mandatory before laying of pipes to evaluate soil corrosivity. To assess the corrosivity level in soils, top soil resistivity values (Table 2) have been used as the mean thickness of the top soil (1.365m) falls within the average limiting depths of burial of pipes usually taken to be 2m [27]. The soils in some part of southwestern Nigerian have been reported to contain some metallic minerals preserved from mineralogical compositions of the granitic protoliths [28]-[31]

The classification of soil corrosivity in Kwata-Zawan area is shown in Figure 11 and was done according to [32] [33], and the classification is presented in Table 3. The resistivity value of >180 Ωm indicates noncorrosive soil at VES 1, 2, 3, 4, 5, 6, 8, 9, 10, 12, 13, 14, 15, 16, 17 and 20; resistivity value of 60 to 180Ωm indicates that the soil is slightly corrosive at VES 7 and 18 while values of 10 to 60 Ωm show moderately corrosive soil at VES 11 and 19. This indicates that very strongly corrosive soil was not identified in Kwata-Zawan area. Therefore, soils with practically non-corrosive, slightly corrosive and moderately corrosive tendencies occupy top soil of the study area with practically non-corrosive soils occupying the greater part. Therefore, the soils are largely not aggressive and may host metallic materials without serious danger of corrosion.

Table 3. Classification of Soil Resistivity in terms of Corrosivity [32] [33]

Soil resistivity (Ωm)	Soil corrosivity
<10	Very strongly corrosive (VSC)
10-60	Moderately corrosive (MC)
60-180	Slightly corrosive (SC)
>180	Practically non-corrosive (PNC)

3.5. Coefficient of Anisotropy

The coefficient of anisotropy for Kwata-Zawan area to the top of the basement rocks shows values of 0.478 to 1.623 (Table 2) as shown in Figure 12 where purple colour has values that range from 1.5 to 1.6, orange colour of 1.4 to 1.5 and lilac colour of 1.3 to 1.4 These values of electrical anisotropy are relatively high values with possibly good groundwater yield at locations where these values occur within the purple colour. Coefficient of anisotropy and groundwater yield likely have a linear relationship and locations with the highest range of electrical anisotropy values may have the highest groundwater yield for the area

