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Delineation of Aquifer Protective Capacity and Groundwater Yield of Surrounding Environment of Ikpeshi, Akoko-Edo, Edo State, Nigeria

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ABSTRACT: The objective of this paper was to delineate the aquifer protective capacity and groundwater yield of the environment of Ikpeshi, Akoko Edo, Edo state, Nigeria using electrical resistivity method. Four (4) vertical electric soundings (VES) in Schlumberger configuration were conducted using ABEM Terrameter for acquisition of data. Results of geo-electric sections revealed that most of the aquifers were semi confined, consisting of coarse grained-sand and fine-grained sand with different thickness. The major curve types are HAA and HKH. The results of Dar zarrouck parameters evaluated indicated that the mean longitudinal conductance for VES2, VES3 and VES 4 were 0.21186, 0.009178, 0.06910 and 0.06683 respectively. This implies that the aquifer protective capacity in the study area were generally poor with exception of VES1 that was considered moderate. The mean hydraulic conductivity ranging from 0.000448 to 19.098 indicating that the yielding potential ranged from low to moderate. The transmissivity values for VES1 (114.06 m2 /day) and VES4 (74.57 m2 /day) show moderate groundwater potential while VES2 (48.05m2 /day) and VES3 (33.2 m2 /day) indicates low groundwater potential. Transverse resistance ranged from 3386.35 to 128300.34 Ωm^2 and were below 200,000 Ωm^2 indicating inadequate aquifer thickness and low groundwater potential. Geochemical analysis of water and soil samples from the area is therefore recommended in order to ascertain contaminant sources, migration and preferred treatment methods.

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In any environment, there is a strong relationship between human activities and water pollution of that environment due to anthropogenic activities resulting from the growth of industries and technological advancement. Groundwater is considered vulnerable when the protective capacity of an overburden overlying and aquifer is not capable of resisting contaminants moving under gravity (Olusola and Omorogieva 2020). It is dependent on intrinsic susceptibility; sources of contaminants, fate and transport of contaminants and depth to the water table. The sources of pollution in mining terrain in Ikpeshi are open pits, waste disposal area, haulage roads, processing plant mills, tailing, and waste rock piles area. Direct degradation can occur to groundwater sited downhill from a surface mine by the flow of contaminated drainage from the mine. The quality of groundwater can be compromise by leaching of geogenic contaminants derived from weathering of rocks of as a result of the transfer of contaminants from soil to infiltrating recharge water (Adepoju, 2009). Indirect degradation of groundwater could result from

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blasting which causes a temporary shaking of the rock and results in the new rock fracture near working area of the mine. Blasting can also cause the old pre-existing rock fracture to become more open or permeable, by loosening mineral debris or cement in this fracture; this could affect nearly vertical fractures located up to several hundred feet away from the surface mine causing vertical leakage of pond mine drainage from nearby abandoned deep mines to underlying aquifers (Nwachukwu *et al.*, 2018). Marble mining in Ikpeshi is could pose threat to groundwater due to huge stockpiles of tailings produced from its operations and the possibility of chemical leaks and petroleum spillage through groundwater recharge zones in the mining areas. Presently, the application of the Dar Zarrouck parameters (Longitudinal conductance and Transverse resistance, hydraulic conductivity and transmissivity) to delineate subsurface conditions with respect to groundwater contamination and groundwater yield has not been sufficiently utilized. Consequently, it is therefore important to decipher the sequence of rock strata overlying the aquifer in the area in order to established their vulnerability to potential contamination, providing essential information for proper management of groundwater resource in this area. This was achieved by conducting geophysical investigations. Vertical electrical sounding is a geo electric method that retains current and electrode along a straight line at the same relative spacing around a fixed point. (Kwami *et al.*, 2019) proved an analytical existence between aquifer transmissivity and transverse resistance. Hence, the objective of this paper was to delineate the aquifer protective capacity and groundwater yield of the surrounding environment of Ikpeshi, Akoko Edo, Edo state, Nigeria using appropriate standard methods and Four (4) vertical electric soundings (VES) in Schlumberger configuration were conducted using ABEM Terrameter for acquisition of data.

