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Geoelectrical Techniques Applied to Evaluation of Aquifer Potential and the Protective Capacity of its Overburden Units in Some Parts of Bende Local Government Area, Abia State, South Eastern Nigeria.

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ABSTRACT: Geoelectrical techniques involving vertical electrical sounding (VES) were employed to evaluate the groundwater potential and aquifer protective capacity of the overburden units in the study area. Schlumberger electrode configuration was used to acquire geoelectric data for nineteen (19) VES stations. The results of the qualitative interpretation of the VES data indicate that the study area is underlain by four (4) to six (6) geoelectric layers. The curves identified in the study area show that majority of the field curves terminated at the boundary of the aquifer and the aquifer substratum as A or H shaped type curves. Thus the dominant Dar Zarrouk parameter for estimation of transmissivity in the study area is longitudinal conductance. The results of the correlation analysis applied to establish the empirical relationship between transmissivity and longitudinal conductance showed high coefficient of reliability R^2 of 0.97. Krasny's classification scheme for transmissivity magnitude and variation was used to identify the groundwater supply potential and heterogeneity of the study area. Transmissivity analysis based on Krany's classification scheme delineated the study area into five (5) groundwater supply potential zones: 10.52% negligible, 5.26% very low, 42.10% low, 31.57% intermediate and 10.52% high groundwater potential zones. The standard deviation value of 0.98 in the transmissivity index (y) represents a very large transmissivity variation and a very heterogeneous hydrogeological environment. The results obtained from this study showed that geoelectrical techniques can be used successfully to estimate the groundwater resources potential and the protective capacity of the overburden units of the aquifers. It can be concluded that the information provided in this study should therefore serve as a guide to optimum development and proper management of groundwater resources in the area.

KEYWORDS: Dar Zarrouk parameters ;Longitudinal conductance; Transmissivity; Coefficient of reliability

I. INTRODUCTION

Water plays a vital role in the development of any activity in a region. The availability of surface water and groundwater governs the process of planning and development. Many communities in Nigeria rely on surface and groundwater resources for domestic, industrial and agricultural water supplies. However, the demand for groundwater has increased over the years due to the inadequacy of surface water resources to meet the entire water requirements for all purposes. Thus, groundwater quality and quantity are continuously under threat due to abuse of the resources. Problems of falling groundwater table and deteriorating groundwater quality have become a common problem throughout the world.

In Nigeria, many of the rural populace do not have access to adequate water and therefore depend on alternatives like wells and surface water sources for domestic use [1]. Over 75% of the population of Abia State, South-Eastern Nigeria, live in rural communities where modern water supply facilities are lacking. The inhabitants depend on traditional sources that are generally of questionable quality, insufficient in quantity and often liable to seasonal failures. The availability of groundwater depends on the presence of hydraulic properties of aquiferous units; and its potability depends on the presence of its hydrogeochemical properties and vulnerability to contamination pollution [2], [3].

The determination of aquifer characteristics of hydraulic conductivity and transmissivity is best made on the basis of data obtained from well pumping test. However, this method can be time consuming and yield results relevant only to a relatively small portion of the aquifer [4]. An alternative non invasive and less expensive approach that



provides more regional information is the estimation of aquifer hydraulic characteristics using the Dar Zarrouk parameters from geophysical surveys .

Geophysical methods especially Vertical Electrical Soundings (VES) have been used successfully for investigating groundwater quality and aquifer protective capacity in different lithological settings. [5]. The VES survey data can be employed to develop spatial distribution maps of groundwater quality, layer thickness, aquifer protective capacity and to determine the water-bearing formation potential [6]. These aquifer characteristics data are crucial for groundwater resource management and the present study is to use geoelectrical techniques to evaluate the groundwater potential and the vulnerability of the aquifers to surface contamination

II. STUDY AREA

The study area (Fig. 1) is located in Bende Local Government Area of Abia State Southeastern Nigeria. It lies between latitudes N 5° 24' N to 5° 52' N and longitudes 7° 28' E to 7° 46' E. The towns and villages under the study area includes Okayitem, Akanu, Amankalu Alayi, Eluokwe, Onu-Ibina, Okafia, AmankaluIgbere, Ezi-Igbere, AmaobaElu, Umuhu-Ezechi, Ozuitem, Ngwu Amankwo, Okputong, Etiti-Ulo, Amankwo and Bende.

