Hydrogeologic Survey Using Electrical Resistivity Method for Sustainable Water Supply Development in Parts of Owerri, Southeastern Nigeria

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***Abstract*: Electrical resistivity method for evaluation of groundwater potential in the Owerri North was carried out based on aquifer transmissivity obtained using Dar Zarouk parameters and pumping test data. Twenty vertical electric soundings (VES) were carried out in this study. The field data were acquired using the Omega-500 resistivity meter and interpreted using Advanced Geoscience Incorporation (AGI) 1D resistivity inversion software. Five of the VES stations were sited near existing boreholes from which pumping test data were acquired. Transverse resistance and Longitudinal conductance were determined, which together with hydraulic conductivity derived from pumping test data enabled the estimation of aquifer transmissivity and its variation in the study area. The aquiferous layers are composed mainly of sands and sandstones. Resistivity values varied with depth and ranges from 0.10Ωm to 1208.50Ωm. The aquifer depth varied from 8.50m to 67.07m. The aquifer thickness varied across the study area from a value of 8.32m around ChukwumaNwoha to 199.42m measured at Agbala. Areas having high aquifer thickness also have corresponding high Transmissivity values and so have high groundwater potential. High transverse resistance above 10000Ω were observed in areas around Owaelu, while low values of 3100Ω and less were observed in areas such as Emekuku. Areas around VES 6, 11 and 15 are underlain by high Longitudinal conductance aquifer materials. Transmissivity values are fairly high and varied from 264m^2/day at Azaraegbelu to 276m^2/day at Shoprite Egbu. The study revealed that the study area has good prospect for sustainable groundwater supply.**

***Keywords*: Groundwater, Transmissivity, Pumping test, Dar Zarouk parameter, resistivity**

I. INTRODUCTION

There is growing necessity for improved water supply for domestic, agricultural and industrial uses. There is also need to establish safe means of sewage disposal in the study area to control the sanitation related diseases, prevalent in the area. The Government's inability to provide water to citizens has resulted to proliferation of private shallow and substandard water wells, predominantly producing water of poor quality (Nwachukwu, 2022). Hence there are several cases of abortive, failed and abandoned water wells in several homes, causing economic loss, stress and unhappiness to households. Sometimes an individual may have made two or more abortive wells before success, which still produce water for a period not exceeding five years. The fact remains that there is increasing water crises in the study area despite all private efforts and constrained effort of Government. Hence the United Nations millennium development goal that declared water for all by the year 2015 ended with no success in this area (Nwachukwu, 2022).

In the light of the foregoing, this research is designed to carry out thorough geophysical survey of the study area, incorporating the borehole information to delineate the depth to water table and sites for drilling standard water wells to solve the water problems in the area.

A lot of research work on the theory and application of vertical electrical sounding (VES) in groundwater exploration and development have been published and are available in literature.

Various types of hydro-geophysical techniques available for ground water evaluation can be found in Telford and Sheriff (1990). Eke and Igboekwe (2011) applied Vertical Electrical Sounding (VES) method to conduct geoelectric analysis of groundwater in Ohafia area.

Similarly, groundwater potential evaluation has been successfully carried out using Vertical Electrical Sounding (VES) by Joseph (2012), Ekine and Iheonunekwu (2007), Layade et al. (2017), Nnamdi et al. (2019), Okiongbo and Akpofure (2012), Ruth (2014), Coker et al, (2009) and Oyedele and Olayinka (2012)

Location Of The Study Area

The study was carried out in Owerri North, Imo State Nigeria. It lays between the coordinates 05^{0}31'N, 07^{0}01'E and 05^{0}22'N, 07^{0}08'E (Fig 1). There is good road network in the study area which enhanced movement during the field work. There is virtually no surface water draining the area. The Otamiri River which joins Nworie River in Owerri municipal and drain westwards has its source at Egbu in the study area, hence the inhabitants depend solely on groundwater for their water needs.

Geology Of The Study Area

Fig. 2 shows the geological map of Imo and Abia States in which the study area is located. The following stratigraphic units can be identified: The Benin Formation, Nsukka

Formation, Imo Shale Group, Ameki Formation, Ogwashi-Asaba Formation and Ajali Formation

Owerri North is underlain by the Benin Formation, which consists mainly of loose sands, very coarse sandstone and some little gravel and intercalation of shale/clay lenses of Pliocene to Miocene age (Horton, 1965; Ananaba, et al., 1993). The sandstone deposit has high porosity of 30% to 40% and a high permeability value ranging between 1 to 2 Darcy's (Onyeagocha, 1980). These characteristics of the sandstone are responsible for the availability of groundwater within the study area. Thickness of the formation is about 800m at its depocenter while the average depth of water table is within the range of 23m (Nwachukwu et al. 2010).