MATERIALS AND METHODS

Description of the Geology of the Study Area: The study area Ikpeshi located Akoko Edo local government Area of Edo State lies Latitude 07° 08.00N and Longitude 6° 11.70E is part of the Igarra schist belt and a part of the Southwest Basement Complex believed to be of Precambrian age. The major rock units in this area are the migmatite gneiss complex, metaconglomerates, metasediments which includes Quartzite schists, Biotite schists, Calc gneisses, Amphiboles, Marbles and older granites. Cretaceous sediments deposited in this area belong to the Lokoja-Basange formation which is the oldest unit in the Benin flank of the Anambra Basin. It lies non conformably on the Igarra schist belt and it's characterized by horizons of sand, silt stones, mudstones and clay. The basal unit in contact with the basement rock is highly consolidated and ferruginized. The sediments in the middle are friable and poorly sorted (Imeokparia and Emofurieta 1991). The sand ranged from fine to coarse sand grain.

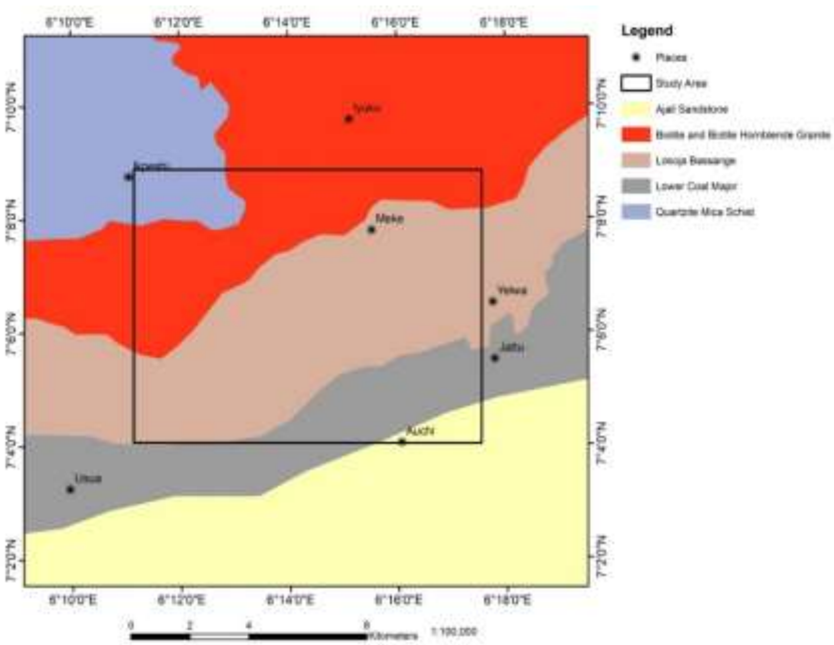

Fig. 1: Geological map of the study area
Source: Nigerian Geological survey agency, modified by Ojeaga and Osauzou (2024)

The Description of climatic and vegetation conditions of the sampling area: The sampling area Ikpeshi and environs as shown in Fig. 2 has witnessed increased infrastructural developments. It falls within the Guinea savannah vegetation belt. The vegetation is predominantly made up of sparsely distributed trees, herbs, shrubs, and grasses. Trees in the area are mostly concentrated along fracture zones within plutonic bodies and on quartzite ridges. Agricultural crops such as maize, yam, cassava, cocoa, pineapple, cashew, mango and sugarcane are grown in the area is located on a slightly undulated terrain with elevation of 300m above sea level. The physical feature of the area may account for poor drainage condition and erosion problems.

