

Original Research Article

Delineating Aquifer Systems Using Dar Zarouk Parameters

Determined From Surface Geoelectric Survey: Case Study of Okigwe District, Southeastern Nigeria.

ABSTRACT

This study is aimed at delineating the aquifer systems in the study area and hence determine the parts with higher aquifer yield. To achieve this, 120 vertical electrical soundings (VES) were carried out in Okigwe District of Imo State of Nigeria, using the Schlumberger electrode array and a maximum electrode spread of 900m. Twelve of the VES stations were sited near existing boreholes to enhance interpretation. The resistivity of the **aquiferous** zones varied across the study area. The highest thickness of 104.4m for the aquifer is recorded at Amonze (VES 95). Using an average transmissivity of 1032.0848 m²/day determined from pumping test data of the boreholes in the area, a mean conductance value of 91.222 m/day was obtained for the area. The hydraulic conductivity values obtained from the VES results varied from 9.8854 to 115.9646 m/day. The transmissivity values range from 992.04 to 10388m²/day. The storativity or storage coefficient determined for the area ranged from 1.59x10⁻⁴ to 7.80x10⁻³ while the specific capacity is fairly uniform with magnitude of about 877. Using Dar Zarrouk parameters determined for the area, three aquifer systems have been identified viz: the Coastal plain sands aquifer, the Bende-Ameki sandstone/shale aquifer and False bedded sandstone aquifer. The coastal plain sands aquifer serves the Southern part of Isiala Mbano, Ehime Mbano, Ihitte Uboma and the entire Obowo L.G.As. The Bende Ameki sandstone aquifer serves part of Ihitte Uboma, the Northern part of Ehime Mbano and Isiala Mbano. The False bedded sandstone aquifer serves the Northwestern part of the study area in Okigwe. Groundwater potential evaluation of the district based on borehole hydrogeological information revealed that the Southern part of the district is the most prolific in terms of groundwater exploitation and thus the most promising for siting productive boreholes.

Key Words: Hydraulic conductivity, Aquifer Systems, Aquiferous Zones, Dar Zarouk, VES.

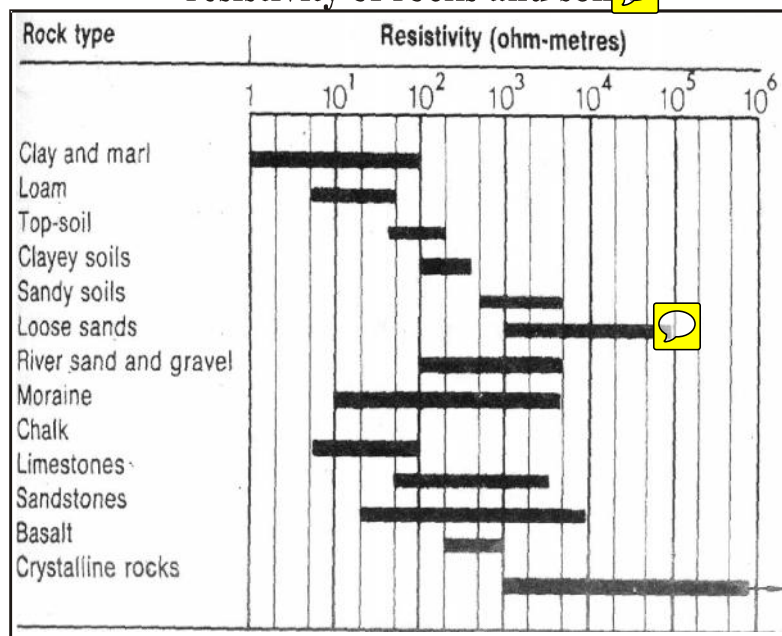
INTRODUCTION

Okigwe District is in Imo State of Nigeria. The area lies between **latitude** 5°30'N to 5°57'N and **longitude** 7°04'E to 7°26'E (Fig. 1) covering a land area of about 1824 km². The District is made up of six Local Government Areas (L.G.As) namely, Isiala Mbano, Ihitte Uboma, Ehime Mbano, Onuimo, Obowo and Okigwe. **Scarcity of portable water in both rural and urban areas of Okigwe district especially during the dry seasons has become a source of worry to Government and the citizens of the area.** Government intervention by siting the Okigwe regional water scheme in Onuimo L.G.A. did not yield the desired results of supplying **portable** water from the Imo

River channel largely due to pollution and lack of fund for extensive project execution. There are many failed boreholes in the area in places like Uturu Isukwunato (in old Okigwe District), Umunakanu Ehime and some areas around Okigwe. The complex geological setting of the area especially around the northern part and inadequate or lack of geophysical information may have accounted for the failure of these boreholes. Hence proper geophysical survey of the area is required as the area is fast experiencing increase in commercial and industrial activities owing to rapid urbanization.