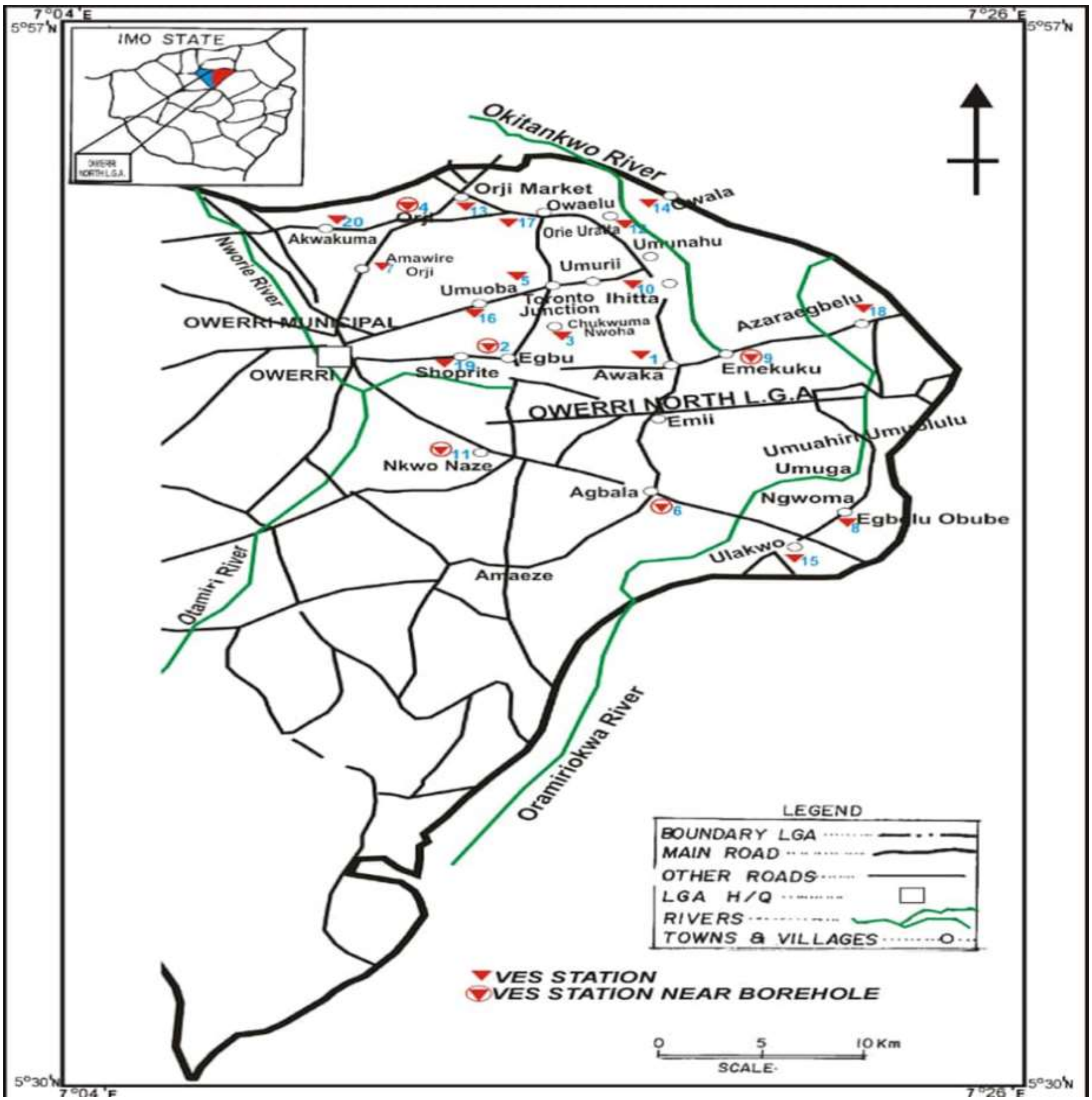

Fig. 1: Map of the Study Area Showing the VES Stations

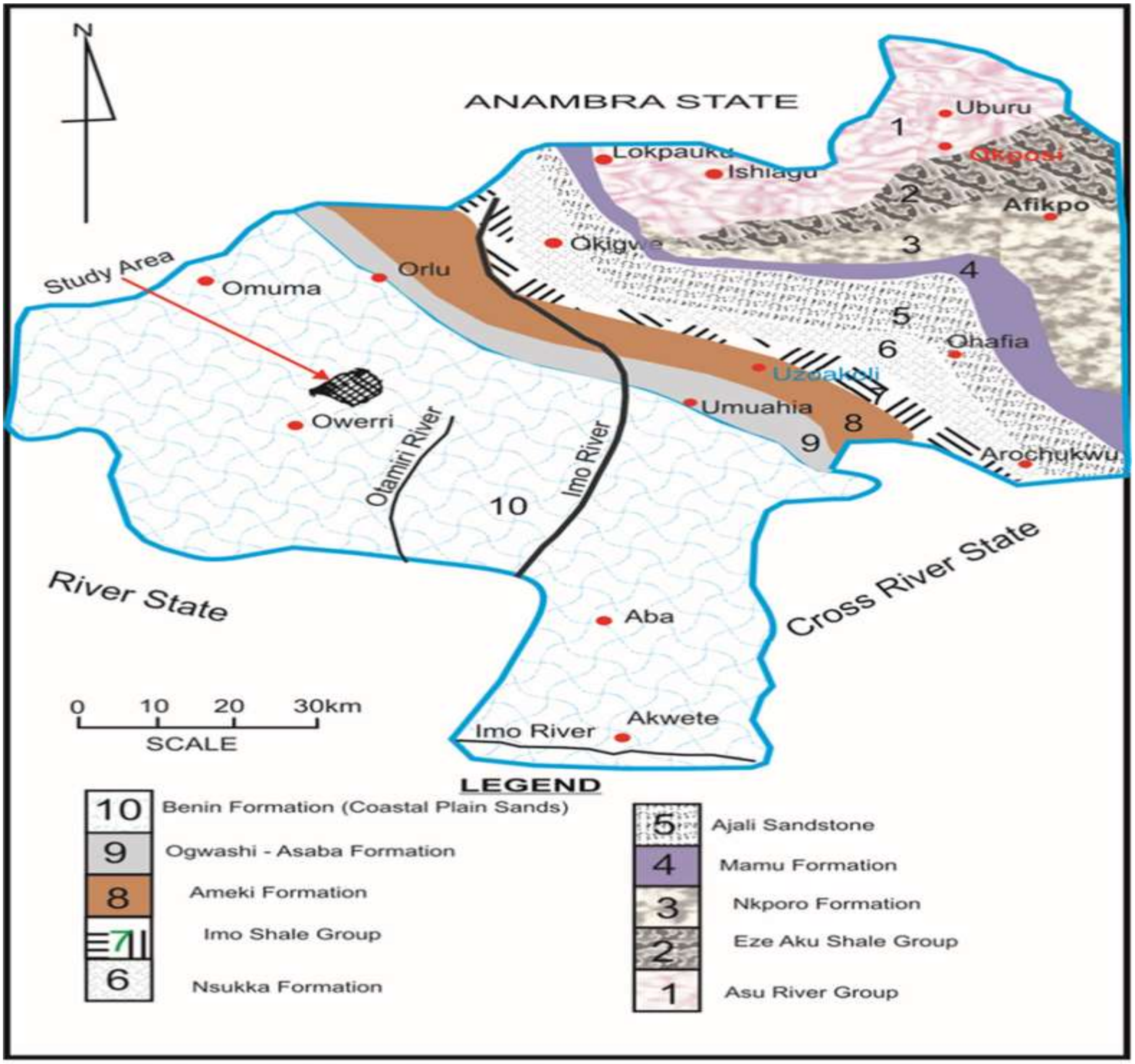

Fig. 2: Geological map of the study area. (Adapted from Nwosu and Ndubueze, 2016)

II. THEORETICAL BACKGROUND

Geoelectric parameters: There are two main quantities that can be used to describe a geoelectric layer. These are the resistivity p_i and thickness h_i where

i = the position of the layer (Zhody et al., 1974). Other parameters include longitudinal conductance and transverse resistance which are derived from the layer resistivity and thickness.

By considering a column of unit square cross sectional area cut out of group of layers of infinite extent, the total transverse unit resistance R is given as:

$$R = \sum_{i=1}^{n} h_1 p_i \quad i = 1,2,3, \dots n \qquad 1$$

The total longitudinal unit conductance,

$$S = \sum_{i=1}^{n} \frac{h_1}{p_i} \quad i = 1,2,3, \dots n \qquad 2$$

Where p_i and h_i are the resistivity and thickness of the *ith* layer. The average longitudinal resistivity,

$$p_i = \frac{H}{S} \qquad 3$$

$$\text{where} \quad H = \sum_{i=1}^{n} h_i i \quad i = 1,2,3, \dots n \qquad 4$$

and the average transverse resistivity

$$p_i = \frac{R}{H}$$

The longitudinal conductance S_i can also be represented by

$$S_1 = \sigma_1 h_i \qquad 5$$

Where σ_i is the layer electrical conductivity which is analogous to the layer transmissivity, T_{ri} used in groundwater hydrology (Mbonu et al, 1990), given by.

$$T_{ri} = K_i h_i \qquad 6$$

where Ki is the hydraulic conductitivty of the ith layer of thickness hi. The parameters R and S are called the Dar Zarrouk parameters which have been proved to be very powerful in enhancing the interpretation of groundwater surveys (Zhody et al., 1974).

The relationship between aquifer transmisivity T_r and transverse resistance R and that between T_r and S have been derived analytically by Niwas and Singhal (1981) as follows:-

$$T_i = \mathrm{K}\sigma\mathrm{R} = \frac{\mathrm{KS}}{\sigma} \qquad 7$$

According to Niwas and Singhal (1981), in areas where the geologic setting and water quality do not vary greatly the product Kσ remains fairly constant. Hence if the values of K from the existing boreholes and σ from the sounding interpretation around the borehole are available, it is possible to estimate the transmissivity and its variation from place to place from the determinations of R or S for the aquifer.