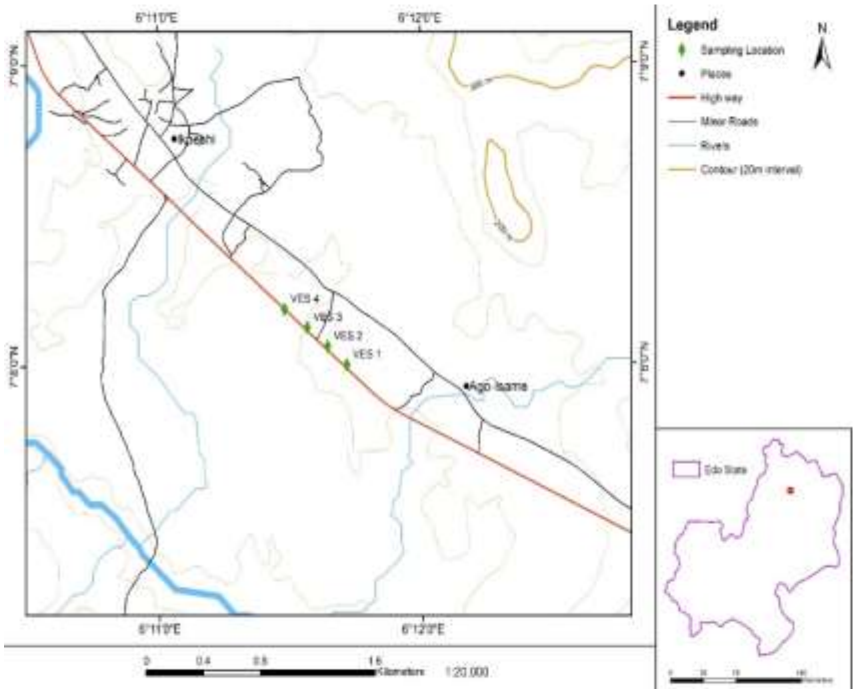

Fig. 2: Sampling map of the study area
Source: Ojeaga and Osauzuo (2024)

Estimation of longitudinal conductance: The longitudinal conductance (S) is a measure of the impermeability of a rock layer (Billing, 1972). Electrical anisotropy is a measure of stratified rock which is generally more conductive in the parallel plane than the perpendicular (Malick *et al.,* and Cihan *et al.,* 2014). For a sequence of horizontal, homogenous and isotropic layers of resistivity $e1$ and thickness $h1$, the Dar Zarrouk parameters is defined as follows

$$S = \frac{h1}{e1} + \frac{h2}{e2} + \frac{h3}{e3} + hn/en = \sum_{i=0}^{n} \frac{hi}{ei} \quad (1)$$

$$TR = e1h1 + e2h2 + \cdots .. e3h3 = \sum_{i=0}^{n} eihi \quad (2)$$

The relationship between aquifer transmissivity, and longitudinal conductance is established by the equation derived by Todd, (1980).

Where T_r = Aquifer Transmissivity, K= Hydraulic conductivity in m/day

h_i= layer thickness of aquifer
R = Transverse Resistance, S = Longitudinal Conductance

Transmissivity (Tr)= K.hi (3)

Determination of Resistivity Sounding: A total of 4 vertical electric soundings were carried out in the study area. The electrode configuration used for the work was Schlumberger array as depicted in Fig 3. The vertical electric sounding requires current (AB) and potential electrodes (MN) to be placed along a straight line at the same spacing over a fixed point. The field procedure consists of expanding the current electrode AB while keeping the potential electrodes MN relatively fixed. For each reading, the current is sent into the ground through A and B which setup the measured potential difference between the potential electrodes M and N, the magnitude of the potential difference is a measure of the electrical resistance between the probes. The resistance is in turn a function of the geometric configuration of the electrodes and the electrical parameters of the ground (Dobrin, 1976). The electrode separation (AB/2) is 200m on either side which brings it to a total of 400m spread. The ABEM Terameter was positioned half way between the potential electrodes M and N, and was connected to terminals P1 and P2 and to terminals M and N. The current electrodes A and B was connected to terminals C1 and C2 respectively.

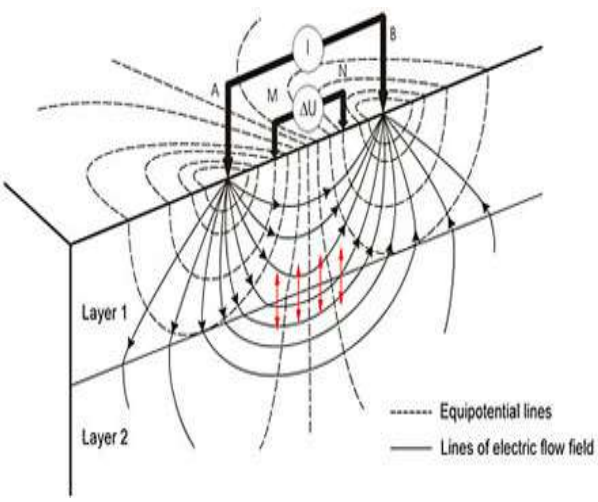

Fig. 3: 4-point-measurement electric flow field electrodes.