The physiographic information on Abia State reveals that the climate of the area falls within the equatorial climatic belt with two major seasons, dry and wet seasons [7]. The study area is a humid zone. The relative humidity is usually high throughout the year, reaching a maximum during the rainy season when values above ninety percent (90%) are recorded. The prominent topographic feature is generally undulating topography made up of highlands which consists of sandstones and the lowlands which consist of shale. The highest elevation of the study area is 585 ft. The drainage system of the study area is controlled by relief, topography, and rock types. The major water bodies that drain the area are River Inyong, Okwanka stream, River Ehie, River Igwu and River Idonyi.

The sedimentary terrain of Bende LGA falls within Imo River basin. The geology sequence comprises of the Benin formation, Ameki formation, Imo shale group, Nsukka formation, Ajall sandstone, Mamu formation, Nkporo shale group, Ezeaku shale group and Asu river group. (Fig. 2).

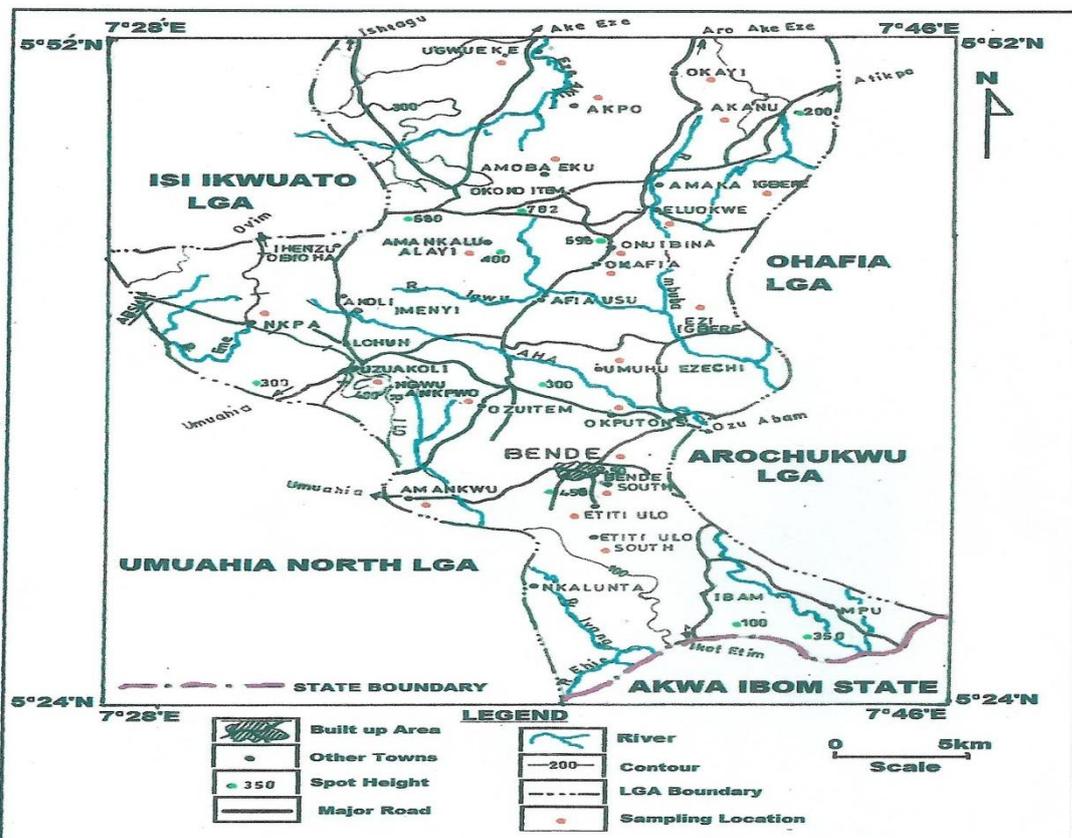


Figure 1: Map of study area

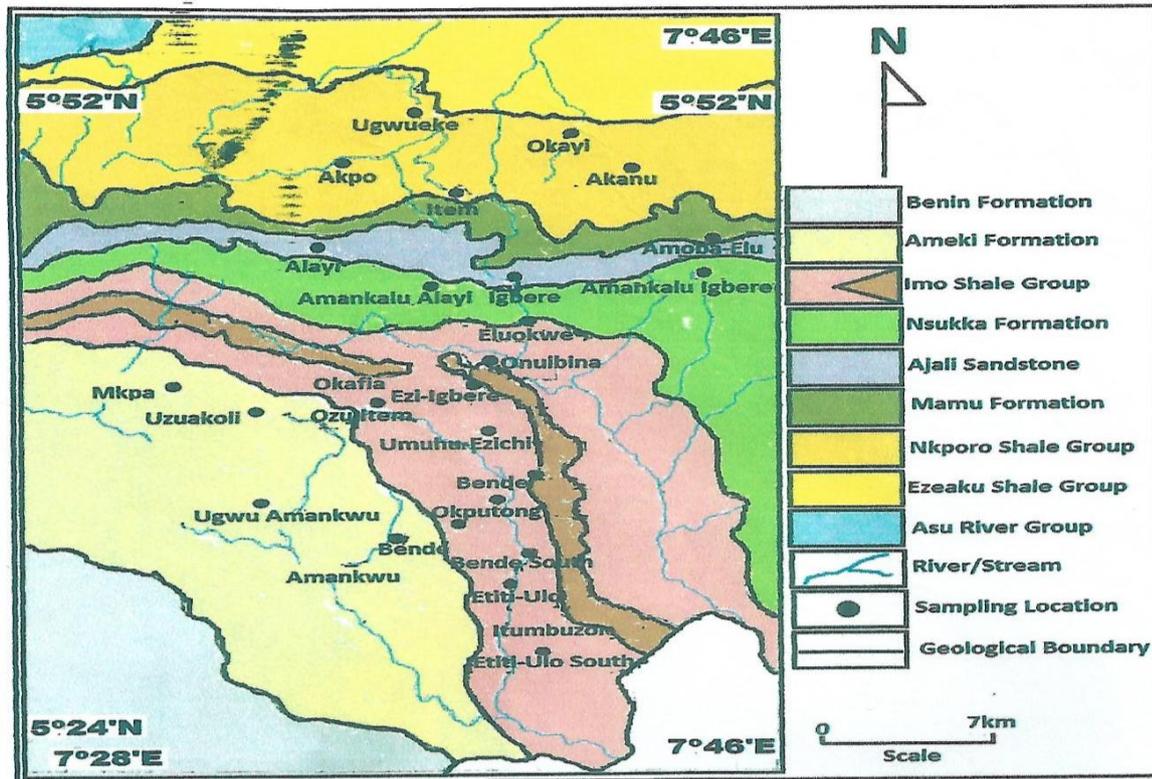


Figure 2: Geology and hydrogeology map of the study area

III. MATERIALS AND METHODS

DATA ACQUISITION AND INTERPRETATION

The geophysical field surveys were conducted using Vertical Electrical Sounding (VES) to determine the vertical and lateral distribution in the ground electrical properties.

The ABEM SAS-1000 Terrameter resistivity meter was used to measure the apparent resistivity distribution in nineteen (19) stations in the study area. The current electrode separation ($AB/2$) of 500m across the area was used for adequate depth penetration.

