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Full Length Research Article

Evaluation of Geophysical Parameters for Groundwater Productivity in the Commune of Jesse, Delta State Nigeria

[*1]M. O. Ofomola, [1]E. O. Abriku, [1]O. Anomohanran, [2]P. O. Otheremu and [3]B. S. Utieyin
[1]Department of Physics Delta State University Abraka Nigeria
[2]Department of Physics, Delta State University of Science and Technology Ozoro Nigeria
[3]Department of Science Laboratory Technology, Delta State Polytechnic, Otefe-Oghara, Nigeria
[*Corresponding Author: Email: ofomola@delsu.edu.ng; ☎ +234(0)8035057322]

ABSTRACT
Aquifer geohydraulic properties in Jesse were studied by the application of vertical electrical sounding (VES) and pumping test. The VES data was collected using ABEM SAS 1000 Terrameter and results processed using manual matching of curves and computer iteration, and interpreted in the forms of geologic models and geoelectric layers. The aquiferous unit was found at a depth of 5.30 m to 30.30 m with a range of resistivity from 87.30 Ω-m to 1945.40 Ω-m. Dar-Zarrouk parameters estimation and results of borehole pumping test produced the aquifer hydraulic parameters. The hydraulic conductivity values range from8.171 - 8.279 m/day, transmissivity from 43.8770 - 517.7480 m^2/day, and formation factor from 0.369 - 8.501. These results are indications of a prolific and high yielding aquifer capable of withstanding long duration of pumping. Results of groundwater electrical conductivity and total dissolved solids ranged from 11.65 - 198.80 μs/cm, and 29.40 - 35.40 mg/dm^3 respectively, signifying very moderate mineralization of the groundwater. The average electrical conductivity of 68.04 μS /cm and total dissolved solids of 32.58 mg/L were lesser than the acceptable limits of the Nigerian Standard for Drinking Water Quality (NSDWQ) of 1000 μS/cm and 500 mg/L respectively. This study affirmed that the aquifer in Jesse is suitable for groundwater exploitation for local and regional purposes.
KEYWORDS: Formation factor, Hydraulic conductivity, Transmissivity, Total dissolved solids, Vertical electrical sounding

INTRODUCTION
Geoelectric resistivity is a vital tool in geophysical methods with large scale application significance, primarily during the exploration phase of feasibility studies of the earth. It has been used to study the geology, lithostratigraphy, civil engineering/foundation works, environmental applications and, shallow and deep groundwater models (Ekanem, 2020, Thomas *et al*., 2020; Obiora and Ibuot 2020; Anomohanran, 2015; Mgbolu *et al*., 2019; Iserhien-Emekeme, *et al*., 2021). The quality of groundwater is primarily a function of the volume of infiltration of contaminants from the unsaturated zone into the aquifer. The aquifer capacity to retain and filter percolating ground surface polluting contaminants can be described by the longitudinal conductance (S). This is achieved by the values gotten from the layer thickness to resistivity quotient (Henriet, 1976; Braga *et al*. 2006; Ofomola, 2014; Obiora *et al*. 2020). According to George *et al*., (2017), the aquifer physical and hydrogeological properties, porosity and volume of interconnected voids can significantly influence groundwater flow and groundwater yield. This void interconnectivity can be affected by the prevailing compaction and cementation factors. The hydraulic properties which include transverse resistance, longitudinal conductance, hydraulic conductivity, and transmissivity of aquifer are crucial in evaluating the hydrogeological settings (Anomohanran *et al*., 2023; Ofomola *et al*., 2022; Nwachukwu *et al*., 2019). Traditionally, pumping tests from wells have been conducted to measure these parameters. However, such tests are expensive and time consuming and can only provide limited geospatial information. The application of vertical electrical sounding (VES) technique serves as a cheap alternative, to quantitatively determine the aquifer parameters of an investigated area (Ofomola, 2015; Raji and Abdulkadir, 2020; De Almeida *et al*., 2021). Jesse is a growing community and does not have a functional water scheme, and as such, the people depend on water from ponds and hand dug wells to meet their water needs. There is also the problem of knowing the actual depth to good quality water since no geophysical study for groundwater has been carried out in the area. This study therefore sought to unravel the geologic settings, lithologic and geohydraulic parameters associated with the groundwater conditions and development in Jesse using the vertical electrical sounding (VES) and pumping test techniques.