RESULT AND DISCUSSION

Data obtained from geophysical survey were interpreted using the WIN-Reset software. The information derived from vertical electrical sounding data is essential in the identification and interpretation of geo electric parameters which are number of layers, resistivity, thickness, depth, and curve type and aquifer systems (Table 1). HAA curve. A maximum of 6 layers with varying resistivity and thickness was provided in VES 1 as presented in table 1. The Resistivity ranges from 24.032Ωm to 3140.3Ωm. The first layer (top soil or overburden) has a resistivity of 114.76Ωm thickness of 0.8050m. The second layer (lateritic soil) has resistivity of 83.056 Ωm and thickness of 3.6597m. The third geoelectric layer of VES 1 is described as Silt with apparent resistivity of 74.68Ωm and thickness value of 3.6628m and the depth of 8.1275m. The fourth geoelectric layer is medium to coarse sand with apparent resistivity of 3140.3Ωm and thickness value of 16.656m with a depth 24.784m. The fifth geoelectric layer is clay with apparent resistivity of 194.00Ωm, thickness value of 20.650m and at a depth of 45m. The sixth geoelectric layer has a resistivity of 24.032Ωm and a thickness was not determined. The fourth geoelectric layer has prospect of be an aquifer. The curve type is HKH curve, $P_1<P_2>P_3$ as shown in Figure 1. The Modelling of VES 2 reveals five (5) Geo electric layers as shown in table2. The Resistivity ranges from 68.950Ωm to 93374Ωm. The first layer which is the overburden has a resistivity of 68.95Ωm and a thickness and depth values of 0.9886m and 0.9886m respectively. The second geoelectric layer also lateritic soil has resistivity of 58.603Ωm and a thickness of 1.5557m. The third geo electric layer of VES 2 is revealed to be silt with apparent resistivity of 98.975Ωm and thickness value of 4.4592m and the depth of 7.0036m. The fourth and fifth geoelectric layer is revealed to be fine Sand and Basement Complex Rock with an apparent resistivity of 689.76Ωm and 93374Ωm. The thickness and depth for layer four was 4.0386m and 11.042m respectively. While those of layer five was not determined. The curve type is HAA curve, $P_1<P_2<P_3$ as shown in Figure 3 and 4.

Table 1: Electrical resistivity sounding parameters

VES NO	Location	Latitude	Longitude	Layer No	Resistivity	Thickness	Inferred Lithology	Curve type	Aquifer system
VES 01	Ikpeshi	07°08.00′N	06°11.708′E	1	114.76	0.80504	top soil	HKH	Coarse sand
				2	83.056	3.6597	laterite		
				3	74.68	3.6628	silt		
				4	3140.3	16.656	coarse sand		
				5	194	20.65	Clay		
				6	24.032	----	----		
				VES 02					
VES 02	IKpeshi	07°08.62′N	06°11.636′E	1	68.95	0.98864	Top soil	HAA	Fine sand
				2	58.603	1.5557	Laterite		
				3	98.975	4.4592	Silt		
				4	689.76	4.0386	Fine sand		
				5	93374	----	----		
				VES 03					
VES 03	IKpeshi	07°08.125′N	06°11.559′E	1	81.133	0.906	Topsoil	HAA	Coarse sand
				2	25.123	1.303	Lateritic		
				3	825.29	3.3037	Medium sand		
				4	3888.9	8.0441	Coarse sand		
				5	61555	----	----		
				VES 04					
VES 04	Ikpeshi	07°08.186′N	06°11.473′E	1	91.184	0.8224	Topsoil	HAA	Fine sand
				2	26.916	1.2859	Laterite		
				3	638.69	6.6332	Fine sand		
				4	60497	----	-----		

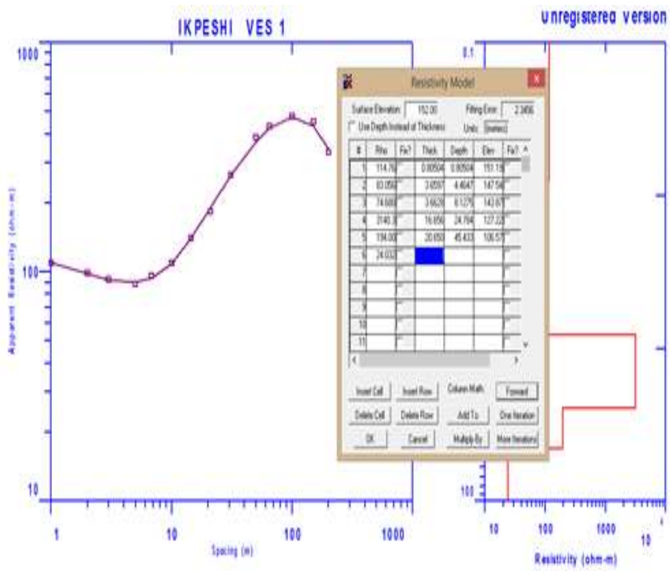

Fig. 4: Geoelectric curves for VES 1.