The apparent resistivity values (ρ_a) were obtained as the product of the resistance (R_a) read from the resistivity meter and its corresponding geometric factor (k) using the standard equations

$$\rho_a = kR_a \tag{1}$$

$$k = \pi \frac{(AB/2)^2 - (mN/2)^2}{mN} \tag{2}$$

$$R_a = \Delta V / I \tag{3}$$

where, AB is the current electrode spacing, MN is the potential difference between the pair of electrodes M and N , I is the current flow between a pair of electrodes A and B , k is the geometric factor and R is the resistance of the geoelectric layer.

The apparent resistivity values obtained were plotted against half current electrode separation spacing on a bi-logarithmic graph to obtain the field curves. The VES curves were manually smoothed to check resistivity curve discontinuities generated by different MN spacing of the same AB spacing induced by lateral inhomogeneity, anisotropy effect and other signatures arising from ambient noise on the resistivity curves.

The VES curves were subjected to standard curve matching to obtain the initial layer parameters i.e. resistivity and thickness values of each layer. The layer parameters obtained from the curve matching technique were inputted into the computer for inversion modeling interpretation using the IPI2WIN computer software. The inversion yielded resistivity models with minimal fitting error between the observed and theoretical resistivity values. Typical iterated curves generated from the field measurements are shown in Fig. 3. Table 1 shows the geoelectric parameters and inferred lithologies from the geoelectric interpretation of the layers within the depth penetrated in the study area.