MATERIALS AND METHODS
The Study Area
Jesse is the traditional headquarters and commercial nucleus of the Idjerhe kingdom and also one of the fast-growing towns in Delta State. The area lies within Latitude 5.870°N and Longitude 5.750°E, and 290 kilometers southeast of Lagos, Nigeria, and also 8 km from Sapele town (Figure 1). The area consists of arable land, swamps and age long streams connecting the Ethiope River. It has elevation that is rarely higher than15 m abovesea level, with a slope decreasing toward the Ethiope River. Rainfall in the area varies during the seasons but usually exceeding 3000 mm per annum (Ohwoghere-Asuma *et al*., 2020). Also, the prevailing climatic conditions give rise to the temperature ranging from 24 - 34 ^{o}C. The geological formations inherent in Jesse area is a component of the coastal sedimentary basin and has undergone three sequences of deposition. The first is the marine incursion and land invasion mild folding stage, starting from the middle Cretaceous and terminated in the Santonian time. The second gave birth to the emergence of a Proto Niger Delta and is from the late Cretaceous to the Paleocene era. The third

sequence is from Eocene to Recent which gave an extension of the major Niger Delta (Short and Stauble, 1967). The area is also within the tertiary Niger Delta with three stratigraphic formations. These formations include the Akata, Agbada and Benin, with the Benin Formation being the major water bearing zone. The Coastal and Deltaic plain deposits cover the lithostratigraphic sequence (Ofomola, *et al*., 2016; Anomohanran and Orhiunu, 2018).

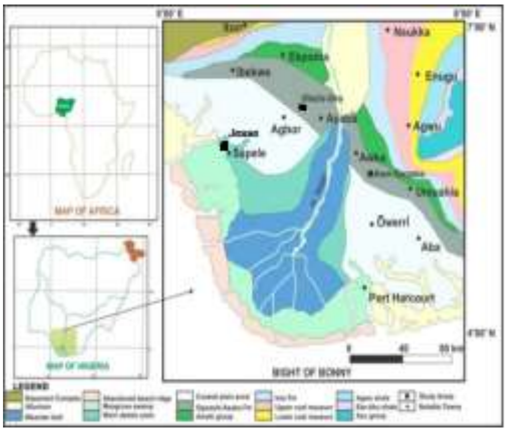

Figure 1. Geological map of Southern Nigeria showing the location of the study area

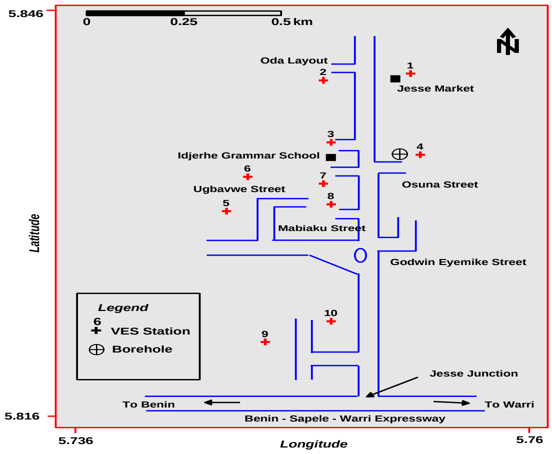

Figure 2. Data acquisition map of the study location

Geoelectrical Resistivity Survey

The ABEM SAS 1000 Terrameter was utilized to acquire ten VES data with the application of schlumberger electrode design at specific locations as shown in Figure 2. The apparent resistivity (ρ_a) for every given position was determined using equation 1.

$$\rho_a = \pi.\left(\frac{\frac{AB^2}{2} - \frac{MN^2}{2}}{MN}\right)\frac{\Delta V}{I} \qquad (1)$$

where AB is the current electrode separation and *MN* the potential electrode separation. Also, I is the injected current and $\Delta V$the measured potential difference. The obtained bi-logarithmic resistivity plot is interpreted by adopting the partial curve matching procedure using master and auxiliary curves (Orellana and Mooney, 1966) to determine the thickness and resistivity of the various layers. Computer iteration constrained by initial curved matched results was later carried out using the Win Resist software (Vander Velpen, 2004) and the true resistivity (ρ) and thickness (h) of the subsurface layers were determined

Measurement of Total Dissolved Solids (TDS) and Electrical Conductivity (EC)