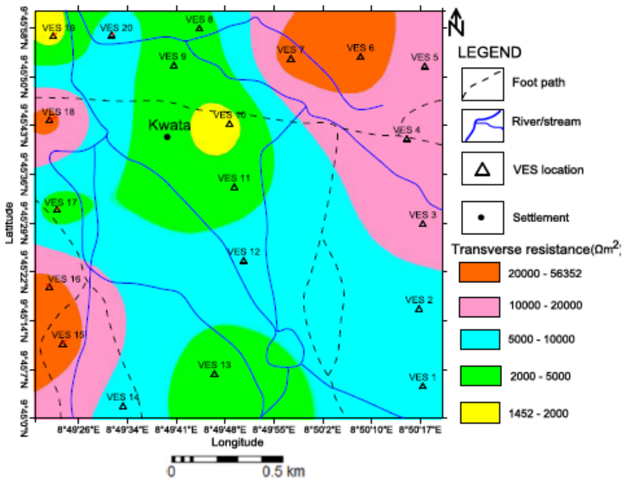

Fig. 9. Total Transverse Resistance map of Kwata-Zawan

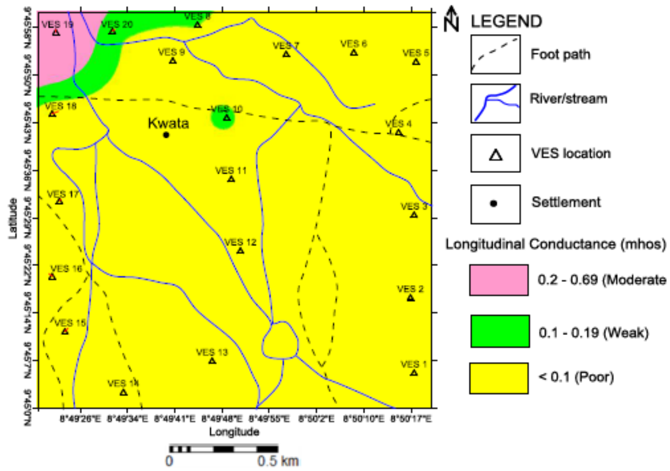

Fig. 10. Total Longitudinal Conductance Map of Kwata-Zawan area

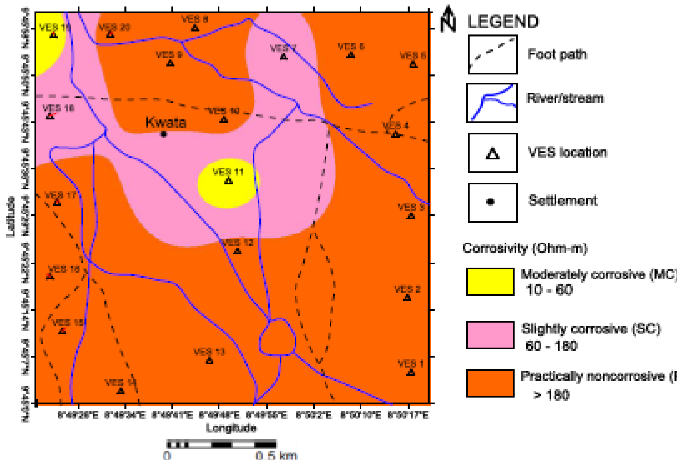

Fig. 11. Soil corrosivity map of Kwata-Zawan

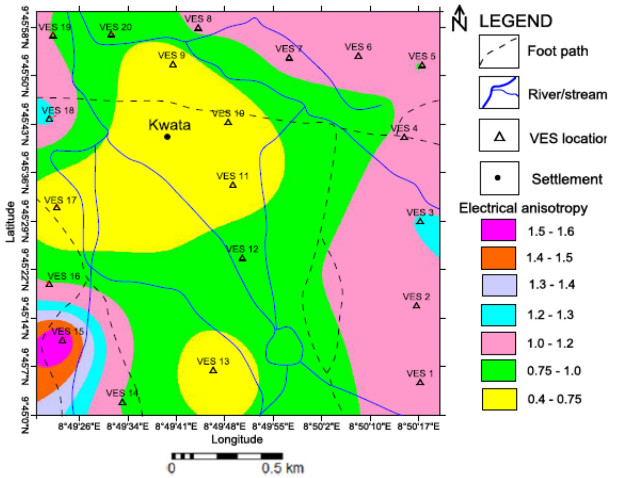

Fig. 12. Electrical Anisotropy/Coefficient of Anisotropy of Kwata-Zawan

3.6. Aquifer Thickness

The overburden of thickness across the Kwata-Zawan area with values 14 to 49 m is shown in Figure 13. The recommended 20 to 30 m overburden feasible for groundwater yield according to [34]-[36] and the locations with overburden thickness of 26 to 49 m are viable for groundwater abstraction at VES 4, 6, 15, 16, 17, 19 and 20.

3.7. Basement Topography

The topography map of Kwata-Zawan is shown in Figure 14 and the yellow, cyan and purple colours denote the basement depression zones. The orange colour areas represent the basement ridges

3.8. Groundwater Potential Assessment

The good groundwater potential zone must have overburden greater than 10m, with resistivity value of less or equal to 800 Ωm [37] [38]. According to [39], the coefficient of anisotropy value should be greater than 1.2 and the zone classified as basement depression. The ground water potential map is shown in Figure 15 and characterized as poor aquifer potential zone which accounts for about 21.21 %, low groundwater potential zone accounts for 51.52 % and good aquifer potential zone accounts for 27.27 % of Kwata-Zawan area. The good groundwater potential rating isfound at VES 4, 6, 15, 16, 17,19 and 20.

4. Conclusion

In this study, aquifer protective capacity and ground water potential evaluation of the overburden units at Kwata-Zawan area, Jos, Nigeria was undertaken using 20 VES points. The qualitative interpretation indicates HK, HA, KH, AA,AKQ, QH, HHK, HKQ, AAK, H, KHK, AK, AKH, K, and A type curves. The geologic sections showed three (3) to five (5) geo-electric layers; Top soil, laterite, clay, fracture basement and fresh basement. The total transverse resistance map reveals that approximately 90% Kwata-Zawan area has good aquifer transmissivity and approximately 10% of the study area has moderate aquifer transmissivity.