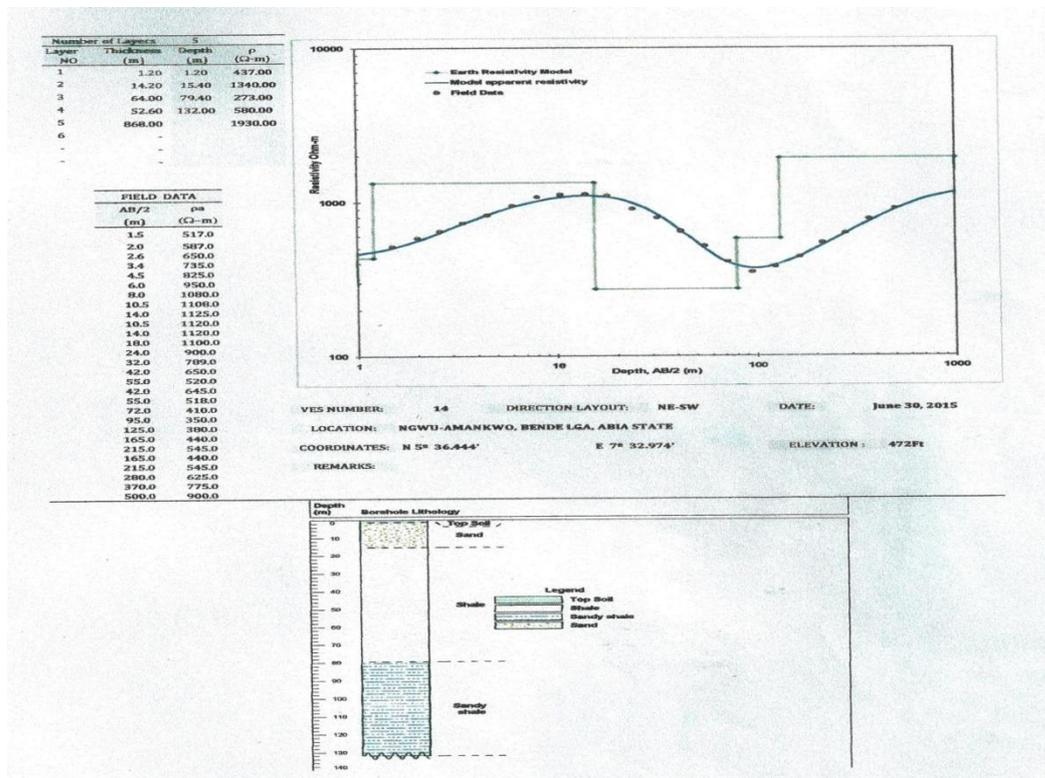


Figure 3: Typical iterated sounding curve of the study area at VES 14

TABLE 1: LITHOLOGICAL CHARACTERISTICS, HYDRAULIC AND GEOELECTRIC PARAMETERS OF AQUIFERS IN BENDE LGA ABIA STATE

S/N	Longitude /Latitude	Location	VES NO	Lithology	Aquifer layer Lithology	Aquifer protective capacity	Aquifer resistivity	Aquifer depth	Aquifer thickness	Aquifer transmissivity	Aquifer hydraulic conductivity	Aquifer longitudinal conductance
1	N5° 50.312 E 7° 41.382'	Okayitem	C1	KQHA	SAND	0.00086	1340	0.9	1.6	0.74	0.46	0.0011
2	N5° 48.483 E 7° 42.092'	Akanu	C2	KHKQ	SAND	0.0093	2010	62.1	39.9	0.033	0.00082	0.019
3	N5° 47.307 E 7° 37.829'	AmankaluAlayi	C3	KHKQ	SAND	0.0078	4190	87.8	60.2	0.025	0.00041	0.014
4	N5° 43.343' E7° 34.868'	AmankaluAlayi	C4	KHKQ	SHALE	0.26	197	3.9	57.3	160.26	2.79	0.29
5	N5° 41.990' E 7° 40.197'	Eluokwe	B1	AKH	SHALE	0.30	225	6	44.1	108.96	2.47	0.19
6	N5° 40.367' E 7° 39.842'	Onu-Ibina	C5	HAKH	SILT	0.44	1810	4.7	24.9	8.79	0.35	0.013
7	N5° 40.302' E 7° 36.645'	Okafia	C6	AAKH	SAND	1.66	1390	7.2	20.4	9.22	0.45	0.014
8	N5° 43.614' E 7° 41.026'	Amankalugbere	C7	HAKQ	SAND STONE	0.10	2110	30.3	74.7	22.87	0.30	0.035
9	N5° 39.255' E 7° 38.895'	Ezi-Igbere	C8	AKHA	SAND	0.012	1030	7	14	8.36	0.59	0.013
10	N5° 43.643' E 7° 38.540	AmaobaElu	C9	AAKQ	SAND STONE	0.0092	14700	148	72	3.60	0.05	0.048
11	N5° 36.713' E 7° 39.724'	Umuhu-Ezachi	C10	KQQQ	SAND	0.016	1570	0.9	3.9	1.57	0.40	0.0024
12	N5° 35.903' E 7° 36.290'	Ozuitem	B2	KHA	SAND	0.0021	1070	0.7	3.4	1.96	0.57	0.0031
13	N5° 36.444' E 7° 32.974	NgwuAmankwo	B3	KHA	SAND	0.0027	1340	1.2	14.2	6.64	0.46	0.010
14	N5° 34.280' E 7° 39.487'	Okputong	B4	KQQ	SAND	0.017	234	0.9	1.5	3.57	2.38	0.0064
15	N5° 32.928' E 7° 40.434'	Bende	B5	QHA	SANDY CLAY	0.0013	683	21.7	24.2	21.22	0.87	0.035
16	N5° 31.440' E 7° 40.730'	Bende (500m South)	B6	KQQ	SANDY CLAY	0.020	548	0.9	8.9	12.3	1.38	0.016
17	N5° 29.816' e 7° 40.434'	Etitu-ulo	B7	KHK	SAND	0.020	1130	21.7	58	31.80	0.54	0.051
18	N5° 28.058' E 7° 41.145'	Etitulo (500m South)	A1	KH	SAND	0.0018	2040	0.9	46.2	14.60	0.31	0.022
19	N5° 28.058' E 7° 37.474'	Amankwu	B8	AKQ	SILT	0.022	102	0.8	2.6	13.43	5.16	0.025
Mean	-	-	-	-	-	0.1527	1985	21.45	30.10	22.63	1.02	0.042

