



## ELECTRICAL RESISTIVITY SURVEY FOR GROUNDWATER INVESTIGATION IN PARTS OF OSUN STATE, SOUTHWESTERN NIGERIA

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### ARTICLE INFORMATION ABSTRACT

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This study used a non-invasive, cost-effective geophysical method for locating suitable sites for groundwater development. Thirty-two Vertical Electrical Sounding (VES) were probed in the investigated area using Schlumberger array. The data acquired were interpreted using the partial curve matching technique and computer-aided iteration through WINRESIST. The aquifer properties such as transverse resistance, longitudinal conductance, hydraulic conductivity and transmissivity were computed from the primary geoelectric parameters. The results of the study revealed that the investigated area is marked by heterogeneous lithology with three to five geoelectric layers. The aquifer resistivities ranged from 18 to 318  $\Omega\text{m}$  while the aquifer thicknesses ranged from 1.7 to 46.2 m. The computed transverse resistance revealed the groundwater development in the investigated area as low/moderate. Also, the transmissivity values computed from the primary aquifer parameters revealed that 72% of the investigated area has low aquifer transmissivity, while 28% have moderate aquifer transmissivity. This implies that the investigated area has low/moderate water-bearing potentiality. The quantitative analysis of the aquifer protective rating revealed that 78.1% of the investigated area has a good natural filter. Based on the aquifer potential rating and the protective capacity, VESes 10-12, 16, 19-20, 23-25 were recommended for drilling sites. The result of this study provides some important conclusions for future groundwater exploration and management in the investigated area.

### 1.0 Introduction

Water is essential for all human activities and crucial importance for society. Water can be referred to as the economic, social, and physical lifeblood of humanity, which provides support for agriculture, industry, transportation, energy production, and life itself. Despite its importance, there are looming threats to this vital resource as patterns demonstrate expanding use due to intensification of agribusiness, urbanization and economic growth (Agbasi *et al.* 2019; Awosika *et al.* 2020; Abdulrazzaq *et al.* 2020). By 2050, the United Nations evaluated that about two-thirds of the global population will face a shortage of water resources. The available water resource is not evenly distributed and considerable amount of this resource is been wasted, polluted and unsustainably managed. The shortage is both a human-made and a natural phenomenon. In most crystalline basement regions, the demand for water resources exceeds the supply. The management of these resources for sustainable development requires quantitative knowledge of the aquifer hydraulic properties as well as the effective protection of the water-bearing zone (George *et al.* 2018). The hydrogeological parameters, such as transverse resistance, longitudinal conductance, hydraulic conductivity and transmissivity are

key properties in depicting the subsurface hydrology. Traditionally, hydraulic parameters such as transverse resistance and longitudinal conductance are usually estimated by classical methods like pumping tests, tracer studies, etc. which are the most effective but expensive, labour intensive, time-consuming and sometimes destructive (Gelhar 1993; Niwas *et al.* 2011; Benabdelouahab *et al.* 2019; Ullah *et al.* 2020)

The use of the surface resistivity technique, particularly the vertical electrical sounding (VES) can provide useful information on aquifer properties in regions where pumping test data is sparse or unavailable, also when there is an insufficient budget for pump test (Pratap and Dev 2015; Sattar *et al.* 2016; Helaly, 2017). This method is simple, fast, cost-effective and non-invasive. The method measures the potential differences on the surface of the earth due to the current flow within the ground, and it has also been extensively used in groundwater prospecting (George *et al.* 2014; Obiora *et al.* 2015; Hasan *et al.* 2019; Awosika *et al.* 2020), groundwater vulnerability studies (Aweto and Ohwoghre-Asuma 2018; Ejiogu *et al.* 2019), salinity effect on the aquifer system (Zarroca *et al.* 2011; Hasan *et al.* 2018), delineation of the contaminated plume (Adebayo *et al.* 2015; Olagunju *et al.* 2017; Akinola *et al.* 2018 ) and engineering site investigation (Adenika *et al.* 2018).

The secondary aquifer parameters (transverse resistance and longitudinal conductance) calculated from vertical electrical sounding results (layer resistivity, and thickness) have demonstrated to be effective in understanding the spatial distribution of aquifer hydraulic parameters. The relationship between aquifer hydraulic properties and geoelectric properties had been established and applied to evaluate aquifer hydraulic properties and vulnerability (Obiora *et al.* 2016; Niwas and Singhal 1981; Heigold *et al.* 1979; Kelly 1977; Maillet 1947)

The investigated area can be regarded as a water-scarce region and the need for exploiting quality water resources is of utmost importance to the inhabitants of the investigated area and environ. Evaluating aquifer hydraulic properties is germane in resolving hydrogeological problems in this complex geological terrain. Hence, it is imperative to delineate groundwater productive zones for the inhabitants.