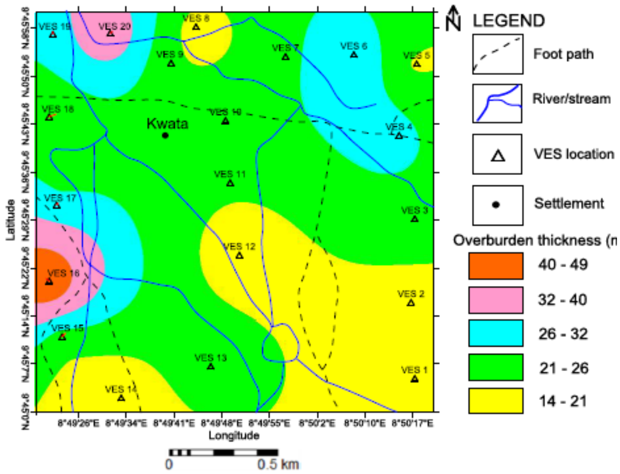

Fig. 13. Aquifer Thickness Map of Kwata-Zawan

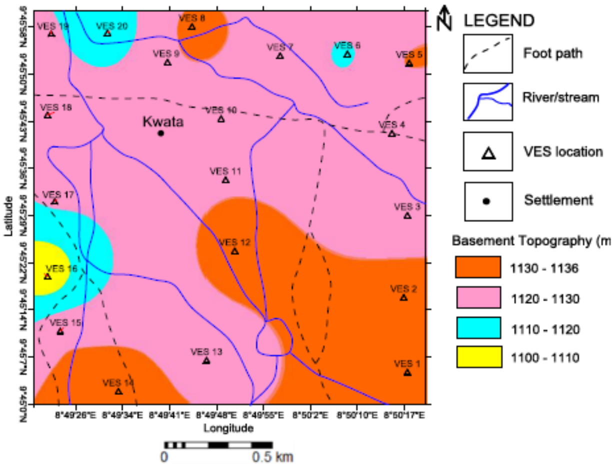

Fig. 14. Basement Topography Map of Kwata-Zawan

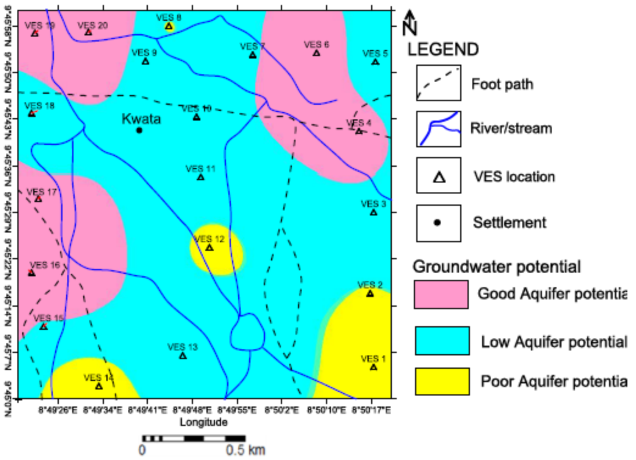

Fig. 15. Groundwater Potential Map of Kwata-Zawan

The extreme northwestern flank has weak to moderate protective capacity which covers about 15% while 85 % has overburden materials of poor protective capacity rating and indicates zones susceptible to surface contaminants. Soil corrosivity results reveals that soils with practically non-corrosive, slightly corrosive and moderately corrosive tendencies occupy top soil of the study area with soils that are practically non-corrosive soil occupying greater part. Therefore, the soils are largely not aggressive and may host metallic materials without serious danger of corrosion.

The Aquifer thickness map of the study area showed locations of thick overburden around VES 4, 6, 15, 16, 17, 19 and 20 which have good groundwater potential and good aquifer potential zone accounts for 27.27 % of the study area at VES 4, 6, 15, 16, 17, 19 and 20.

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