Hydraulic Parameters

The curves identified in the study area show that majority of the field curves terminated as H-shaped or A-shaped type curves at the boundary of the aquifer and the aquifer substratum. Since the general shapes are characteristic of a highly resistive substratum, both the current flow and hydraulic flow are dominantly horizontal in the aquifer [8]. Thus the relationship between hydraulic conductivity (k) and electric resistivity (ρ) is inverse and the dominant Dar Zarrouk parameters for estimation of transmissivity in the study area is longitudinal conductance:

$$L_c = h/\rho \tag{4}$$

The transmissivity of aquifer is

$$T = k\rho L_c \tag{5}$$

Since the area has the same geologic characteristics as the type studied by Heigold et al. [9], the hydraulic conductivity (k) was estimated using

$$k = 386.40 R_{rw}^{-0.93828} \tag{6}$$

where R_{rw} is the resistivity of the aquifer. The aquifer transmissivity (T_r) was estimated using the relation [10]:

$$T_r = kh \tag{7}$$

The summary of the Dar Zarrouk parameters and the hydraulic characteristics estimated from the geoelectric parameters and hydraulic parameters from the VES data interpretation were employed to generate resistivity map, longitudinal conductance map and transmissivity map. (Fig.4 – 6)

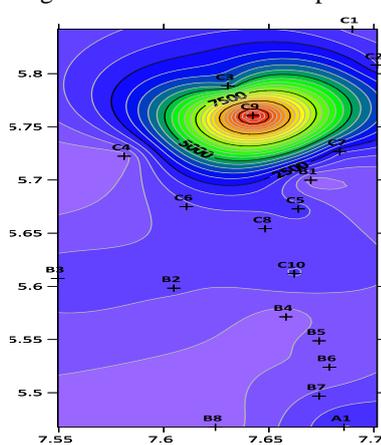


Figure 4. Resistivity map

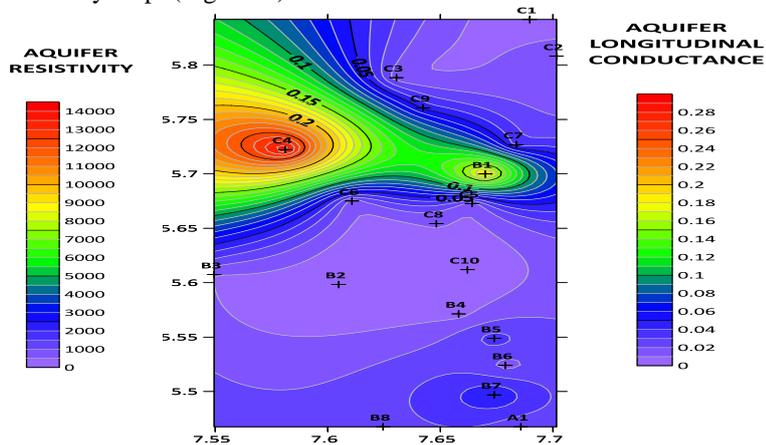


Figure 5. Longitudinal Conductance map

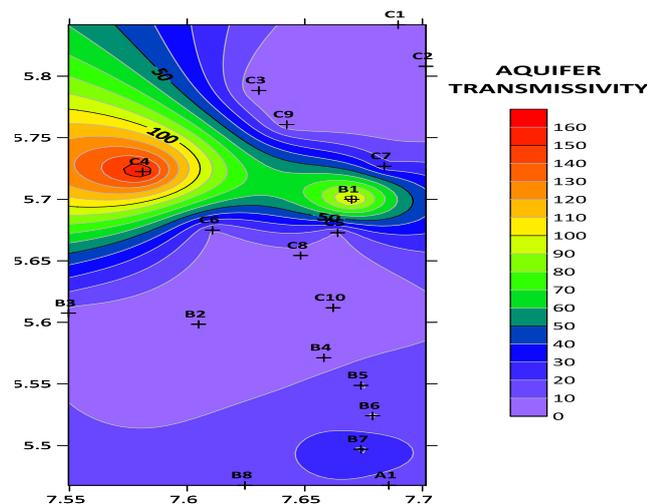


Figure 6. Aquifer transmissivity

SPATIAL ANALYSIS OF TRANSMISSIVITY

The transmissivity analysis was carried out using two methods: (i) descriptive statistical testing using the mean value and standard deviation of the transmissivity index and (ii) Krasny’s classification scheme [11] based on the results of transmissivity index (y), transmissivity magnitude (T) and transmissivity variation (ΔT).



Statistical Testing

The relationship between transmissivity (T) and logarithmic transmissivity index (y) is

$$T = 10^{y-8.96} (86400) \tag{8}$$

$$y = \log(T/86400) + 8.96 \tag{9}$$

where T is transmissivity in m^2/day .