Electrical resistivity of rocks is an extremely variable property that depends on a number of factors which include the resistivity of the contained electrolyte and is inversely related to the porosity and degree of saturation of the formation. The resistivity of rock layers vary considerably from formation to formation as well as within a particular layer. This variation can be very large for any particular layer. There is therefore no specific correlation of lithology with resistivity. Table 1 gives approximate ranges for the electric resistivity of rocks and soil which was useful in the interpretation of VES data in this work.

Table 1. : Approximate ranges for the electric resistivity of rocks and soil



Source: Vingoe P., 1972

Dar Zarouk parameters - the transverse resistance and the longitudinal conductance derived from layer resistivity and thickness obtained during Vertical Electrical Sounding (VES) survey have been proved to be very useful in enhancing the interpretation of groundwater survey (Zhody, et al., 1965; Ekine et al., 2006). Niwas and Singhal (1981) derived analytically the relationship between aquifer transmissivity and transverse resistance and that between transmissivity and longitudinal conductance and showed that in areas where the geologic setting and water quality do not vary greatly, the conductivity

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Fig. 1: Map of study area showing sounding stations and interpretative Geoelectric Cross-Section (IGCS) traverse.

GEOLOGY OF THE STUDY AREA

A review of the geology of the district (Fig. 2) reveals the following stratigraphic units; the Benin Formation, the Ogwashi - Asaba Formation, the Bende - Ameki Formation, Imo Shale Formation, Nsukka Formation and Ajali Formation (Akaolisa and Salamo, 2009).

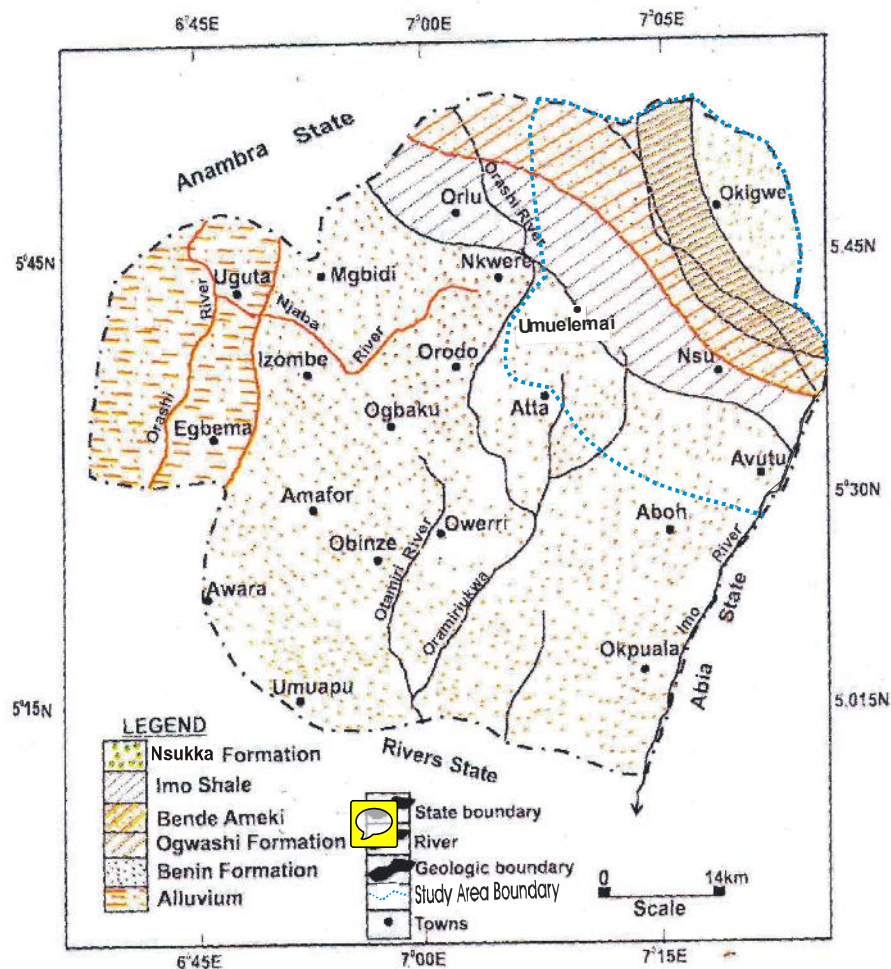


Fig. 2 Geological map of Imo State showing the study area
(Adapted from Akolisa and Selemon 2009)