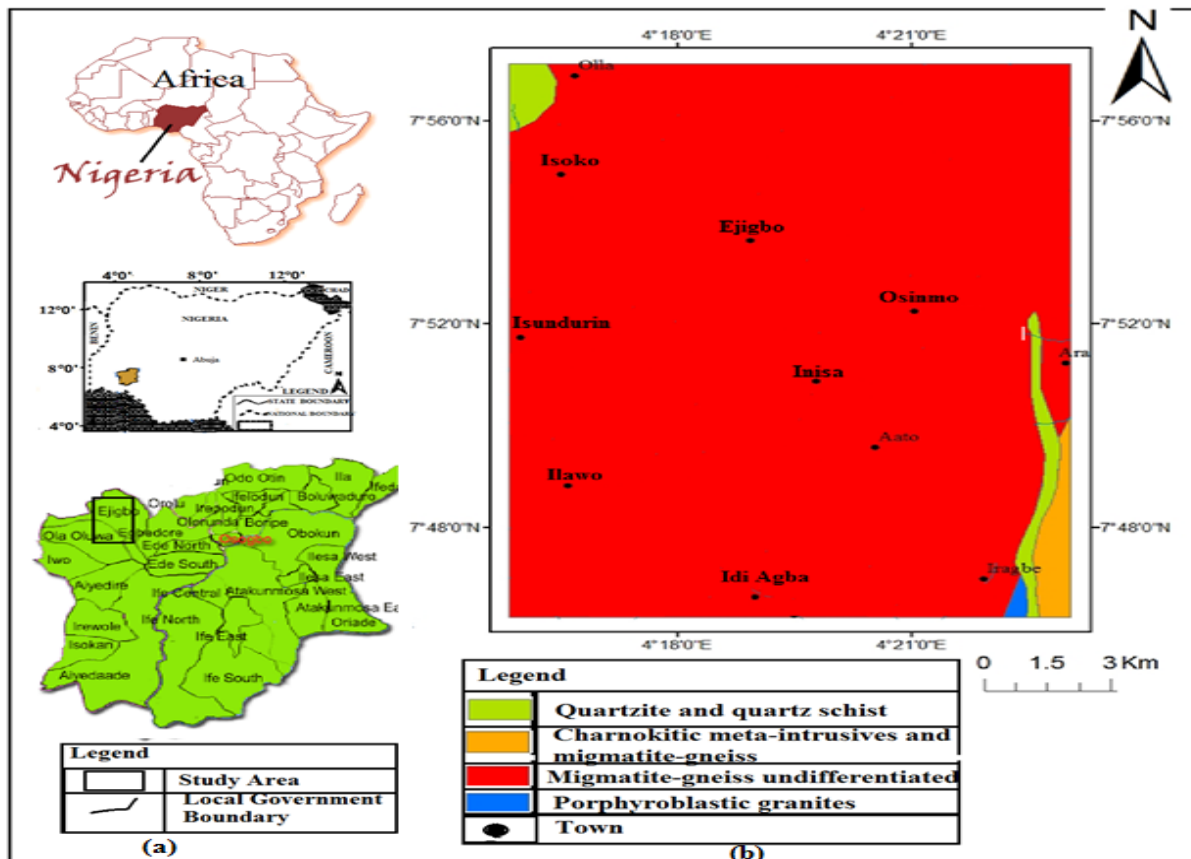
This study aims to evaluate hydraulic parameters and aquifer protective capacity using a cost-effective, non-invasive geophysical method for locating suitable sites for groundwater development. Prior to the evaluation of the hydraulic parameters and aquifer vulnerability index, a quantitative interpretation of the primary geoelectrical parameters will be carried out. The evaluated hydraulic properties will provide useful information for future groundwater exploration and management

## **2. Materials and Methods**

### **2.1 Description of the study area**

The investigated area is situated between latitudes 7°46'N and 7°57'N and longitudes 4°16'E and 4°23'E in Ejigbo, Southwestern Nigeria as presented in Figure 1a. The area is influence by two distinct seasons (wet and dry seasons), the wet season lasts from April to October with an average annual rainfall of 1500 m (Iloeje, 1980), the wet season ensures aquifer recharge and it is very essential for the agriculture activities. The dry season is between November to March. The annual temperature experience in the investigated site is between 25 and 30°C. Geomorphologically, Ejigbo is located within the western uplands of Southwestern Nigeria, with gently undulating topography. The investigated site is part of basement complex rocks of southwestern Nigeria and the main lithology units noticed in the area are quartzite and quartz schist, charnokitic meta-intrusive and migmatite-gneiss, migmatite-gneiss undifferentiated, and porphyroblastic granites (Figure. 1b). In this region, the groundwater occurrence, flow and infiltration are influenced by weathering and tectonic development. The weathered layer aquifer may stand alone or occur in conjunction with the fractured aquifer in the same locality. The major factors that determine the ability of basement rock ability to store, transmit and yield a reasonable amount of groundwater are the extend of the interconnection of the

voids/pore spaces within the weathered regolith, the extent, thickness and continuity of the fractures and on the degree to which the fractures are hydraulically connected.



**Figure 1:** (a): Location map of the investigated area. (b): Geologic map of the investigated area

## 2.2 Methodology

Thirty-two Vertical electrical sounding (VES) profiles (Figure 2) were carried out in the investigated area using electrical survey meter (DDR-3 resistivity equipment). The terrameter sent direct current into the sub-surface (Figure 3) through a pair of electrodes called current electrodes (A and B) and the resulting potential difference generated is measured by another pair of electrodes referred to as the potential electrode (M and N). The generalized measured apparent resistivity is given by equation (1)

$$\rho = GR \quad (1)$$

where G is the geometric factor which depends upon the particular electrode array system used, R is the measured resistance, from Ohm's law,  $R = \frac{V}{I}$ .

For the Schlumberger Array employed in this study,  $AB > 5MN$  and the measured apparent resistivity is given by equation (2)

$$\rho_{sa} \approx \frac{\pi R \left(\frac{AB}{2}\right)^2}{MN} \quad (2)$$

where,  $\frac{\pi \left(\frac{AB}{2}\right)^2}{MN}$  is the geometric factor.