Aquifer Parameters from Pumping Test Data: The parameters are determined using the Logan (1964) - approximation method for calculating the transmissivity T_r and hydraulic conductivity k. The basis of this approximation is Thiem's (1906) in Logan (1964) - equations for steady state flow conditions in confined aquifer, which was based on the following assumptions:

(i) The aquifer must be of infinite extent, homogeneous, isotropic and of uniform thickness.
(ii) That prior to pumping, the piezometric surface and/or the phreatic surface *must* be horizontal over the area influenced by the pumping test
(iii) That the aquifer is pumped at a constant discharge rate, the pump penetrating well into the entire aquifer and receiving water from the aquifer by horizontal flow.

Based on the above assumptions Thiem's equation for an observation well a distance of r_1 from the pumped well is given by:

$$\mathrm{Q} = \frac{2\pi\mathrm{tkh}S_{\mathrm{mw}} - S_{\mathrm{mi}}}{\mathrm{In}\,\frac{r_{\mathrm{i}}}{\mathrm{r_w}}} \qquad 8$$

Where Q = well discharge in m^3/ day

K = average hydraulic conductivity in m / day
h = thickness of the aquifer in metre
S_{mi} = steady state drawdown in observation well in metres.
S_{mw} = maximum drawdown in the pumped well in metres.
r_i = distance of the observation well from the pumped well.
r_w= radius of the pumped well in metres.

This equation was modified by Logan (1964) for steady state flow in confined aquifer

And further reduces the equation to:

$$\mathrm{Kh} = \frac{1.18\mathrm{Q}}{S_{\mathrm{mw}}} \qquad 9$$

$$\therefore \quad \mathrm{K} = \frac{1.18\mathrm{Q}}{HS_{\mathrm{mw}}} \qquad 10$$

Shown in tables 5 is the pumping test data obtained for some boreholes in the study area.

III. METHODOLOGY

FIELD PROCEDURE; Twenty vertical (20) vertical electrical soundings (VES) using the Schlumberger electrode configuration were carried out. At each location, four electrodes consisting of two current electrodes A and B, and two potential electrodes M and N were placed along a straight line on the land surface such that the current electrode spacing AB is greater than or equals five times the potential electrode spacing MN. This Schlumberger resistivity method measures the variations in the earth's apparent resistivity with depth from a given point of electrode spread. The electrodes of about 0.7m long were pushed into the earth with the aid of a hammer.