The Benin Formation is overlain by lateritic overburden and underlain by the Ogwashi - Asaba Formation which is in turn underlain by the Ameki Formation of Eocene to Oligocene age (Mfonu et al 1990). The Formation consists of coarse - grained gravelly sandstones with minor intercalations of shales and clay. The sand units which are mostly coarse grained, pebbly and poorly sorted contain lenses of fine grained sands (Onyeaguocha, 1980; Short and Stauble, 1967). The Southern part of the study area covering Obowo, Southern part of Ehime Mbano and Isiala Mbano fall within this formation.

The Ogwashi - Asaba Formation is made up of variable succession of clays, sands and grits with seams of lignite. It also forms part of the study area. The Ameki Formation consists of greenish - grey clayey sandstones, shales and mudstones with interbedded limestones. This Formation in turn overlies the impervious Imo Shale group.

THEORETICAL BASIS OF THE STUDY

Using the Logan's approximation of Theim's equation (Logan, 1964), aquifer parameters from pumping test data can be determined for steady state flow of aquifer as follows:

$$Q = \frac{2\pi S_{mw} Kh}{2.3 \log \frac{r_{max}}{r_w}} \quad 1$$

Where Q = well discharge in m³ / day

K = average hydraulic conductivity in m / day

h = thickness of the aquifer in metre

S_{mw} = maximum drawdown in the pumped well in metres.

r_w = radius of the pumped well in metres.

r_{max} = radius of influence in metres of the pumping.

The area circumscribed by r_{max} is the area in the borehole environment that contributes water to the well.

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

$$Kh = \frac{2.3Q \log \frac{r_{max}}{r_w}}{2\pi S_{mw}} \quad 2$$

And since the logarithm of the ratio of r_{max} to r_w is very small, assuming average condition of radii, r_{max} = 50 r_w, then

$$\log \frac{r_{max}}{r_w} = 3.21$$

The equation further reduces to:

$$Kh = \frac{1.18Q}{S_{mw}} \quad 3$$

$$\therefore K = \frac{1.18Q}{hS_{mw}} \quad 4$$

Table 3 shows the pumping test data obtained for some boreholes in the study area and computation of the aquifer parameters using equations 1 to 4 gave the values displayed in Table 2 for parameters 1 to 6.

Dar Zarouk Parameters equations are derived 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, and total longitudinal unit conductance S, are respectively given as:

$$R = \sum_{i=1}^n h_i p_i \quad i = 1, 2, 3, \dots, n \quad 5$$

The total longitudinal unit conductance,

$$S = \sum_{i=1}^n \frac{h_i}{p_i} \quad i = 1, 2, 3, \dots, n. \quad 6$$

Where p_i and h_i are the resistivity and thickness of the i th layer. The average longitudinal resistivity,

$$p_L = \frac{H}{S} \quad 7$$

$$\text{where } H = \sum_{i=1}^n h_i \quad i = 1, 2, 3, \dots, n \quad 8$$

and the average transverse resistivity

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

The coefficient of anisotropy is the square root of the ratio of p_t to p_L

The longitudinal conductance S_i can also be represented by

$$S_i = \sigma_i h_i \quad 9$$

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

$$T_{ri} = K_i h_i \quad 10$$

Where K_i is the hydraulic conductivity of the i th layer of thickness h_i . The parameters R and S are called the Dar Zarouk parameters which have been proved to be very powerful in enhancing the interpretation of groundwater surveys.

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

$$T_r = K\sigma, \quad R = \frac{KS}{\sigma} \quad 11$$

Thus, it is possible to estimate the transmissivity and its variation from place to place from the determinations of R or S for the aquifer.

Parameters 7 to 15 of Table 3 were determined using the above equation. Notice the close agreement between parameters 2 and 15 for Madonna II Ihitte Uboma which attests to the reliability of VES results.