The apparent resistivity computed using equation 2 was plotted against the half current electrode spacing (AB/2) using the log-log graph and the curves were smoothed to expel the

effects of lateral heterogeneities and noisy signature where necessary (Chakravarthi *et al.* 2007; Ibuot *et al.* 2013). The smoothed curves were interpreted using a partial curve matching technique with the aid of the master curve and auxiliary curves. The partial curve matching technique was used to estimate the geoelectric parameters (the resistivity and thicknesses) of the various layers. These geoelectric parameters were used as initial model parameters for a 1-D computer-aided forward modeling interpretation involving WINRESIST VERSION 1.0 software.

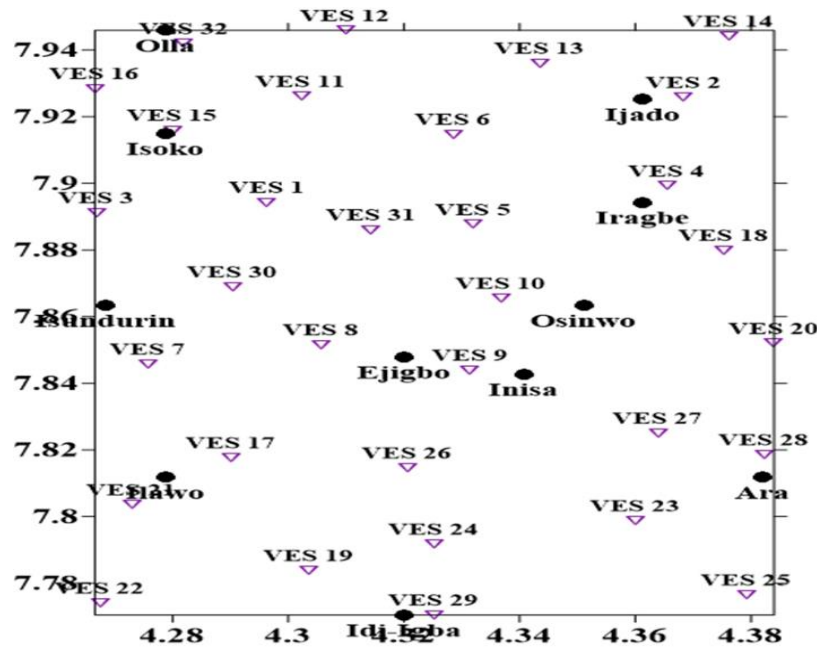


Figure 2 Data Acquisition Map

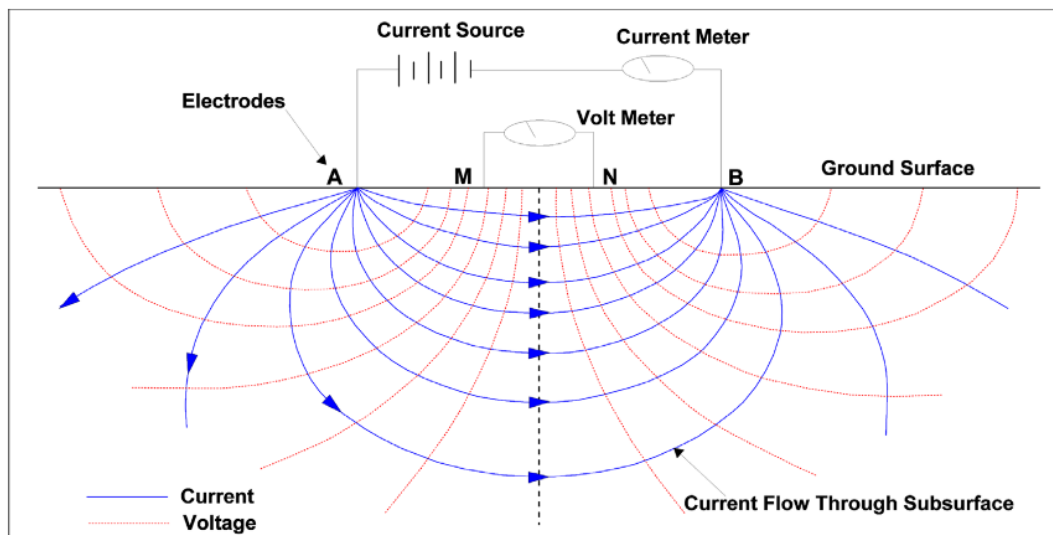


Figure 3 Fundamental concepts for resistivity measurements (modified after Todd and Mays, 1980)

### 2.3 Hydraulic parameters

The relationship between the estimated geoelectric parameters (thickness and resistivity) and hydraulic parameters are presented in equations 3-6. Equation 3 gives the transverse resistance

( $T_r$ ) in  $\Omega m^2$

$$T_r = \sum_{i=1}^n h_i \rho_i = h_1 \rho_1 + h_2 \rho_2 + h_3 \rho_3 + \dots + h_n \rho_n \quad (3)$$

While the longitudinal conductance ( $S_c$ ) in Siemens is given by equation 4

$$S_c = \sum_{i=0}^n \frac{h_i}{\rho_i} = \frac{h_1}{\rho_1} + \frac{h_2}{\rho_2} + \frac{h_3}{\rho_3} + \dots + \frac{h_n}{\rho_n} \quad (4)$$

where  $\rho$  is the resistivity in  $\Omega\text{m}$ ,  $h$  is the thickness calculated in meters, and  $i$  is the number of layers.

In fractured hard rock aquifer like the investigated site, the hydraulic conductivity  $K$  (m/day) is given by empirical relation postulated by Singh 2005,

$$K = 8 \times 10^{-6} e^{-0.0013\rho} \quad (5)$$

Where  $\rho$  is the resistivity of the aquifer.