Ten groundwater samples were also collected from boreholes around every VES location and direct in-situ measurement was done to obtain total dissolved solids (TDS) and electrical conductivity (EC). The specific resistivity of pore water was obtained from the reciprocal of the conductivity for each water sample. Also, formation factor and porosity were calculated from equations 2 and 3 by employing the relationship in Archie (1942) and Agbasi (2013) respectively.

$$F = \frac{\rho_o}{\rho_w} \qquad (2)$$

Where ρ_o = specific resistivity of water saturated sand, ρ_w = specific resistivity of pore water and F = Formation factor

$$\emptyset = \left(\frac{a}{F}\right)^{\frac{1}{m}} \qquad (3)$$

Where $\emptyset$ = Porosity, F = Formation, a = empirical constant (default = 1) m = cementation exponent (default = 2).

Pumping Test

A single well pumping test was executed to evaluate the well capacity and the hydraulic characteristics of the water bearing formation. The static water level was measured before pumping began. Also after pumping, the drawdown was measured again in the well after the specific time interval. The Cooper-Jacob's straight-line approach was used for the pumping test data interpretation (Jiao and Rushton, 1995; Kruseman and de Ridder, 2000; Anomohanran, 2014). The graph of draw-down against time of pumping was plottedon a semi-logarithmic paper andemploying the Cooper Jacob solution as shown in equations 4-7, layer transmissivity (T), storativity (S), specific capacity (Sy) and hydraulic conductivity (K) were calculated.

$$\mathrm{T} = \frac{2.3\mathrm{Q}}{4\pi\Delta\mathrm{s}} \qquad (4)$$

$$S = \frac{2.25\,Tt_0}{r^2} \qquad (5)$$

$$\mathrm{Sy} = \frac{Q}{\Delta S} \qquad (6)$$

$$K = \frac{T}{b} \qquad (7)$$

where Q is the discharge rate measured in m^3/s, Δs is the gradient in m, t_o is the time since pumping started and r, the radial distance from the test well and b is the aquifer thickness.

Data Analysis
Geoelectric Aquifer Parameters
The first order layer parameters (resistivity and thickness) were used to generate the second order geoelectric indices or the Dar-Zarrouk factors, namely, longitudinal unit conductance S and transverse unit resistance T_r (Reynolds, 1997). Longitudinal conductance S_L in mhos for a given earth layer can be determined by the equation

$$S_L = \sum_{i=1}^{n}\left(\frac{h_i}{\rho_i}\right) \quad (8)$$

where ρ_i and h_i are the layer parameters. Also, equation 9 gives the value of total transverse resistance (T_r)

$$Tr = \sum_{i=1}^{n}(h_i p_i) \quad (9)$$

The transmissivity (T) is determined as the product of layer hydraulic conductivityand thickness, as shown in equation 10.

$$T = Kh \quad (10)$$

Equation 11 is the connection of aquifer electrical characteristics and hydraulic property and gives an estimation of the hydraulic conductivity across the area (Niwas and Singhal, 1981)

$$T = K\sigma R = K\rho S = Kh \quad (11)$$

where T is the transmissivity, K the hydraulic conductivity, R the transverse resistance (product of resistivity and thickness), S is the longitudinal conductance, σ is the electrical conductivity (inverse of resistivity, ρ) and h is aquifer thickness. If there are no substantial variation in the geologic setting and water quality, the product Kσ is always stable. Values of R and S can be calculated from pumping test generated K and, σ from VES results of stations close to the test borehole, using equation 11. Aquifer transmissivity is the water flow rate across a unit breadth and hydraulic slope (Deeb, 2005). Higher transmissivity values give rise to more prolific aquifer, and smaller values of drawdown from the well (Anomohanran and Iserhien-Emekeme, 2014). Table 1 shows aquifer potential classificationbased ontransmissivity magnitude (Gheorghe, 1978; Krasny, 1993). According to Archie (1942), the specific resistivity of water saturated sand ρ_o, the specific resistivity of pore water ρ_w and the formation factor F are relatedby the expression in equation 12,

$$F = \frac{\rho_o}{\rho_w} \quad (12)$$

.

Also, the Formation factor is related to the porosity by

$$\emptyset = \left(\frac{a}{F}\right)^{\frac{1}{m}} \quad (13)$$

where $\emptyset$ = Porosity, F = Formation, a = empirical constant (default = 1) m = cementation exponent (default = 2) (Agbasi, 2013).