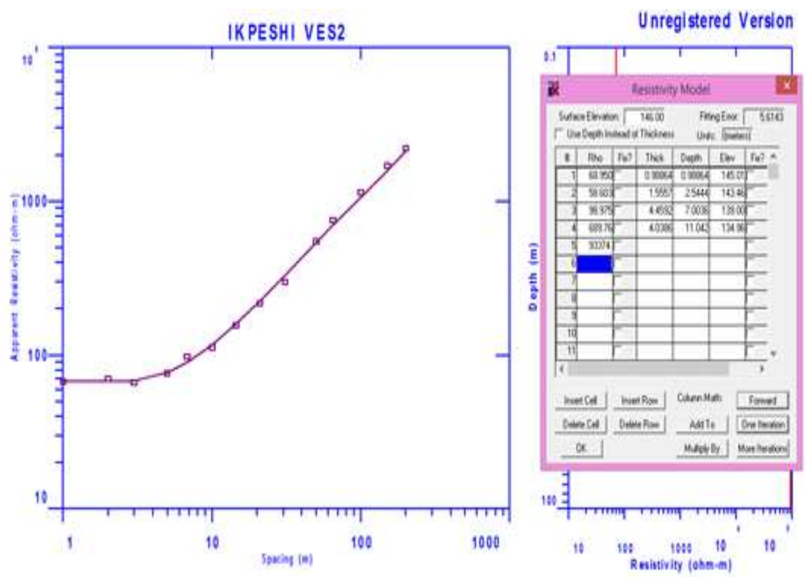

Fig. 5: Geoelectric curves for VES 2.

The Modelling of VES 3 reveals five (5) Geoelectric layers. The Resistivity ranges from 81.133Ωm to 61555Ωm. the overburden has a resistivity of 81.133Ωm, thickness of 0.906m and depth of 0.906m. The second layer described as lateritic soil has resistivity of 25.123 Ωm and a thickness of 1.303m. The third geoelectric layer of VES 3 is revealed to be medium sand with apparent resistivity of 825.59Ωm, thickness value of 3.3037m and the depth of 5.5127m. The fourth and fifth geoelectric layer is revealed to be medium to Coarse Sand and Basement Complex Rock with an apparent resistivity of 3888.9Ωm and 61555Ωm and thickness value of 8.0441m and infinity. Their depth ranges from 13.557m to infinity as shown in Figure 5 and 6. The curve type is HAA curve, $P_1<P_2<P_3$.

The Modelling of VES 4 reveals four (4) geoelectric layers. The Resistivity ranges from 91.184Ωm to 60497Ωm. The first layer described as overburden has a thickness value of 0.8224m and depth of 0.8224m the second layer with resistivity of 26.916 Ωm and a depth of 1.2859m. The third and fourth geoelectric layer of VES 4 reveal that they were classified as fine sand and Basement complex rock with apparent resistivity of 638.59Ωm and 60497Ωm, while the thickness of the third layer was 6.6332m that of the fourth layer was not determined. The curve type is HAA curve, $P_1<P_2<P_3$.

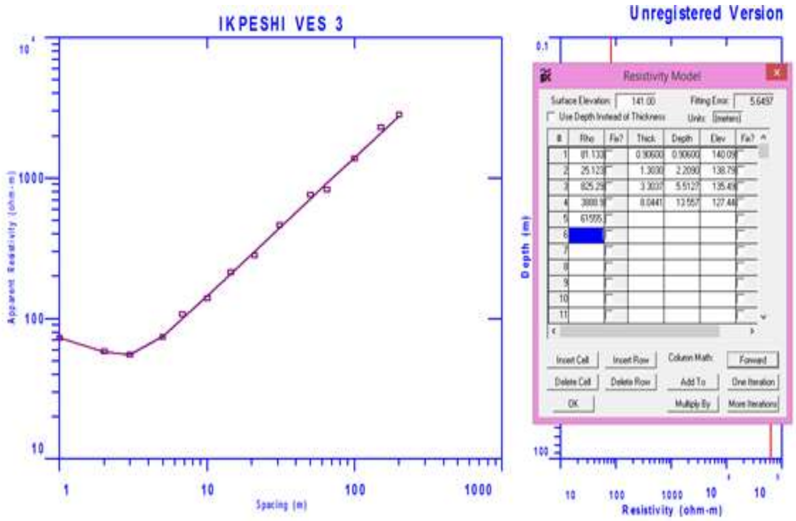

Fig. 6: Geoelectric curves for VES 3.