Equation 6 gives the aquifer transmissivity (Fetter 1988):

$$K = \frac{T}{h} \quad (6)$$

where  $K$  is the hydraulic conductivity in m/day,  $T$  is the transmissivity in  $\text{m}^2/\text{day}$ , and  $h$  is the aquifer thickness in meter.

From the hydraulic parameters, the groundwater potential and aquifer protective capacity was determined. The classification of the groundwater potential withdrawal capacity and the fluid flow ability was based Krasny's (1993) rating (Table 1). The aquifer protective capacity rating which preveis how safe the aquifer layer from contaminants was deduced from the estimated longitudinal conductance. The rating classification (Table 2) proposed by (Kumar et al., 2016) was used in this research.

**Table 1:** Aquifer Protective Capacity Rating (Henriet 1976; Oladapo and Akintorinwa 2007; Kwami et al 2019).

S/N	Total Longitudinal conductance (mho)	Protective capacity rating
1	< 0.1	Poor
2	0.1 – 0.19	Weak
3	0.2 – 0.69	Moderate
4	0.7 – 4.9	Good
5	5 – 10	Very good
6	> 10	Excellent

**Table 2.** The Modified Transmissivity Magnitude Classification (Gheorghe 1978; Krasny, 1993).

S/N	T( $\text{m}^2/\text{day}$ )	Aquifer potential	Groundwater yielding capacity
1	< 0.1	Negligible	Impermeable sources for local water supply are difficult
2	0.1 – 0.9	Very Low	Withdrawal of local water supply with limited consumption
3	1 – 9.9	Low	Smaller withdrawal for local water supply (private consumption)
4	10 – 99	Moderate	Withdrawal of local water supply (small community)
5	100 – 1000	High	Withdrawal of lesser regional importance
6	>1000	Very High	Withdrawal of great regional importance

### 3 Results and Discussion

#### 3.1 Primary and secondary hydraulic parameters interpretation

The summary of the analysis and interpretation of the processed thirty-two VESes data acquired in the investigated area is presented in Table 3. The table gives the primary aquifer properties (resistivities and thicknesses) and shown that the investigated area is marked by heterogeneous lithology with three to five geo-electric layers. Figure 4 gives the typical geoelectric sounding curves in the study area. The contour maps of the variation in aquifer resistivities and thicknesses are presented in Figure 5a and b respectively. The values of the aquifer resistivities ranged from 18 to 318  $\Omega\text{m}$  with an average value of 99.12  $\Omega\text{m}$  while the aquifer thicknesses ranged from 1.7 to 46.2 m with an average value of 12.07 m.

The Dar-Zarrouk parameters (transverse resistance and longitudinal conductance) evaluated using equations 3 and 4 are presented in Table 4. The evaluated values of the transverse resistance in the investigated area ranged from 35.70 to 8518.40  $\Omega\text{m}^2$  with an average value of 1383.23  $\Omega\text{m}^2$ . These values revealed a very low groundwater development class. The contour map of the transverse resistance (Figure 4c) shows the lowest concentration in the southwestern region (VESes 17,19,22), VESes points 6, 20, 25, 27 and 28 also display low values of transverse resistance. The highest value of transverse resistance was observed in the northwest and northeast regions of the investigated area. The transverse resistance is an important geological formation property that is used to express the opposition of an aquifer to vertical flow of fluid.

The evaluated values of the longitudinal conductance varied from 0.023 to 0.189 Siemens with an average value of 0.885 Siemens. The contour map of the longitudinal conductance (Figure 4d) shows the lowest concentration in the western region (VESes 7, 15, 17, 22) and the highest value was observed at the southeastern (VESes 23, 24, 25, 29) and eastern (VESes 10,18, 20) parts of the study area. The high values of longitudinal conductance at these points are presumably due to the thick sequence of alluvium deposits and or comprises of highly weathered. Galin (1979) revealed that the longitudinal conductance assists in differentiating the variation in the total thickness of the subsurface low resistivity geo-materials.