RESULTS AND DISCUSSION

Geoelectric Survey
The typical sounding curves and interpreted VES results for the ten locations are presented in Figure 3 and Table 2, respectively. Geological units inferred from the geoelectrical cross-section are supported by lithologic logs obtained from a borehole, indicating that the region is has three to five distinct geoelectric layers (Figure 4), identified aslateritic topsoil, laterite sand, fine sand, fine to medium grain sand and coarse grain sand. The aquifer resistivity spatial distribution map is shown in Figure 5 with the minimum value of aquifer resistivity (87.30 Ω-m) recorded in VES 6 and the maximum value (1945.40Ω-m) in VES 9. The aquifer depth has a minimum value (5.30 m) at VES 1 and maximum (30.30 m) at VES 4 and spatially distributed as presented in Figure 6. The aquifer depth in the area is 11 - 20 m as indicated around the central part of the map. The average aquifer resistivity and thickness is 694.90 Ω-m and 21.78 m respectively, with an average depth to aquifer of 13.61 m.

Pumping Test Results
From Figure 7, the drawdown per log cycle was determinedas 0.41 m. The well has radius of 0.11 m with discharge of 0.1728 m^3/min. The time of pumping is 3.4 s and average aquifer thickness is 13.4 m. These values were entered into the Cooper–Jacob equation to obtain the various aquifer parameters.

$$T = \frac{2.3\ Q}{4\pi \times \Delta S} = \frac{2.3 \times 0.1728\ m^3/min}{4\pi \times 0.41\ m} = 0.077\ m^2/min$$

For specific capacity,

$$Sy = \frac{Q}{\Delta S} = \frac{0.1728}{0.41} = 0.421\ m^2/min$$

For storativity,

$$S = \frac{2.3\ Tt_0}{r^2} = \frac{2.3 \times 0.077\ m^2/\min \times 3.4\ min}{0.11^2\ m} = 49.764$$

Hydraulic conductivity, K:

$$K = \frac{T}{b} = \frac{0.077\ m^2/min}{13.4\ m} = 0.00574\ m/min$$

Hence, converting hydraulic conductivity to units of m/day,

$$K = 0.00574 \times 24 \times 60 = 8.26\ m/day$$

Table 1: Aquifer Potential classificationon (Gheorghe, 1978; Krasny, 1993)

T (M^2/DAY)	AQUIFER POTENTIAL	GROUNDWATER YIELDING CAPACITY
>1000	Very High	Very high Withdrawal of great regional importance
100 – 1000	High	Withdrawal of lesser regional importance
10 – 100	Moderate	Withdrawal of local water supply (e.g., small community)
1 – 10	Very low	Smaller withdrawal for local water supply (private consumption)
0.1 – 1	Low	Withdrawal of local water supply with limited consumption
< 0.1	Negligible	Impermeable sources for local water supply are difficult