The position of the current and the potential electrodes were also noted before readings were marked using the measuring tape. The cables were ran in parallel adjacent to the Ohmega-500 resistivity meter. The current is initiated by the "start" button or key on the resistivity meter. The field resistance is displayed and then recorded. The readings of the resistance taken were recorded against its corresponding electrode spacing as observed from the resistivity meter as current electrode spacing increased. The potential electrodes were kept constant as current electrode spacing increased until it became necessary to increase when the recorded signal diminished. At each VES station, the Global Positioning System GPS was usedto measure and record the coordinate and elevations.

Data Analysis And Interpretation; after initial manual computation to obtain the apparent resistivity, a computer based interpretation was done using the Advance Geosciences Incorporation (AGI) ID resistivity inversion software and Schlumberger Automatic Analysis Version. The model results obtained are shown in Fig. 3 to 5 and Tables 1 to 3. The lithologic units were assigned by integrating information from standard resistivity values of soil according to (Vingoe, 1972) and available borehole information (Table 5 and Fig. 6). Dar Zarouk parameters of Transverse resistance and Longitudinal conductance were determined using equations 1 to 7, which together with hydraulic conductivity derived from pumping test data enabled the estimation of aquifer transmissivity using equations 8 to 10.

IV. RESULTS AND DISCUSSION

Typical model results obtained for the study area are shown in Fig. 3 to 5 and corresponding analytical results showing the lithologic units in Tables 1 to 3. The study area is underlain by multi-layered earth, with the aquiferous layers composed mainly of sands (Fig 6). The aquifer resistivity ranges from 0.1Ωm to 1208.5Ωm. Table 4 is the summary of the VES model results for the study area. Table 5 is the pumping test data obtained in the study area while Table 6 is the summary of the aquifer characteristics computed for all the VES stations in the area.

Table 1. Analytical result at Owala-Uratta, Owerri North

Layer	Depth (M)	Resistivity (Ohm-M)	Lithology	Color
1	3.27	9657.5	Topsoil lateritic/ sandstone	Orange
2	6.59	1409	Sand	Red
3	25.84	2363	Sand	Red
4	33.08	2681	Sand	Yellow
5	49.35	5836.2	Sandstone	Green
6	165.00	94.9	Clay	Blue

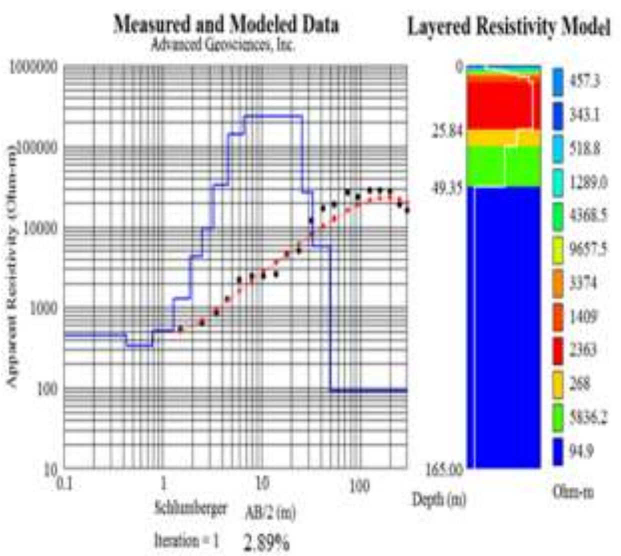

Fig.3: Model result for VES at Owala-Uratta, Owerri North

Table 2. Analytical result at Orji, Owerri North

Layer	Depth (M)	Resistivity	Lithology	Color
1	1.9	865.32	Topsoil	Yellow
2	6.06	331.7	Sandy clay	Green
3	11.06	223.1	Sandy clay	Light blue
4	14.61	454.8	Lateritic sand	Green
5	23.59	2485.4	Siltstone	Red
6	42.91	2084.1	Siltstone	Orange
7	68.75	186.5	Saturated aquifer	Blue

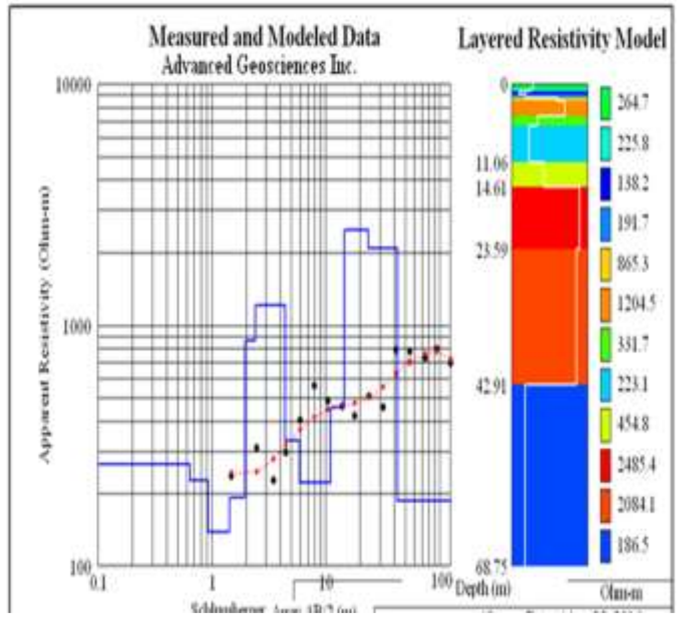

Fig 4: Model result for VES at Orji, Owerri

Table 3. Analytical result at Toronto Junction, Owerri North

Layer	Depth (M)	Resistivity	Lithology	Color
1	1.5	720.5	Topsoil	Yellow
2	2.619	1657.2	Siltstone	Red
3	15.0	141.0	Sand	Light blue
4	17.0	476.4	Lateritic sand	Green
5	25.95	2529.7	Siltstone	Red
6	42.8	1270.4	Sandstone	Yellow
7	88.0	68.6	Sand (Aquifer))	Blue