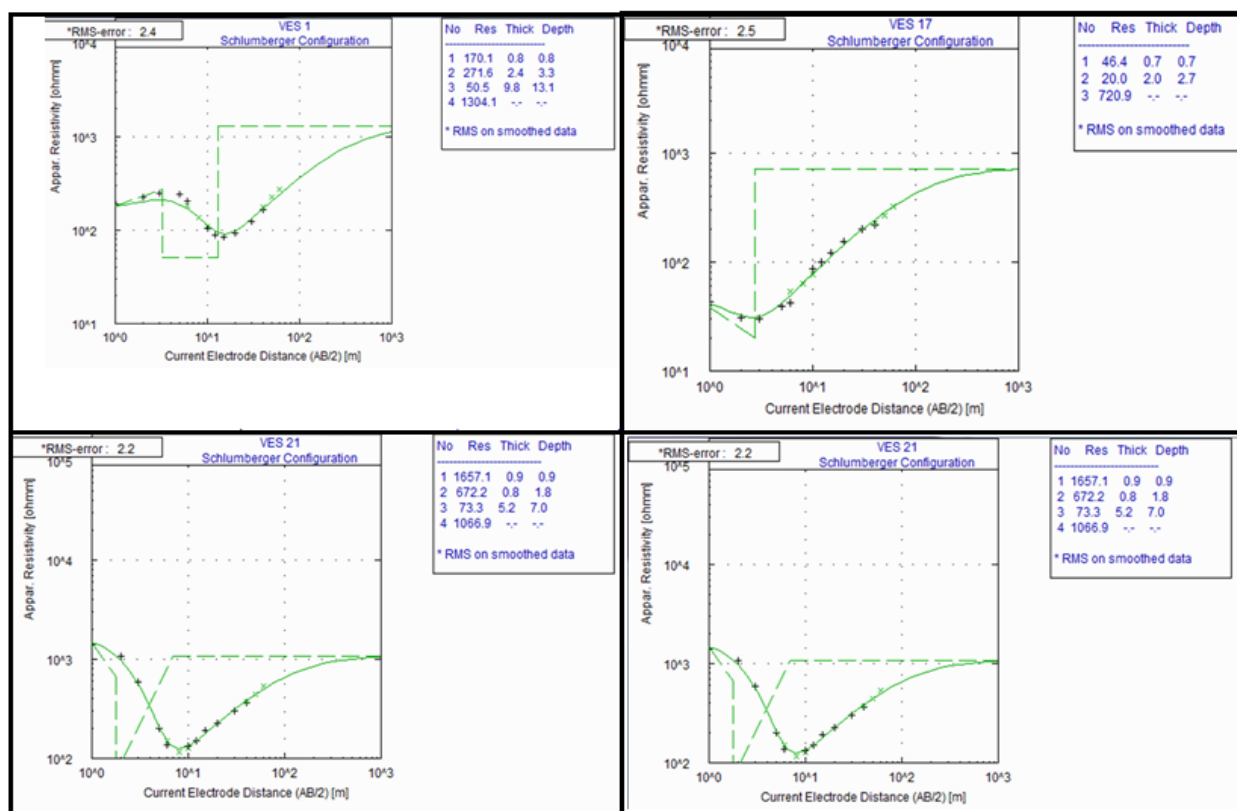


Figure 4: Typical geoelectric curves of the investigated area

**Table 3.** Geoelectric parameters of the investigated area

VES Points	Number of Layers	Resistivity of layers ( $\Omega\text{m}$ )					Thickness of Layers (m)			
		$\rho_1$	$\rho_2$	$\rho_3$	$\rho_4$	$\rho_5$	$t_1$	$t_2$	$t_3$	$t_4$
1	4	170.1	271.6	50.5	1304.1	-	0.8	2.4	9.8	-
2	4	703.9	170.8	52.8	2609.0	-	0.6	2.4	14.9	-
3	5	2692.3	585.6	108.2	356.1	1032.2	1.3	0.7	3.7	45.6
4	4	1778.2	526.8	75.5	3783.5	-	0.4	2.5	7.8	-
5	4	1508.7	446.8	282.4	1222.2	-	0.7	3.8	6.9	-
6	5	154.3	64.0	20.5	72.0	156.0	0.8	0.6	2.9	133.
7	4	171.9	110.5	133.6	589.8	-	0.9	7.2	12.9	1
8	3	977.2	231.5	847.9	-	-	1.0	5.3	-	-
9	4	510.8	2335.6	108.3	9573.8	-	0.5	1.4	6.8	-
10	3	1527.8	44.1	90.9	-	-	1.2	6	-	-
11	5	280.1	125.1	1159.5	182.5	276.0	0.5	0.9	4.4	34.6
12	3	1377.7	52.4	272.5	-	-	1.8	2	-	-
13	4	25.2	139.1	192.2	399.2	-	0.9	4	9.3	-
14	5	105.1	192.6	628.6	317.8	1043.6	0.9	2.0	5.0	16.0
15	4	259.1	89.1	181.0	276.2	-	0.7	4.0	22.8	-
16	5	889.9	407.4	554.1	242.3	152.3	0.7	4.6	14.5	35.2
17	3	46.4	20.0	720.9	-	-	0.7	2.0	-	-
18	4	145	55.9	10.3	94.4	-	1.3	6.3	12.0	-
19	3	133.1	35.1	264.7	-	-	2.6	8	-	-
20	5	97.2	126.9	390.8	62.0	384.9	1.1	1.1	4.7	16.1
21	4	1657.1	672.2	73.3	1066.9	-	0.9	0.8	5.2	-
22	4	261.1	36.3	202.4	101.8	-	0.7	2.6	14.3	-
23	5	163.0	45.8	166.6	86.1	142.1	0.7	3.6	24.7	16.7
24	5	170.1	53.3	103.6	31.0	77.3	0.9	3.0	3.2	17.7
25	4	268.1	123.8	21.6	167.5	-	1	0.9	15.6	-
26	3	622.3	84.8	80.6	-	-	1.4	14	-	-
27	3	329.5	21.3	8981.2	-	-	0.7	1.7	-	-
28	3	251.4	18.2	1647.5	-	-	1.3	2.9	-	-
29	4	107.7	48.5	84.6	213.2	-	1.0	5	14.7	-
30	4	390.6	44.6	295.0	1290	-	0.5	4.4	43.8	-
31	5	96.5	31.5	503.7	110.4	73.2	0.6	1.2	7.6	7.9
32	3	24.8	278.9	543.9	-	-	1.0	4	-	-