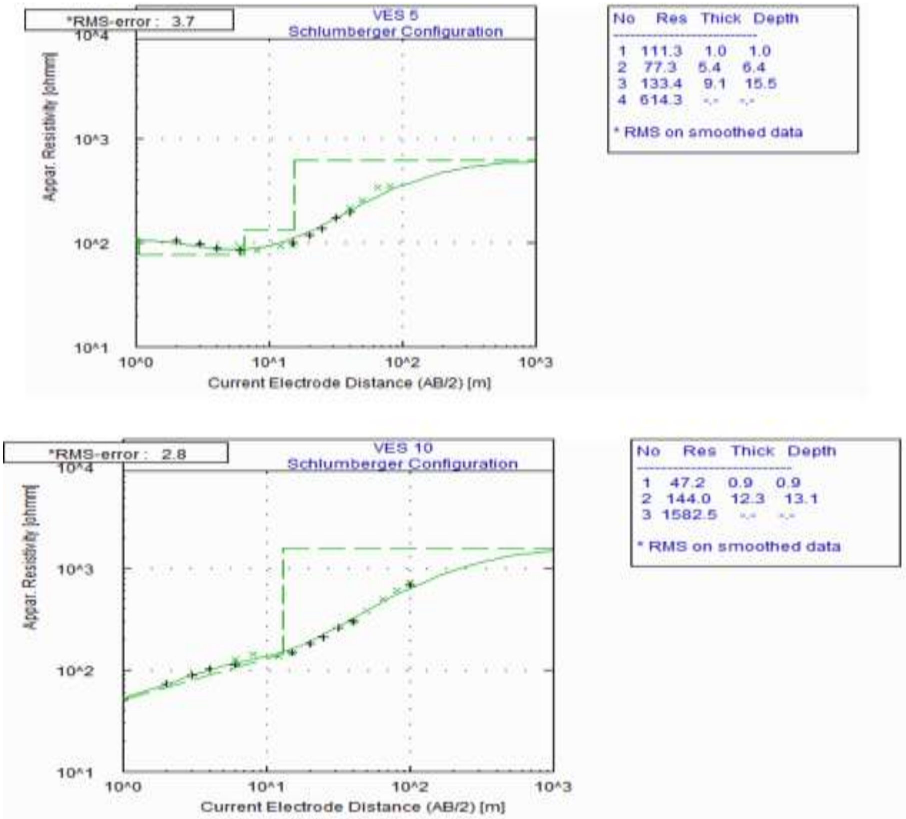

Figure 3: Sounding curves obtained for VES 5 and 10

Geoelectric and other geohydraulic quantities such as the transverse resistance, hydraulic conductivity, transmissivity, and porosity were computed using apparent resistivity, depth as well as aquifer thickness derived from the computer iteration of the primary VES data as presented in Table 3. The hydraulic parameters estimation was computed using equation 5 with hydraulic conductivity data of the single well pumping test given as 8.26 m/day. Hydraulic conductivity obtained across the area varied from 8.171 - 8.279 m/day, and transmissivity from 43.8770 - 517.7480 m^2/day. From the hydraulic conductivity classification scheme of Vrbka *et al.* (1999), the aquifer in the area is described as permeable, which imply a productive high yielding aquifer. Results of transmissivity (Table 4) suggest a prolific aquifer with moderate to high groundwater potential as shown in Figure 8 (Iserhien-Emekeme *et al*., 2017). The storage capacity results of 0.421 m^2/min showed a high yielding aquifer that can support heavy pumping (Anomohanran, 2015). Also, the storativity value is an indication that the aquifer is semi confined with enough pressure to deliver substantial volume of water. The estimated formation factor according to equation 6 ranges from 0.369 - 8.501 (Figure 9). This range of formation factor values is an indication of the existence of finer particles to bigger diameter particles which are most likely sand and this is true for saturated aquifers (Soupios *et al*., 2007).

Table 2: Interpreted field results obtained from computer iteration

VES STATIONS	RESISTIVITY (Ωm)					THICKNESS (m)				DEPTH (m)				CURVE TYPE
	ρ_1	ρ_2	ρ_3	ρ_4	ρ_5	h_1	h_2	h_3	h_4	d_1	d_2	d_3	d_4	
VES 1	387.5	493.6	390.5	1725.0	-	1.5	0.6	5.3	-	1.5	2.1	7.3	-	KA
VES 2	533.7	1036.5	1324.8	3477.0	-	0.9	2.1	6.9	-	0.9	3.0	9.9	-	AA
VES 3	555.7	957.2	860.4	1320.0	1034.0	0.7	1.6	6.1	54.6	0.7	2.3	8.4	63.1	KHK
VES 4	108.0	564.3	747.5	925.4	-	0.5	29.7	62.4	-	0.5	30.3	92.7	-	AA
VES 5	111.3	77.3	133.4	614.3	-	1.0	5.4	9.1	-	1.0	6.4	15.5	-	HA
VES 6	98.1	87.3	499.7	-	-	1.4	10.1	-	-	1.4	11.5	-	-	H
VES 7	75.4	195.7	356.7	1150.7	-	0.8	8.3	14.6	-	0.8	9.0	23.7	-	AA
VES 8	68.9	496.9	498.4	1167.1	-	1.0	5.0	28.2	-	1.0	5.9	34.1	-	AA
VES 9	87.7	282.7	106.1	1945.4	599.2	0.7	1.0	8.6	14.3	0.7	1.7	10.3	24.7	KHK
VES 10	44.2	144.0	1582.5	-	-	0.9	12.3	-	-	0.9	13.1	-	-	A