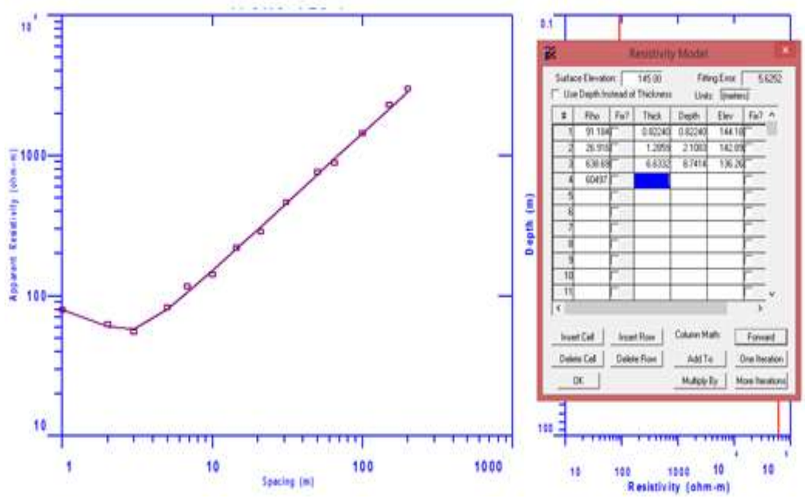

Fig. 7: Geoelectric curves for VES 4.

Table 2: Dar Zarrouck parameters obtained in the study area

VES NO	Layer No	Resistivity	Thickness	Longitudinal Conductance	Transverse resistance	Hydraulic Conductivity	Transmissivity
VES 01	1	114.76	0.80504	0.00701	92.38639	4.630231	3.72752116
	2	83.056	3.6597	0.04406	303.9600	6.260229	22.9105601
	3	74.68	3.6628	0.04905	273.5379	6.912831	25.3203174
	4	3140.3	16.656	0.00530	52304.84	0.211328	3.51987917
	5	194	20.65	0.10644	4006.100	2.837312	58.5904928
	6	24.032	----	----			
				VES 02			
VES 02	1	68.95	0.98864	0.01434	68.16397	7.447272	7.36237310
	2	58.603	1.5557	0.02654	91.17646	8.666303	13.4821675
	3	98.975	4.4592	0.04505	441.3493	5.315585	23.7032566
	4	689.76	4.0386	0.00585	2785.664	0.868989	3.50949897
	5	93374	----	----			
				VES 03			
VES 03	1	81.133	0.906	0.01117	73.50650	6.398532	5.79706999
	2	25.123	1.303	0.05186	32.73527	19.09890	24.8858667
	3	825.29	3.3037	0.00400	2726.510	0.735087	2.42850692
	4	3888.9	8.0441	0.00207	31282.70	0.000448	0.00360376
	5	6155	----	----			
				VES 04			
VES 04	1	91.184	0.8224	0.02394137	38761.1212	0.4908525	14.9528397
	2	26.916	1.2859	0.00417708	27021.0816	2.8373116	30.1435984
	3	638.69	6.6332	0.02165141	34778.7234	0.4926587	18.5190474
	4	60497	----	0.01706389	62629.4178	0.3350907	10.9544501

Table 3: Summary of Longitudinal Conductance (S) and Transmissivity (Tr) of Aquifer with its classification in according to (Oladapo and Akintorinwa 2007 and Offodile, 1983).

S/N	Location Coordinate points	Longitudinal Conductance (S, Ω^{-1})	Protective Capacity Rating	Ranking	Transverse Resistance Ωm^2	Transmissivity (m^2/day)	Ranking	Classification of well	Curve type
VES 1	07° 08.00´N, 6° 11.708´E Elevation: 152m	0..21186	Moderate	4	56980.82	114.06877	2	Moderate potential	HKH curve
VES 2	07° 08.062´N, 6°11.636´E Elevation: 146m	0.09178	Poor	7	3386.35	48.0573302	3	Low potential	HAA curve
VES 3	07° 08.125´N, 6° 11.559´E Elevation: 141m	0.06910	Poor	7	34115.45	33.115051	3	Low potential	HAA curve
VES 4	7° 08.186´N, 6° 11.473´E Elevation: 143 m	0.06683	Poor	7	128300.34	74.569940	2	Moderate potential	HAA curve

Table 4: Mean of Hydraulic conductivity of aquifers in the study area

VES NO	Location coordinates	Hydraulic conductivity K (m/day)
1	07° 08.00´N, 6° 11.708´E Elevation: 152m	4.17
2	07° 08.062´N, 6°11.636´E Elevation: 146m	5.58
3	07° 08.125´N, 6° 11.559´E Elevation: 141m	6.56
4	7° 08.186´N, 6° 11.473´E Elevation: 143 m	1.04

Dar Zarrouk Parameters: In order to constrained geological models, there are important parameters that needs to determine using data derived from VES stations (Egbai and Iserhien- Emekeme, 2015). These parameters are also referred to as aquifer parameters and they include Transmissivity, Hydraulic conductivity, longitudinal conductance, and transverse resistance.