**Table 4:** Aquifer parameters of the investigated area

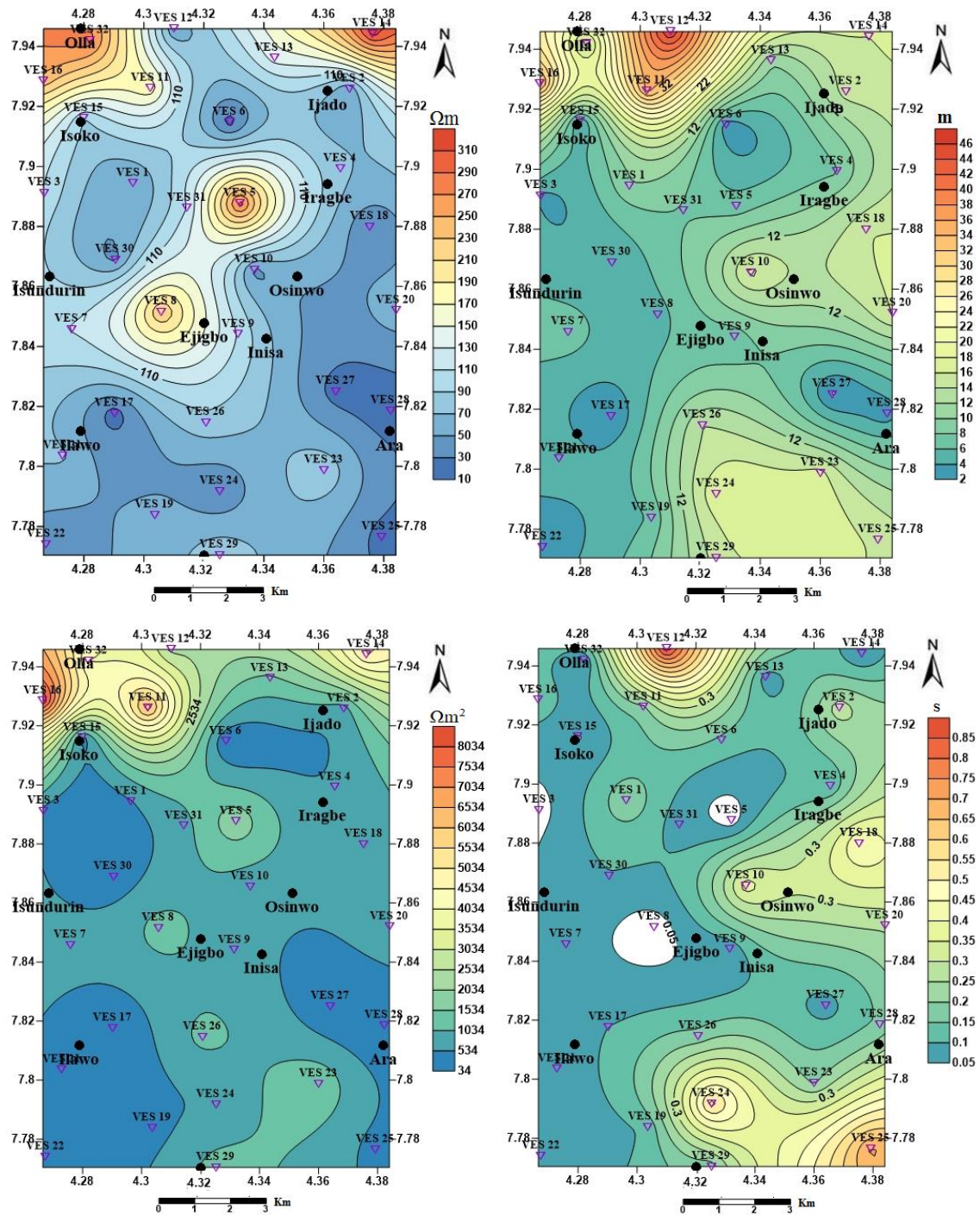
VES Points	Depth to water (m)	Aquifer Resistivity ( $\Omega m$ )	Aquifer thickness (m)	$T_r$ ( $\Omega m^2$ )	$S_c$ (siemen)	K (m/day)	T ( $m^2/day$ )
1	13.1	51	9.8	499.8	0.192	0.6469	6.3392
2	17.8	53	14.9	789.7	0.281	0.6452	9.6132
3	5.7	108	3.7	399.6	0.034	0.6007	2.2224
4	10.7	76	7.8	592.8	0.103	0.6262	4.8842
5	11.4	282	6.9	1945.8	0.024	0.4791	3.3055
6	4.4	21	2.9	60.9	0.138	0.6726	1.9505
7	8.1	111	7.2	799.2	0.065	0.5983	4.3079
8	6.3	232	5.3	1229.6	0.023	0.5112	2.7095
9	8.7	108	6.8	734.4	0.063	0.6007	4.0845
10	17.8	44	16.6	730.4	0.377	0.6528	10.8360
11	40.5	183	34.6	6331.8	0.189	0.5449	18.8522
12	48	52	46.2	2402.4	0.888	0.6460	29.8461
13	11.3	139	10.4	1445.6	0.075	0.5769	6.0001
14	23.9	318	16	5088	0.050	0.4572	7.3145
15	4.7	89	4	356	0.045	0.6157	2.4627
16	55	242	35.2	8518.4	0.145	0.5046	17.7630
17	2.7	20	2	40	0.100	0.6735	1.3469
18	7.6	56	6.3	352.8	0.113	0.6427	4.0488
19	18.4	35	15.8	553	0.451	0.6605	10.4352
20	23	62	16.1	998.2	0.260	0.6377	10.2666
21	7	73	5.2	379.6	0.071	0.6286	3.2688
22	3.2	36	2.6	93.6	0.072	0.6596	1.7150
23	45.7	86.1	16.7	1437.87	0.194	0.6180	10.3207
24	24.8	31	17.7	548.7	0.571	0.6639	11.7510
25	17.6	22	15.6	343.2	0.709	0.6717	10.4787
26	15.4	84	14	1176	0.167	0.6197	8.6757
27	2.4	21	1.7	35.7	0.081	0.6726	1.1434
28	4.2	18	2.9	52.2	0.161	0.6752	1.9581
29	35.3	84.6	14.7	1243.62	0.174	0.6192	9.1024
30	4.9	45	4.4	198	0.098	0.6519	2.8685
31	17.3	110	7.9	869	0.072	0.5991	4.7329
32	15.4	279	14.4	4017.6	0.052	0.4809	6.9254