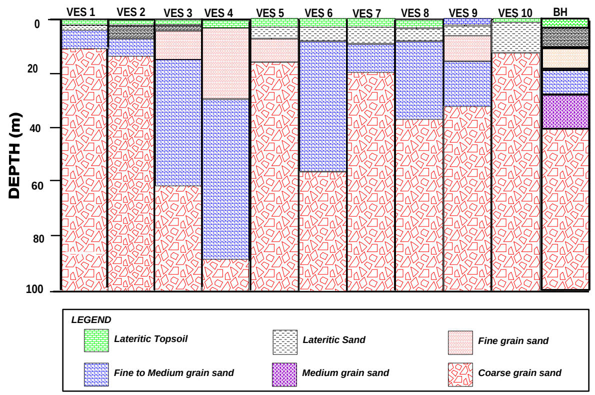

Figure 4: Lithological representation derived from geoelectric data and borehole log

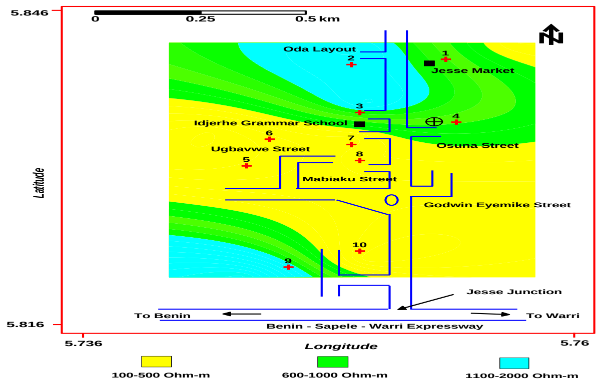

Figure 5: Aquifer resistivity map of Jesse

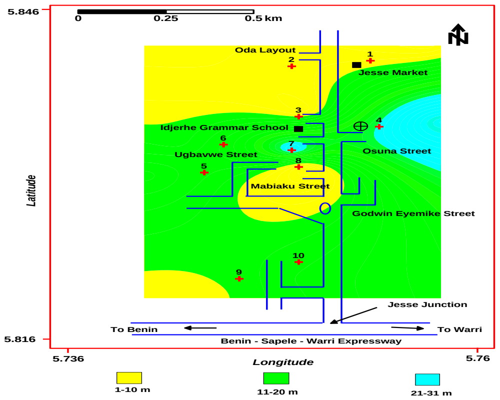

Figure 6: Map of depth to aquifer in Jesse

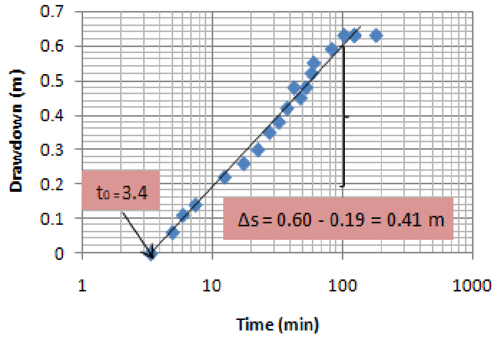

Figure 7: Graph of drawdown (m) against time (min) at Jesse

Table 3: Summary of computed geo-electric and hydraulic parameters

VES STATIONS	ρ_a(Ωm)	h_a (m)	S (Ω)$^{-1}$	T_r(Ωm^2)	Tc (m^2/day)	K_c(m/day)	ρ_w(Ωm)	F	φ (%)
VES 1	390.50	5.30	0.0136	2069.65	43.8770	8.279	858.37	0.455	1.483
VES 2	1324.80	6.90	0.0052	9141.12	56.6750	8.214	660.94	2.004	0.706
VES 3	1320.00	54.60	0.0414	72072.00	454.0540	8.316	535.62	2.464	0.637
VES 4	747.50	62.40	0.0835	46644.00	517.7480	8.297	91.74	8.148	0.350
VES 5	133.40	9.10	0.0682	1213.94	75.1430	8.257	50.30	2.652	0.614
VES 6	87.30	10.10	0.1157	881.73	83.4120	8.259	198.02	0.441	1.506
VES 7	357.70	14.60	0.0408	5222.42	120.6380	8.263	64.52	5.544	0.425
VES 8	498.40	28.20	0.0566	14054.88	233.3110	8.273	191.20	2.607	0.619
VES 9	1945.40	14.30	0.0074	27819.22	116.8410	8.171	228.83	8.501	0.343
VES 10	144.00	12.30	0.0854	1771.20	101.6670	8.266	390.63	0.369	1.647