The mean value and standard deviation were used to obtain the background transmissivity and anomalies. Krasny’s classification scheme for transmissivity magnitude and variation as presented in Tables 2, 3 was used to identify the groundwater supply potential and heterogeneity of the study area. Table 4 is the summary of the results of the transmissivity index (y), transmissivity magnitude (T) and transmissivity variation (ΔT).

Table 2: Krasny’s Classification of Transmissivity Magnitude (T)

	Class of T magnitude	Designation of magnitude	Groundwater Supply Potential
> 1000	I	Very high	Withdrawal of great regional importance
1000-100	II	High	Withdrawals of lesser regional importance
100-10	III	Intermediate	Withdrawals for local water supply (small communities)
10-1	IV	Low	Smaller withdrawals for local water supply (private)
1-0.1	V	Very low	Withdrawals for local water supply with limited
< 0.1	VI	Negligible	Sources for local water supply are difficult

Table 3: Classification of Transmissivity (ΔT) Variation

Standard Deviation Index	Class of Variation	Designation of Variation	Hydrogeological Environment
< 0.2	A	Insignificant	Homogenous
0.2-0.4	B	Small	Slightly heterogeneous
0.4-0.6	C	Moderate	Fairly heterogeneous
0.6-0.8	D	Large	Considerably heterogeneous
0.8-1.0	E	Very large	Very heterogeneous
> 1.0	f	Extremely large	Extremely heterogeneous

Table 4. Results of summary statistics of Transmissivity index (y), Krasny’s magnitude and variation.

S/No	VES No	Transmissivity m^2/day	Transmissivity index (Y)	Results of Transmissivity index (Y)	Results of Transmissivity magnitude (T)	Results of Transmissivity variation (ΔT)
1.	C1	0.74	3.89	Background Anomalies	Withdrawal for local water supply	Very Heterogeneous
2.	C2	0.033	2.54	Negative Extreme Anomalies	Zone without groundwater supply prospect	Very Heterogeneous
3.	C3	0.025	2.42	Negative Extreme Anomalies	Withdrawal for local water supply with limited consumption	Very Heterogeneous
4.	C4	160.26	6.22	Positive Anomalies	Withdrawal for lesser regional importance	Very Heterogeneous
5.	B1	108.96	6.06	Positive Anomalies	Withdrawal for lesser regional importance.	Very Heterogeneous
6.	C5	8.79	4.96	Background Anomalies	Withdrawal for local water supply	Very Heterogeneous
7.	C6	9.22	4.98	Background Anomalies	Smaller withdrawal for local water supply	Very Heterogeneous
8.	C7	22.87	5.38	Background Anomalies	Smaller withdrawal for local water supply	Very Heterogeneous