### 3.2 Hydraulic conductivity (K) and Transmissivity (T)

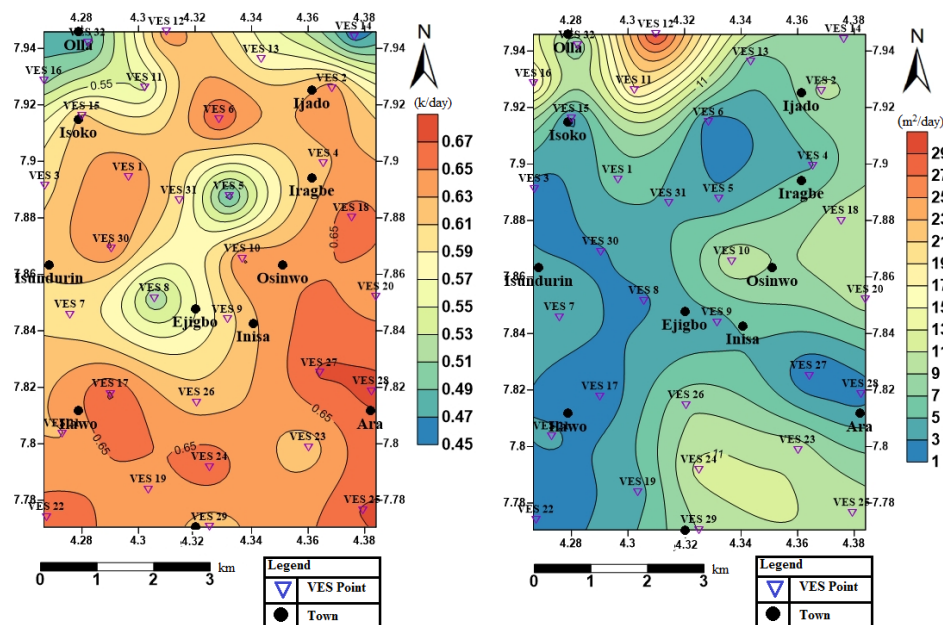
The auriferous layer hydraulic conductivity and transmissivity in the investigated area were estimated and presented in Table 4. The aquifer hydraulic conductivity values evaluated from equation 5 range from 0.4572 to 0.6752 m/day with an average value of 0.6110 m/day. This value indicates a low variability of K in the investigated area and thus implies minimal water bearing zones. The contour map of the hydraulic conductivity (Figure 5a) shows the highest concentration in the north-eastern part of the study area and the lowest concentration in the southern part of the study area. The low values of K observed in some parts may be due to the poor interconnection and geometry of the voids/pore spaces which can affect groundwater flow in the investigated area. Hydraulic conductivity controls the rate at which groundwater flow under a given hydraulic gradient, then, from the map, the groundwater flow directions could be predicted from the zone having high K.



The estimated transmissivity values range from 1.143 – 29.846 m<sup>2</sup>/day with an average value of 7.235 m<sup>2</sup>/day. The variation of the transmissivity values in the investigated area was interpreted using Table 1. it was observed that seventy-two percent (72%) of the VES points show low groundwater potential while twenty eight percent (28%) show moderate groundwater potential (Table 5). Generally, the transmissivity across the investigated area indicates that the groundwater potential is mostly low and partly moderate. This finding is in agreement with the results obtained by Dasho et al. 2017 using remotely sensed satellite data. The contour map of the aquifer transmissivity (Figure 5b) shows that the investigated area is predominated with materials of low transmissivity except in some areas in the southwestern part. These zones with moderate transmissivity in the investigated area are identified as zones with moderate water-bearing potential.



**Figure 5:** Contour maps (a) Aquifer Resistivity (b) Aquifer Thickness (c) Aquifer Transverse Resistance (d) Aquifer Longitudinal Conductance



**Figure 6:** Contour maps (a) Aquifer Hydraulic Conductivity (b) Aquifer Transmissivity

**Table 5:** The inferred aquifer properties

VES Point	Protective Capacity	Aquifer potential
1	Moderate	Low
2	Moderate	Low
3	Moderate	Low
4	Moderate	Low
5	Poor	Low
6	Good	Low
7	Moderate	Low
8	Poor	Low
9	Poor	Low
10	Moderate	Moderate
11	Moderate	Moderate
12	Good	Moderate
13	Moderate	Low
14	Poor	Low
15	Moderate	Low
16	Moderate	Moderate
17	Moderate	Low
18	Good	Low
19	Moderate	Moderate
20	Moderate	Moderate
21	Poor	Low
22	Moderate	Low
23	Moderate	Moderate
24	Moderate	Moderate
25	Good	Moderate
26	Moderate	Low
27	Poor	Low
28	Moderate	Low
29	Moderate	Low
30	Moderate	Low
31	Moderate	Low
32	Poor	Low

### 3.3 Aquifer Protective capacity APC

The values of the total longitudinal conductance calculated were used to evaluate the ability of the overburden unit to retard and filter percolating ground surface polluting fluid into the aquiferous unit. The variation of the aquifer protective capacity values in the investigated area study area was interpreted using Table 2. Table 5 revealed that in the investigated area 12.5% of the VES points have good protective capacity, 65.6% have moderate protective capacity, while 21.9% have poor protective capacity. Majority of the VES locations in the investigated area have Moderate and good protective rating, thus indicating that the aquifers are protected. These locations are less susceptible to contamination due to the presence of natural good filter to percolating fluids and may serve as good points for sitting of shallow hand dug wells if the aquifer potential is rated moderate to very high. The regions around VESes 5, 8-9, 14, 21, 27, and 32 are highly vulnerable to contamination, these areas are not suitable for sitting of shallow hand dug wells even if the aquifer potential is rated moderate to very high, except if good environmental practices such as a reduction in soil pollution loads from a point and non-point sources are put in place. Figure 7 shows the aquifer protective capacity variation within the investigated area.