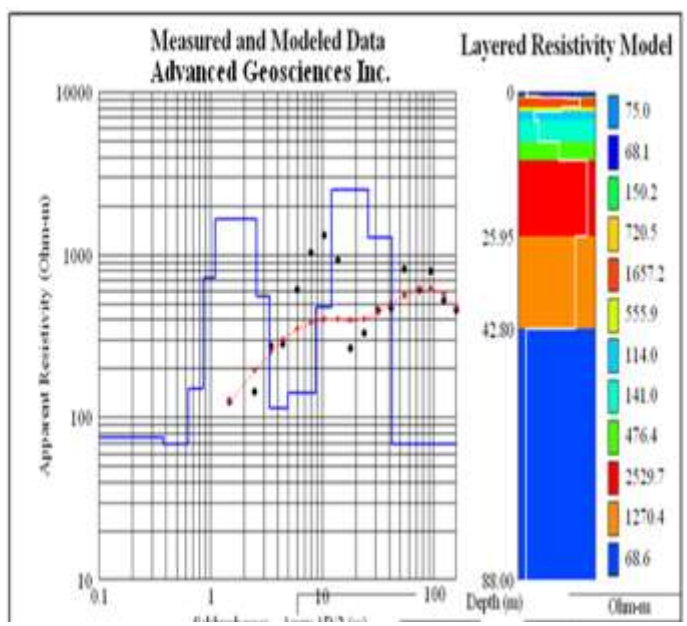

Fig. 5: Model result for VES result at Toronto Junction,

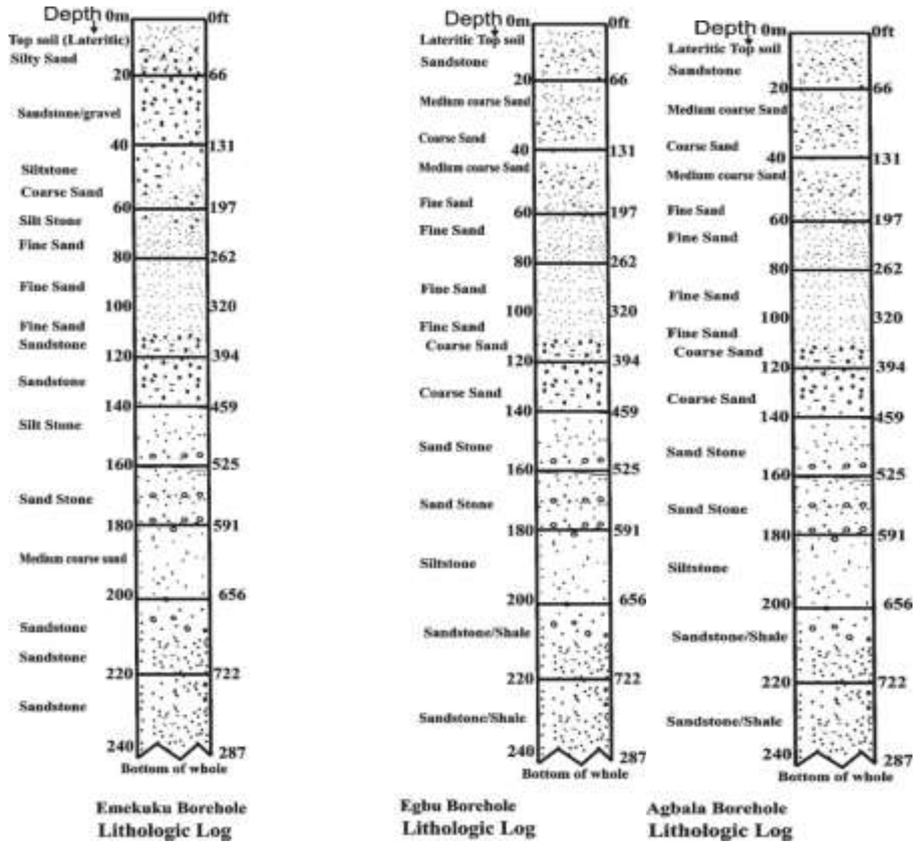

Fig. 6: Borehole lithology of some boreholes in Owerri North LGA (Imo water development agency, IWADA, 2006)

Table 4. Summary of the modeled VES result for Owerri North

VES NO	VES location	Latitude (Degree)	Longitude (Degree)	Elevation (m)	Water Table (m)	Resistivity of Aquifer (Ωm)	Aquifer Thickness (m)
1	Awaka	5.4723	7.0739	86	57.45	37.5	52.55
2	Egbu	5.4822	7.0665	88	50.33	57.6	59.67
3	ChukwuNwoha	5.5045	7.0475	90	8.50	78.6	8.31
4	Orji	5.5273	7.0611	124	42.91	186.5	25.84
5	Toronto Junction	5.4892	7.0842	118	42.80	68.6	45.21
6	Agbala	5.4292	7.0985	71	48.08	1.8	199.42
7	Amawireorji	5.5159	7.0461	121	52.45	59.20	85.05
8	EgbeluObube	5.3723	7.1272	70	51.30	6.8	196.21
9	Emekuku	5.4711	7.1062	114	45.57	4.5	91.93
10	Ihitta	5.4949	7.0855	122	62.57	6.2	184.93
11	Naze	5.4481	7.0704	69	50.40	0.1	87.11
12	OrieUratta	5.5240	7.0849	115	67.07	155.2	180.43
13	Orji Market	5.5346	7.0642	123	46.70	2.9	90.82
14	OwalaUratta	5.5206	7.0838	116	49.35	94.9	115.73
15	Ulakwo	5.4174	7.1267	82	53.49	0.2	127.73
16	UmuobaUratta	5.5011	7.0847	112	53.28	11.1	56.72
17	Owaelu	5.5228	7.0739	123	47.80	327.9	62.22
18	Azaraegbelu	5.4695	7.1070	115	66.00	1208.5	44.00
19	Shoprite Egbu	5.4776	7.0566	67	59.16	266.0	133.34
20	Akwakuma	5.5316	7.0238	69	58.58	309.0	106.42