9.	C8	8.36	4.94	Background Anomalies	Smaller withdrawal for local water supply	Very Heterogeneous
10.	C9	3.60	4.57	Background Anomalies	Smaller withdrawal for local water supply	Very Heterogeneous
11.	C.10	1.57	4.21	Background Anomalies	Smaller withdrawal for local water supply	Very Heterogeneous
12.	B2	1.96	4.31	Background Anomalies	Smaller withdrawal for local water supply	Very Heterogeneous
13.	B3	6.64	4.84	Background Anomalies	Smaller withdrawal for local water supply	Very Heterogeneous
14.	B4	3.57	4.57	Background Anomalies	Smaller withdrawal for local water supply	Very Heterogeneous
15.	B5	21.22	5.35	Background Anomalies	Smaller withdrawal for local water supply	Very Heterogeneous
16.	B6	12.3	5.11	Background Anomalies	Smaller withdrawal for local water supply	Very Heterogeneous
17.	B7	31.80	5.52	Background Anomalies	Smaller withdrawal for local water supply	Very Heterogeneous
18.	A1	14.60	5.18	Background Anomalies	Smaller withdrawal for local water supply	Very Heterogeneous
19.	B8	13.43	5.15	Background Anomalies	Smaller withdrawal for local water supply	Very Heterogeneous

Protective Capacity

The values of the total longitudinal conductance of the overburden layers of the aquifers were used in the evaluation of protective capacity of an aquifer.

$$\rho_c = \sum hi / \rho_i \tag{10}$$

where ρ_c is protective capacity, L_c is longitudinal conductance of *ith* layer, hi is thickness of *ith* layer and ρ_i is resistivity of the *ith* layer.

The rating of protective capacity of an aquifer was described by Oladipo and Akintorinwa [12] as expressed in Table 4.

Table 5. Classification of protective capacity

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

IV. RESULTS AND DISCUSSION

The results of the interpreted resistivity data for the 19 VES stations identified 16 different curve types. Typical iterated curves generated from the field measurements are shown in Fig. 3. Table 1 shows the aquifer parameters and inferred lithologies from the geoelectric interpretation of the layers within the depth penetrated in the study

The computer interpretation of the observed curves resolved the penetrated subsurface layers at the 19 VES sites into 4 to 6 geoelectric layers. The four (4) to six (6) geoelectric layers can be grouped into A, B and C respectively. The characteristic curve type of group A is *kH*. The aquiferous unit consists of sand at A1 with a resistivity value of 2010 ohm-m. The characteristics curve types of group B are *AkH*, *kHA*, *kQQ*, *QHA*, *kHk* and *AkQ*. The aquiferous units are comprised of sand at B2, B3, B4 and B7; shale at B1; silt at B8 ; sandy clay at B5 and B6. The resistivity value of the aquiferous units range from 102 ohm –m to 1340 ohm –m. The characteristic curve types of group C are *KQHA*, *KHKQ*, *HAKH*, *AAKH*, *HAKQ*, *AKHA*, *AAKQ* and *KQQQ*. The aquiferous units consist of sand

at C1, C3, C6, C7, C8, C10; shale at C4; silt at C5; sandstone at C9. The resistivity values of the aquifers range from 197 ohm –m to 14700 ohm – m.

Generally, the aquiferous units consist of sand (63.15%), shale (10.52%), silt (10.52%) and sandstone (5.26%).The results of VES interpretation revealed the average depth to aquifer as 21.45 m with a depth range from 0.7 m at B2 to 87.8 m at C3; average aquifer thickness as 30.10 m with a thickness range from 1.5 m at B4 to 60.2 m at C3; average overburden thickness of 21.45 m with overburden thickness range of 0.7 m at B2 to 148 m at C9.

The hydraulic conductivity(*k*) and Transmissivity (*T*) of the aquifers were determined from geoelectrical techniques and presented in Table 1. The hydraulic conductivity ranges from 0.00082 m/day at C2 to 5.16 m/day at B8 with average of 1.02 m/day; transmissivity ranges from 0.025 m²/day at C3 to 160.26 m²/day at C4 with average of 22.63 m²/day.

Maps of aquifer parameters were constructed to delineate the horizontal variation of the aquifers in the study area (Figs. 4-6). The maps reflect the lateral variation over a horizontal plane of aquifer resistivities, longitudinal unit conductances and transmissivities.

Comparison of resistivity map (Fig.4), longitudinal conductance map (Fig.5) and transmissivity map (Fig. 6) shows that areas underlain by relatively low resistivity aquifer materials have high longitudinal conductance and high transmissivity values. This is expected because transmissivity is a function of aquifer longitudinal conductance in any area with predominance of low resistivity aquifer materials. Correlation analyses were applied to establish the empirical relationships between transmissivity and longitudinal conductance. The results of the analysis (Fig.7) showed high coefficient of reliability *R*² of 0.97.