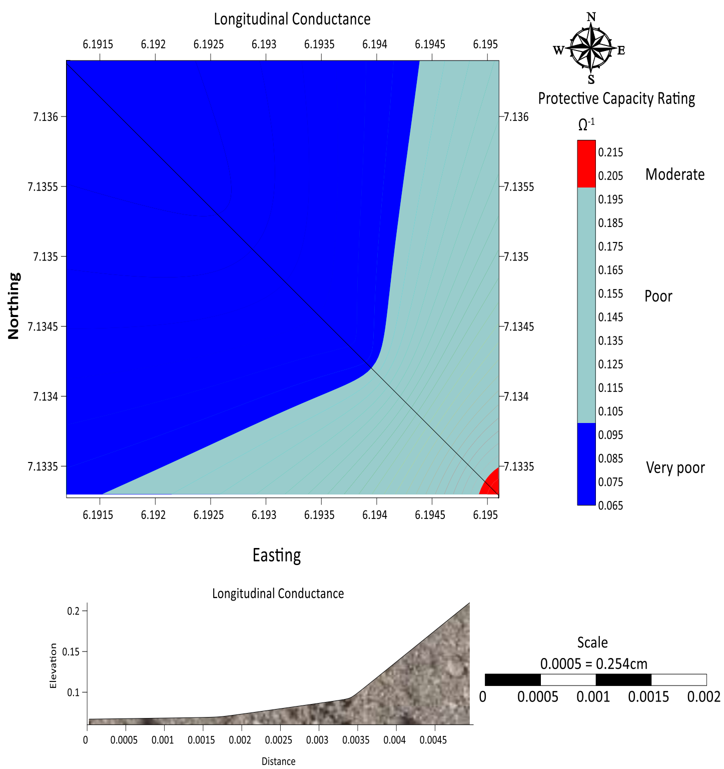

Fig. 8: 2D surface View of Longitudinal conductivity of the study area

Transverse resistance: The values of transverse resistance in the VES stations are shown in Table 2. The mean values of transverse resistance across VES stations ranged from 3386.35 to 128300.34 Ωm^2 presented in Table 3. (Ezeh, 2012) suggests that transverse resistance less than 200,000 Ωm2 may imply that the aquifer thickness is small or consists of finer sediments. Thus, the values of transverse resistance in the study suggests that the aquifer thickness in the study area is not adequate for high water yield rather indicative of low groundwater potential but also give credence to thin aquifer in the area.

Aquifer protective capacity: (Oladapo and Akintorinwa 2007) provided protective capacity rating of aquifers based on the values of longitudinal conductance. Fig. 8 is a map of study area depicting areas with low aquifer protective capacity represented as blue to light blue. Values of longitudinal conductance in the study area ranged from 0.06683 to 0.21186. Findings from the longitudinal conductance results as shown in Table 3 indicates that the aquifer protective capacity in VES 2, VES 3 and VES 4 were poor as the values of longitudinal conductance ranges from 0.06683 - 0.09178 with the exception of VES 1 with a moderate aquifer protective capacity whose value of longitudinal conductance was 0.21186. Findings from this work indicates that aquifer in the study area is susceptible to contaminants infiltrating through the matrix of soil by acid mine drainage and leaks from underground storage facilities.

The aquifer overburden protective capacity in VES 1 is an indication that the location is not vulnerable to pollutants infiltrating down the soil profile.