Table 5. Existing Borehole/Pumping Test Data in Owerri North LGA Borehole Data (Source; Imo Water Development Authorithy, 2006)

S/N	Location	TDD (m)	Casing Diameter (m)	Screen Diameter (cm)	Casing Depth (m)	Screen Length (m)	SWL (m)	Yield (m^3/day)	DD (m)
1	Emekuku	109.76	30.48	20.32	91.46	15.24	33.54	3927.74	12.20
2	Orji	132.32	30.48	20.32	109.76	21.34	49.39	3709.54	38.11
3	Egbu	115.85	34.29	20.32	97.56	15.24	54.88	1571.10	3.35
4	Naze	131.10	30.48	30.48	109.76	21.34	54.57	1636.56	46.95
5	Agbala	182.93	30.48	20.32	134.15	21.34	37.80	2291.18	9.76

Table 6. Summary of Aquifer Characteristics Determined for all the VES stations in Owerri North LGA

VES STATION	AQUIFER RESISTIVITY ρ (ΩM)	DEPTH TO WATER TABLE (m)	AQUIFER THICKNESS h (M)	ELECTRICAL CONDUCTIVITY σ ($\Omega^{-1}m^{-1}$)	TRANSVERSE RESISTANCE R(Ω)	LONGIDUDINAL CONDUCTANCE S ($m\Omega^{-1}$)	HYDRAULIC CONDUCTIVITY K (m/day)	TRANSMISSIVITY T (m^2/day)	Kσ
AWAKA	37.50	57.45	52.55	0.0267	1970.625	1.401	5.20	273.602	0.1388
EGBU	57.60	50.33	59.67	0.0174	3436.992	1.036	4.58	273.901	0.0797
CHUKWUMA NWOHA	78.60	8.50	8.30	0.0127	652.380	0.106	32.93	272.832	0.4182
ORJI	186.50	42.91	25.84	0.0054	4819.160	0.139	10.58	275.328	0.0571
TORONTO JUNCTION	68.60	42.80	45.20	0.0146	3100.720	0.659	6.05	273.887	0.0883
AGBALA	1.80	48.08	199.42	0.5556	358.956	110.790	1.37	273.227	0.7612
AMAWIRE ORJI	59.20	52.45	85.05	0.0168	3105.000	1.440	3.21	273.010	0.0539
EGBELU OBUBE	6.82	51.30	196.20	0.1466	1338.084	28.768	1.39	272.667	0.2038
EMEKUKU	4.50	45.57	91.93	0.2222	413.685	20.429	2.97	273.005	0.6599
IHITTA	6.20	62.57	184.93	0.1613	1146.556	29.827	1.48	273.713	0.2387
NAZE	0.10	50.40	87.10	10.0000	8.710	871.000	3.14	273.494	31.4000
ORIE URATTA	155.20	67.07	180.43	0.0064	28002.740	1.163	1.51	270.618	0.0097
ORJI MARKET	2.89	46.70	90.80	0.3460	262.412	31.419	3.00	272.384	1.0380
OWALA URATTA	94.90	49.35	115.65	0.0105	10975.190	1.219	2.36	271.965	0.0248
ULAKWO	0.20	53.49	127.73	5.0000	25.552	638.650	2.14	273.342	10.7000
UMUOBA URATTA	11.10	53.28	56.72	0.0901	629.592	5.110	4.82	273.420	0.4343
OWAELU	327.90	47.80	62.20	0.0030	20395.380	0.190	4.39	268.607	0.0132
AZARAEGBELU	1208.50	66.00	44.00	0.0008	53174.000	0.036	6.21	264.168	0.0050
SHOPRITE EGBU	266.00	59.16	133.34	0.0038	35468.440	0.501	2.05	276.299	0.0078
AKWAKUMA	309.00	58.58	106.42	0.0032	32883.780	0.344	2.57	270.436	0.0082

The map showing variation of aquifer resistivity (Fig 7) reveals that almost all the VES stations are underlain by relatively low resistant aquifer materials, indicating presence of highly saturated aquifer. The Isopach map shows the variation of aquifer thickness (Fig.8). The aquifer thickness ranges from relatively low value of 8.31m measured at ChukwumaNwoha to a value of 199.42m observed at Agbala. Generally, aquifer is very thick in most parts of the area, indicating high groundwater potential which is consistent with the geology of the area (Benin Formation). Similarly, water table map (Fig 9) shows area of shallow aquifer (light green colour) at the depth of 8.50m observed at VES 3 very close to Lake Nwaebere. At the other stations, relatively deeper aquifers (Yellow colour) were delineated of average depth ranging from 41m to 70m. Aquifer hydraulic conductivity varied across the area ranging from 1.37m/day to 32.93 m/day, indicating easy movement of groundwater through the aquifer.

Analysis of Dar Zarouk parameters computed for the aquiferous zones show variation in both the transverse resistance and the longitudinal conductance. In the transverse resistance map (Fig 10) four zones can be identified. Zone A (green colour) is the least resistive and covers Agbala. Zone B covers only Naze, ChukwumaNwoha and The Northern parts of Orji with values ranging from 101Ω to 500Ω. Zone C (brown colour) is underlain by moderately high resistance aquifer materials with values ranging from 1000Ω to 10000Ω, while Zone D (white colour) is underlain by very high resistant aquifer materials. The variation could be linked to the nature and composition of the formation and their degree of consolidation. On the other hand the longitudinal conductance map of the aquiferous zones (Fig 11) also indicates zones of variation of the parameter. The areas in the blue zone are underlain by low longitudinal conductance (high resistivity aquifer material). They include Azaraegbelu and ChukwumaNwoha. These areas may not be good prospect for drilling borehole with high yield expectations. Other areas are underlain by thick and conductive aquifer materials and thus are good prospects (Mbonu et al., 1990: Nwosu et al., 2013). The distribution of conductivity product Kσ (Fig 12) further demarcates the study area into zones in terms of similar water quality and geology. Niwas and Singhal, (1981) recorded that in areas where geological and water quality do not vary greatly, the conductivity product values remains fairly constant.