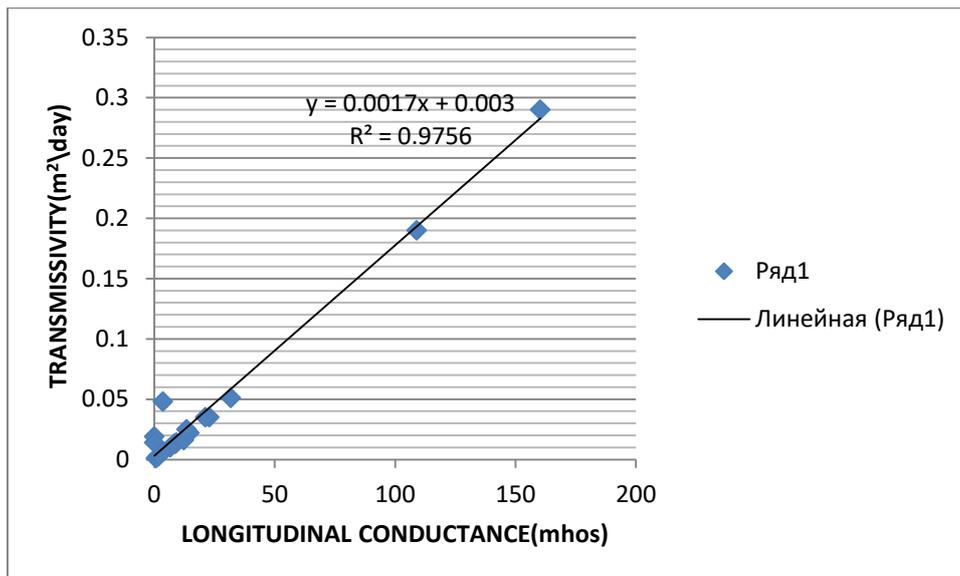


Figure7. Correlation analysis between Transmissivity and Longitudinal conductance in the study area.

Transmissivity analysis based on transmissivity index (*y*) classification (Table 4) delineated the study area into five (5) groundwater supply potential zones: 10.52 % negligible, 5.26% very low, 42.10% low, 31.57% intermediate and 10.52% high groundwater potential rating.

The standard deviation value of 0.98 in the transmissivity index (*y*) represents a very large transmissivity variation and characterized the study area as a very heterogeneous hydrogeological environment.

The total longitudinal unit conductance(Σs) values obtained from the study area, range from 0.0011 mhos at VES C1 to 0.29 mhos at VES C4 with an average of 0.042 mhos. The results of assessment of the aquifer vulnerability (Table 5) classified the study area into 73.68% *poor*, 5.26 % *weak*, 15.78% *moderate* and 5.26% *good* protective capacity. The areas that are classified weak and poor are most susceptible to contamination, while the good and moderate classifications are indication of geological formations that are highly protective to contamination.

V. CONCLUSION

The results of interpretation of the resistivity data and the inferred lithology show that the aquifers in the study area are dominated by sandy materials with attendant low - intermediate transmissivity values.

The correlation analysis applied to establish the empirical relationship between transmissivity and longitudinal conductance showed high coefficient of reliability R^2 of 0.97.

Generally the area was zoned into 10.52% negligible, 5.26% very low, 42.10% low, 31.57% intermediate and 10.52% high groundwater potential ratings.

The assessment and analysis of the materials above the aquifers showed that 73.68% of the area falls within the poor protective capacity rating, 5.26% are under poor protective capacity, 15.78% falls within moderate protective capacity while the remaining 5.26% are under good protective capacity designation. This suggests that aquifers in the area are predominantly poorly protected and by implication vulnerable to infiltration of surface contamination. The low values of the protective capacity is presumably due to the absence of significant overburden impermeable rock materials (clay/shale) which can impede contaminant infiltration. The transmissivity variation in the study area characterized it as a very heterogenous hydrogeological environment. The VES stations C4 (AmankaluAlayi) and B1 (Eluokwe) with high transmissivity values and moderate aquifer protective capacity are considered prospective zones for groundwater exploration, development and siting of productive boreholes. The VES station C6 (Okafia) with low transmissivity value and good aquifer protective capacity is suitable for toxic waste disposals and landfill locations. The results obtained from this study showed that geoelectrical techniques can be used successfully to estimate the groundwater resources potential and protective capacity of the overburden units of aquifers in the study area.

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