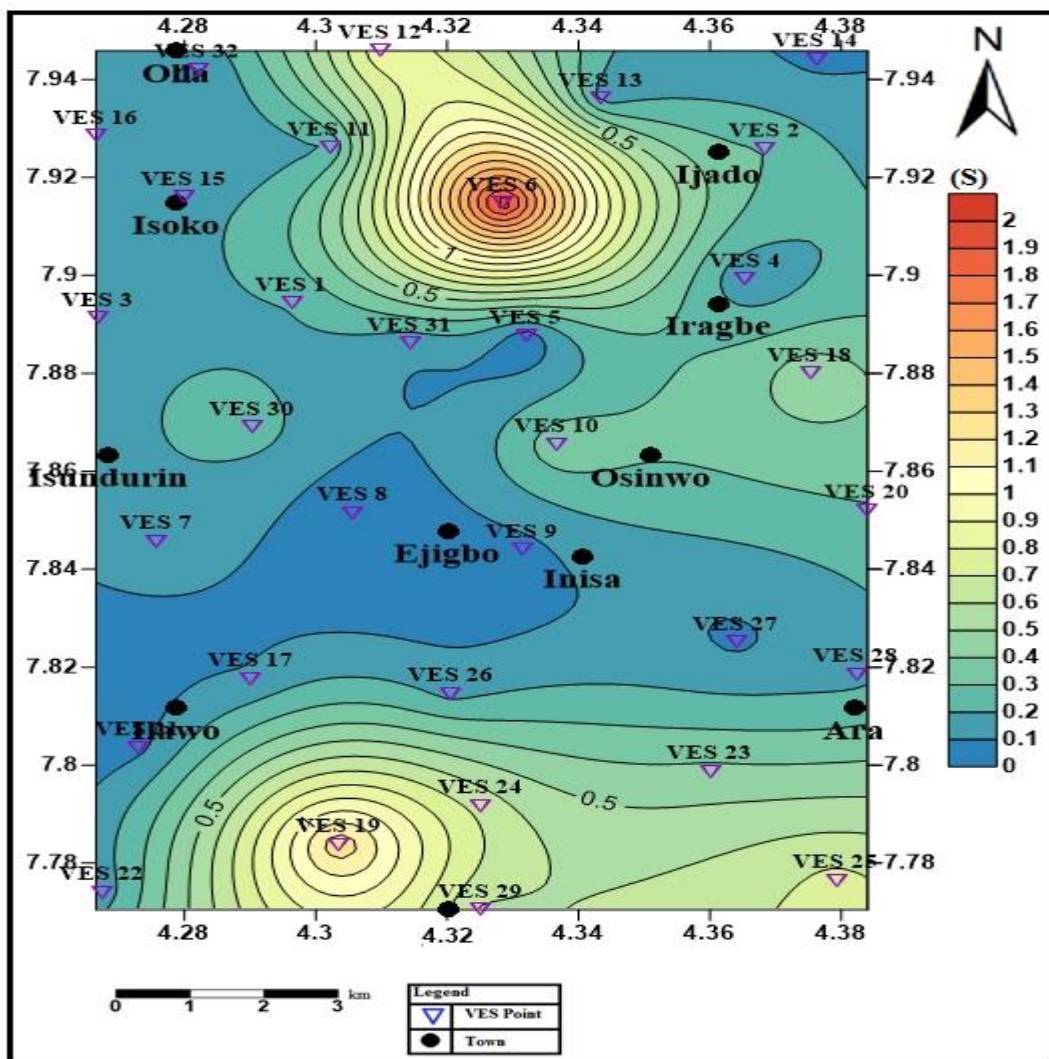


Figure 7 Protective capacity map of the investigated area

### 4. Conclusion

The qualitative and quantitative interpretations of the electrical resistivity data of Ejigbo town and environs were carried out using a non-invasive, cost-effective geophysical method to evaluate the aquifer hydraulic properties and the protective capacity of the investigated area to locate suitable sites for groundwater development. The investigated area is marked by

heterogeneous lithology with three to five geoelectric layers. The aquifer resistivities ranged from 18 to 318  $\Omega$ m while the aquifer thicknesses ranged from 1.7 to 46.2 m. The computed transverse resistance revealed that groundwater development in the investigated area as low/moderate. Also, the transmissivity values computed from the primary aquifer parameters (resistivity and thickness) revealed that 72% of the investigated area has low aquifer transmissivity, while 28% have moderate aquifer transmissivity. This implies that the investigated area has low/moderate water bearing potentiality. The quantitative analysis of the aquifer protective rating revealed that the majority parts (78.1%) investigated area has a good natural filter. Poor environmental practices should be discouraged in areas with poor protective capacity. Based on the aquifer potential rating and the protective capacity, VESes 10-12, 16, 19-20, 23-25 were recommended for drilling sites. The computed hydraulic parameters help in the reduction of the additional cost of carrying out pumping test and offer a cost-effective approach. Conclusively, the groundwater supply potential in the investigated area is between low and moderate ratings.

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