The aquifer transmissivity values (Fig 13) estimated from Dar Zarouk parameters and pumping test data are fairly high and uniform indicating that the entire study area has good prospects for groundwater development.

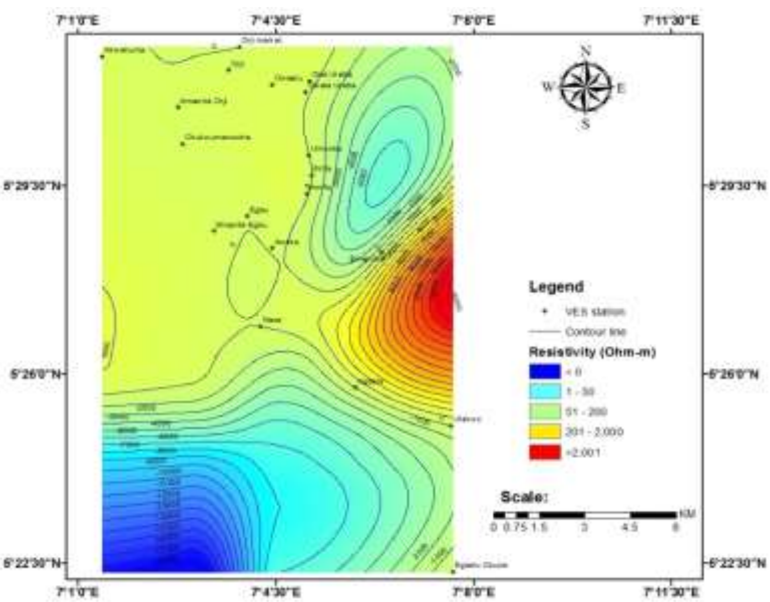

Fig 7: Resistivity contour map

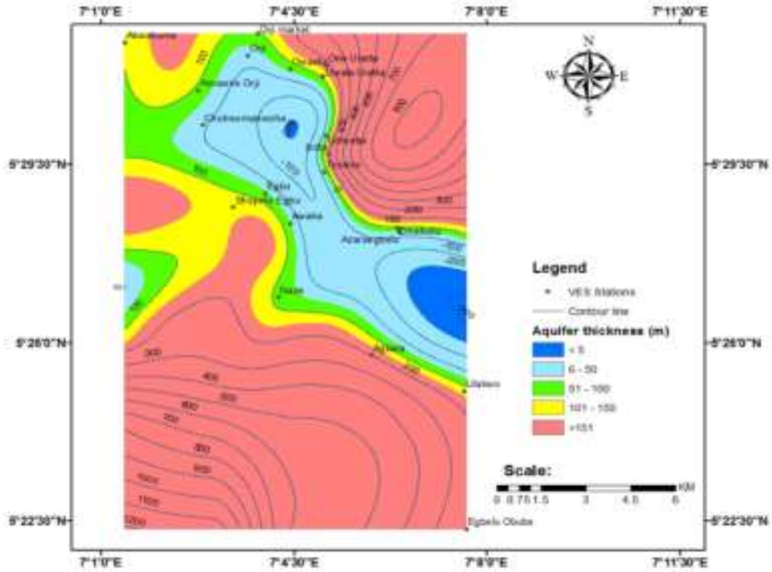

Fig 8: Aquifer thickness contour map

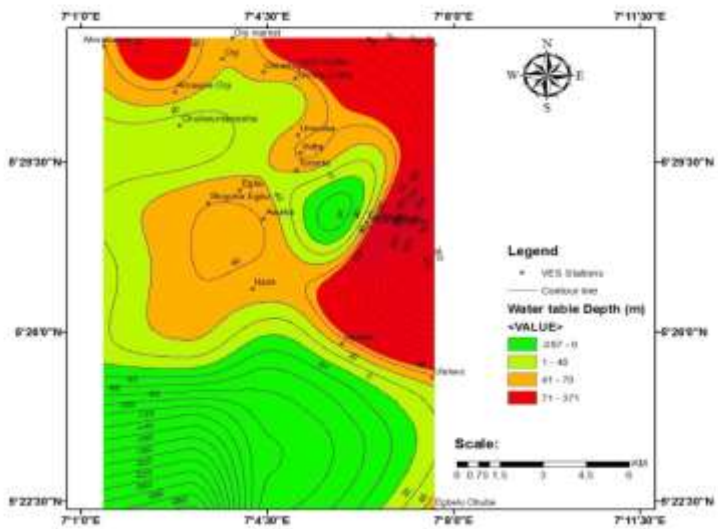

Fig 9: Water table contour map

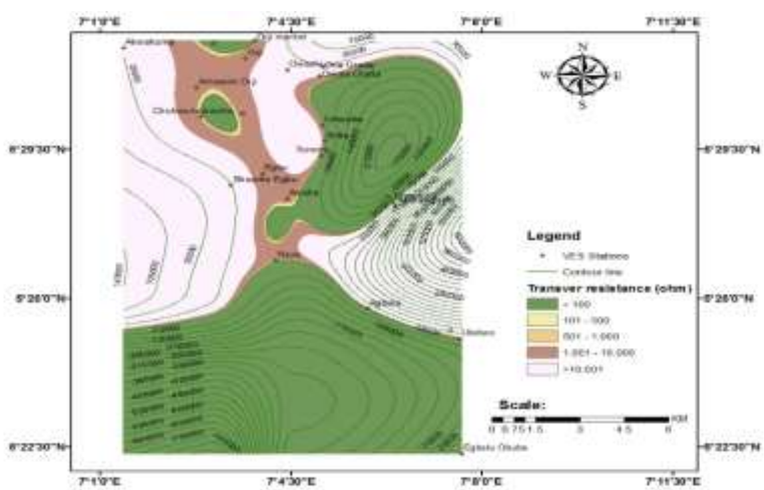

Fig 10: Transverse resistance contour map

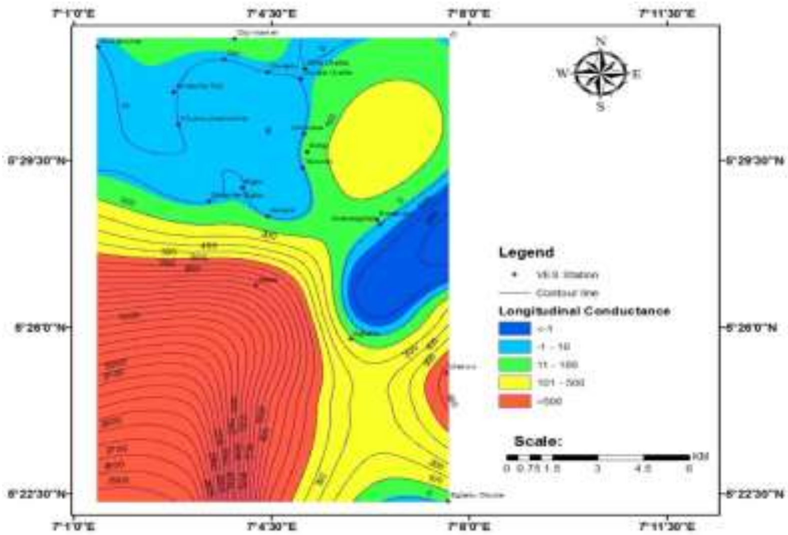

Fig11: Longitudinal conductance contour map.

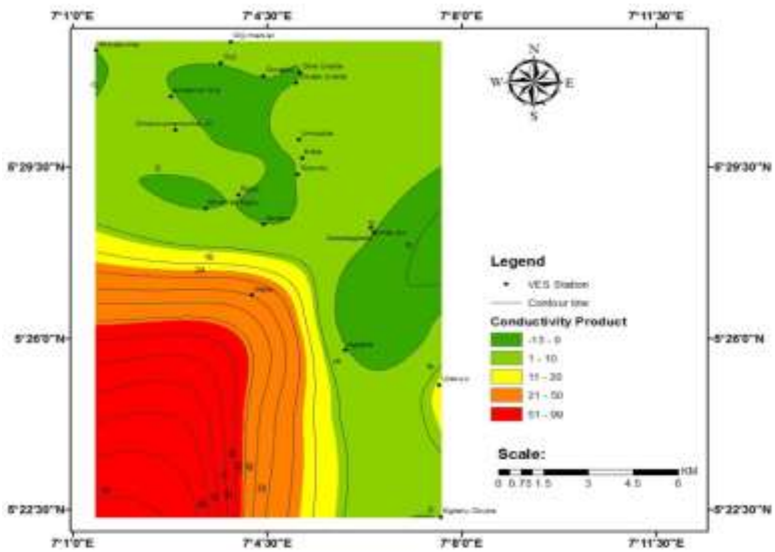

Fig 12: Conductivity product (Kσ) contour map

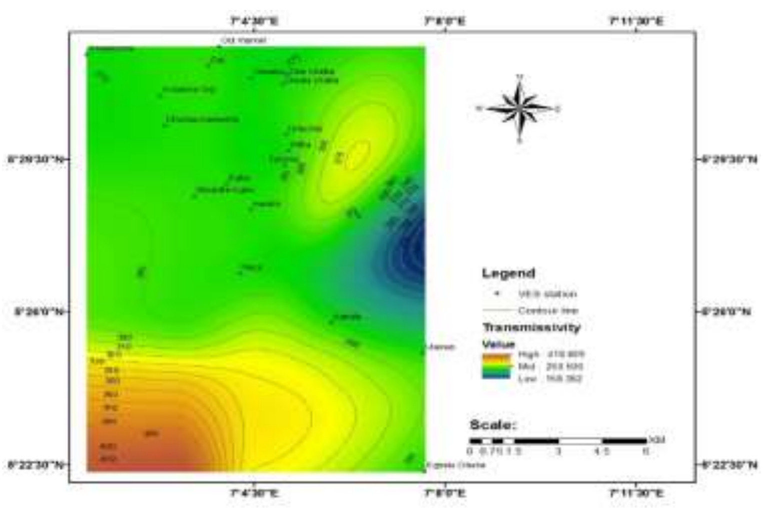

Fig 13: Transmissivity contour map

V. CONCLUSION

The result of this hydrogeologic survey using electrical resistivity method has led to the delineation of the geometry of the aquiferous zone within the study area. The area is underlain by multi-geoelectric layers. The aquifer layers are composed mainly of medium to coarse grain sands intercalated with shale.

The aquifer resistivity varies across the study area. The variation in resistivity could be linked to the nature of the aquifer materials and their composition.

The transmissivity values are fairly uniform across the entire area. The values are moderately high in agreement with the hydrogeology of the study area. The aquifer thickness also varies across the study area. Areas that have high transmissivity values have corresponding high aquifer thickness as transmissivity is a function of aquifer thickness. These areas include Egbelu Obube, Ihitte, Orie-uratta, Orji, Owala and Ulakwo. These areas have high aquifer potential and are prospects for drilling water boreholes with high yield expectations.

On the basis of Dar Zarouk parameter of Longitudinal conductance, areas underlain by high resistivity materials may not be good for drilling boreholes with high yield expectations.

The results of this survey which are reliable and consistent with the geology of the study area can further be verified by employing other geophysical methods such as borehole resistivity logging and seismic refraction method to detect the thin clay layers unable to be resolved in this study. Hydro-chemical analysis is required to ascertain the difference in water quality revealed by the analysis of the conductivity product (kσ) values..

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