Table 4: Transmissivity and aquifer potential rating in Jesse

VES	TRANSMISSIVITY	GROUNDWATER POTENTIAL
1	43.8770	Moderate
2	56.6750	Moderate
3	454.0540	High
4	517.7480	High
5	75.1430	Moderate
6	83.4120	Moderate
7	120.6380	High
8	233.3110	High
9	116.8410	High
10	101.6670	High

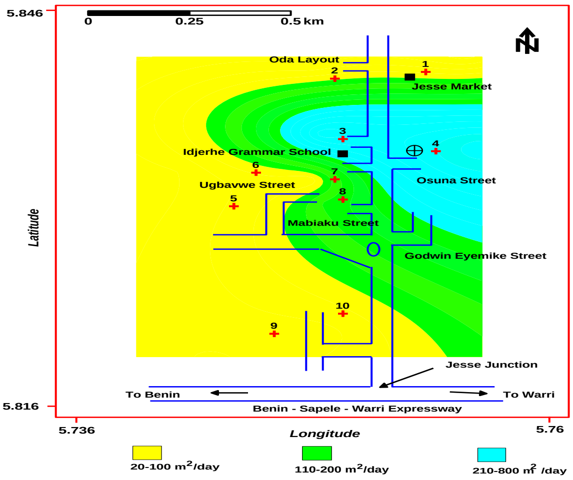

Figure 8: Aquifer transmissivity map

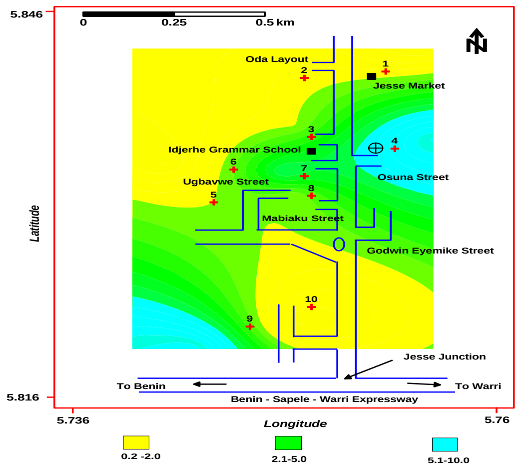

Figure 9: Aquifer Formation factor

Hydro-physical Parameters Analysis

The hydro-physical analysis results for total dissolved solids (TDS) and electrical conductivity (EC) of water samples collected from existing boreholes is presented in Table 5. Table 5 showed that the mean for total dissolved solids is 32.58 mg/L while that for electrical conductivity is 68.04 µS /cm. These values are lower than the allowable limits of the Nigerian Standard for drinking water quality, SON (2015) which is 500 mg/L and 1000 µS/cm for total dissolved solids and electrical conductivity respectively. Low TDS is an indication of fresh to moderately mineralised subsurface, with an improved groundwater suitability for drinking and domestic purposes. Also, low EC means a reduced concentration of pollutants and increase suitability of groundwater. The specific resistivity of pore water was obtained from the reciprocal of the conductivity for each water sample, and this was applied to evaluate the formation factor. The quality of water samples fell within the acceptable level for domestic and agricultural purpose (WHO, 2011).

Table 5: Hydro-physical analysis result of groundwater samples from Existing boreholes

VES STATION	TOTAL DISSOLVED SOLID (TDS) (mg/dm³)	CONDUCTIVITY (µs/cm)
1	32.80	11.65
2	35.40	15.13
3	34.20	18.67
4	33.00	109.00
5	32.60	198.80
6	31.40	50.50
7	32.00	155.00
8	30.60	52.30
9	34.40	43.70
10	29.40	25.60

CONCLUSION

Geoelectric resistivity measurements using VES technology have been successfully used to evaluate the primary geoelectric parameters of aquifers and to calculate the Dar Zarrouk and hydraulic parameters which were used for aquifer potential determination in Jesse. Groundwater potential is high from the calculated transmissivity values. Also, hydro-physical analysis of groundwater samples displayed that the quality of water obtained from the study area were within the acceptable level for domestic and agricultural use. This study highlights the contribution of geophysical methods in the determination and distribution of hydraulic parameters that can be used in a synergistic effort to monitor, evaluate, and manage groundwater in and around the area. Developers and appropriate government agencies are to reduce careless dumping of waste in order to maintain the aquifer integrity and groundwater quality.

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