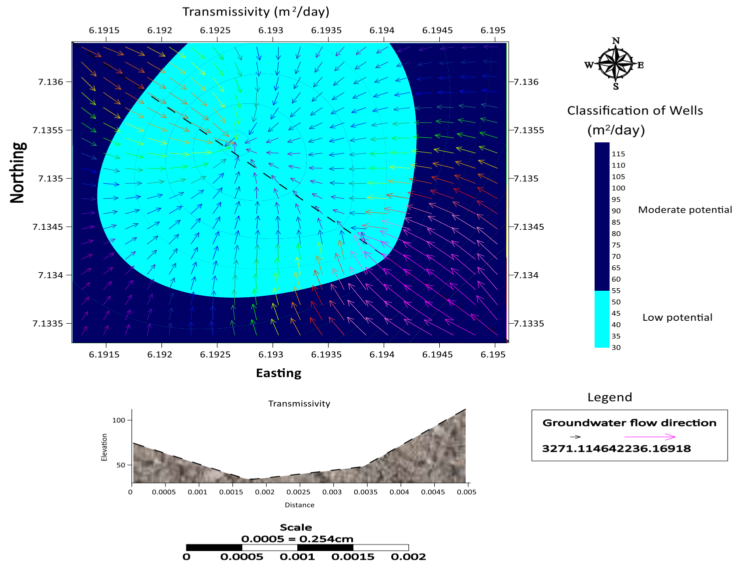

Fig. 10: 2D surface View of Transmissivity and Groundwater flow in the study area.

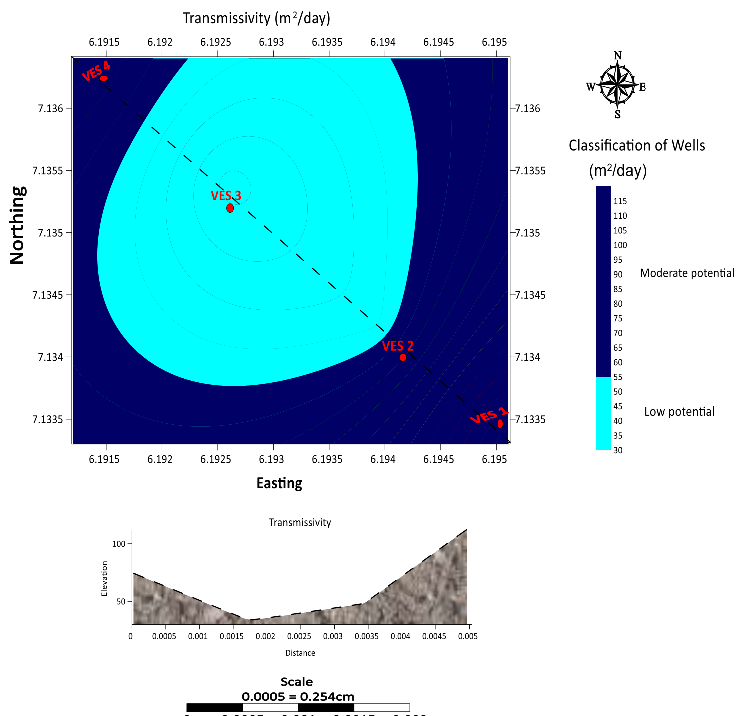

Fig. 9: 2D surface View of Transmissivity of the study area.

Transmissivity: The aquifer transmissivity of the layers in the area of study were calculated and summarized in Table 3 and Fig.10. The transmissivity values range from 33.115051 to 114.06877. The highest value of 114.06877 was recorded in VES1 while the lowest value of 33.115051 was recorded in VES3. Variation in transmissivity values in the area of study was done in accordance with classification of (Offodile, 1983). It was proven that VES1 and VES4 has moderate potential of groundwater development. VES2 and VES3 were classified as low potential. Fig 8 also shows the direction of groundwater. It shows that groundwater flows from VES 1 and VES 4 into VES 3.

Hydraulic Conductivity: The hydraulic conductivity K is the ease in which fluid will pass through a material/ it is defined by permeability of the aquiferous material. The hydraulic conductivity in this study ranged from 1.04m/day to 6.56m/day. This results indicate that the study area, particularly has moderate water yielding potentials.

Conclusion: The results of this study have shown precise delineation of the subsurface geological structure and aquifer properties such as transmissivity and aquifer vulnerability in the study area. The major sounding curves obtained in the area are mostly HAA with the exception of VES 1 with HKH. The aquifer overburden protection capacity in the vicinity of VES 2, VES 3 and VES 4 were rated poor and the aquifer in these areas is susceptible to contamination while the VES1 were rated moderate. The transverse resistance was also rated poor to moderate groundwater development. Hydraulic conductivity and transmissivity values were poor and moderate aquifer potentials. Since the aquifers in the study area is increasingly under threat. Groundwater monitoring wells should be provided in the community and regular water quality analysis conducted. Hydro chemical analysis of water samples from different boreholes is required to ascertain the degree of variation in water quality. Awareness should be created by encouraging the inhabitants to drink potable water from deep boreholes.

Declaration of Conflict of Interest: The authors declare that there is no conflict of interest.

Data Availability Statement: The authors declare that data for this research are available upon request from the corresponding author

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