FIELD MEASUREMENT PROCEDURE

A total of 120 vertical electrical soundings (VES) were carried out in the study area using the Schlumberger electrodes configuration and a maximum electrode spacing of 900m. The ABEM Terrameter (SAS) 300B was used to acquire the data. It has a liquid crystal digital read-out and an automatic signal averaging microprocessor. Four stainless non polarizable electrodes were used, two current electrodes and two potential electrodes. A freshly charged 12V dc supply was used to supply current.

The current electrode spacing was increased symmetrically about the station point, keeping the potential electrode constant until it became necessary to increase the potential electrode as the recorded signal diminished. The apparent resistivity values computed were plotted against half of the current electrode spacing ($L/2$) on a log-log graph scale. The sounding curves obtained were subjected to conventional partial curve matching using the Rijks Waterstaat (1975) master curves to obtain the initial model parameters (resistivities and thickness) for computer aided interpretation. The software package used is the Schlumberger automatic analysis version 0.92 (Hemker, 1985).

RESULTS

The survey revealed a multilayered earth. There is variation in resistivity with depth across the entire study area. The geoelectric section compared favourably with the borehole lithology and the resistivity model gave the resistivity of the probable aquifer, the depth to aquifer and the aquifer thickness. Figures 3, 4 and 5 show typical modeled curve, the geoelectric section and borehole lithology of VES 79 near Isinweke borehole in Ihitte Uboma L.G.A., VES 32 near Anara borehole, VES 110 near Okigwe borehole respectively. The curves are combinations of H- type and K-type (Ekine, 2010) and HKH-type and KQH-type (Oseji 2005).

DISCUSSION OF RESULTS

Interpretative Geoelectric Cross-Section (I.G.C.S) constructed for the area along profile CD, EF and GH (Fig. 1) reveal that there are variations in resistivity and thickness of the

aquiferous zones across the entire study area. The aquiferous layer consists of fine to medium coarse sands, sandstone and sandy shale. The aquifer is thicker in the southern part of the study area. The aquiferous layer is underlain by conductive layer composed of clay-sand/lignite and shale. The geoelectric sections CD, EF and GH (Figures 6, 7 and 8) indicate that the main aquifers are confined in some parts of the traverses. The Northeastern part and the South-South area indicate prospective area for siting boreholes with high yield expectations. Similar observation is recorded by profile GH in the Southern and South-South zone with high aquifer thickness (Maduagwu, 1990; Njoku, 1991).

Table 3 compares aquifer characteristics determined from pumping test data with those calculated on the basis of VES data. Parameters 1 to 6 were determined from pumping test data while parameters 7 to 15 were computed from VES results. Although the computation was based on the screened sections of the aquifer in the borehole, the close agreement between parameters 2 and 15 for Madonna 2 borehole in Ihitte Uboma attest to the reliability on the VES result. The hydraulic properties of the aquiferous zone determined for the VES stations 61 to 80 are displayed in Table 4. The table shows variation in transmissivity and storativity values as well as other hydraulic properties of the aquiferous zones.

The hydraulic conductivity values obtained from the VES results varied from 9.8854 to 115.9646 m/day. The storativity values determined for the area varied from 1.59×10^{-4} to 7.80×10^{-3} while the specific capacity is fairly uniform with magnitude of about 877. The transmissivity values obtained for the study area varied from $992.04 \text{ m}^2/\text{day}$ recorded in the Northern part to $10,38504 \text{ m}^2/\text{day}$ observed in the Southern part with corresponding higher values of aquifer thickness and storage coefficient.

Evaluation of Aquifer Systems in the Study Area

On the basis of the diagnostic electrical and hydraulic conductivity ($K\sigma$) product values, three aquifer systems have been identified (Fig. 9).

(i). The coastal plain sand aquifer (Zone A) is relatively thick and unconfined with high thickness and transmissivity values as well as storage coefficient. The aquifer materials are fine to medium coarse, unconsolidated sand and sandstone with seams of sandy clay (Ekwe et al; 2006). This zone covers the southern part of Isiala Mbano, Ehime Mbano, Ihitte Uboma and the entire Obowo L.G.A. The $K\sigma$ values range from 0.0093 to 0.00921. The relatively lower resistivity value recorded at Okwuoma (VES 81) could be linked to Abadaba lake and that recorded at VES 95 to the presence of Onuinyi River. The aquifer is relatively deep in the zone.

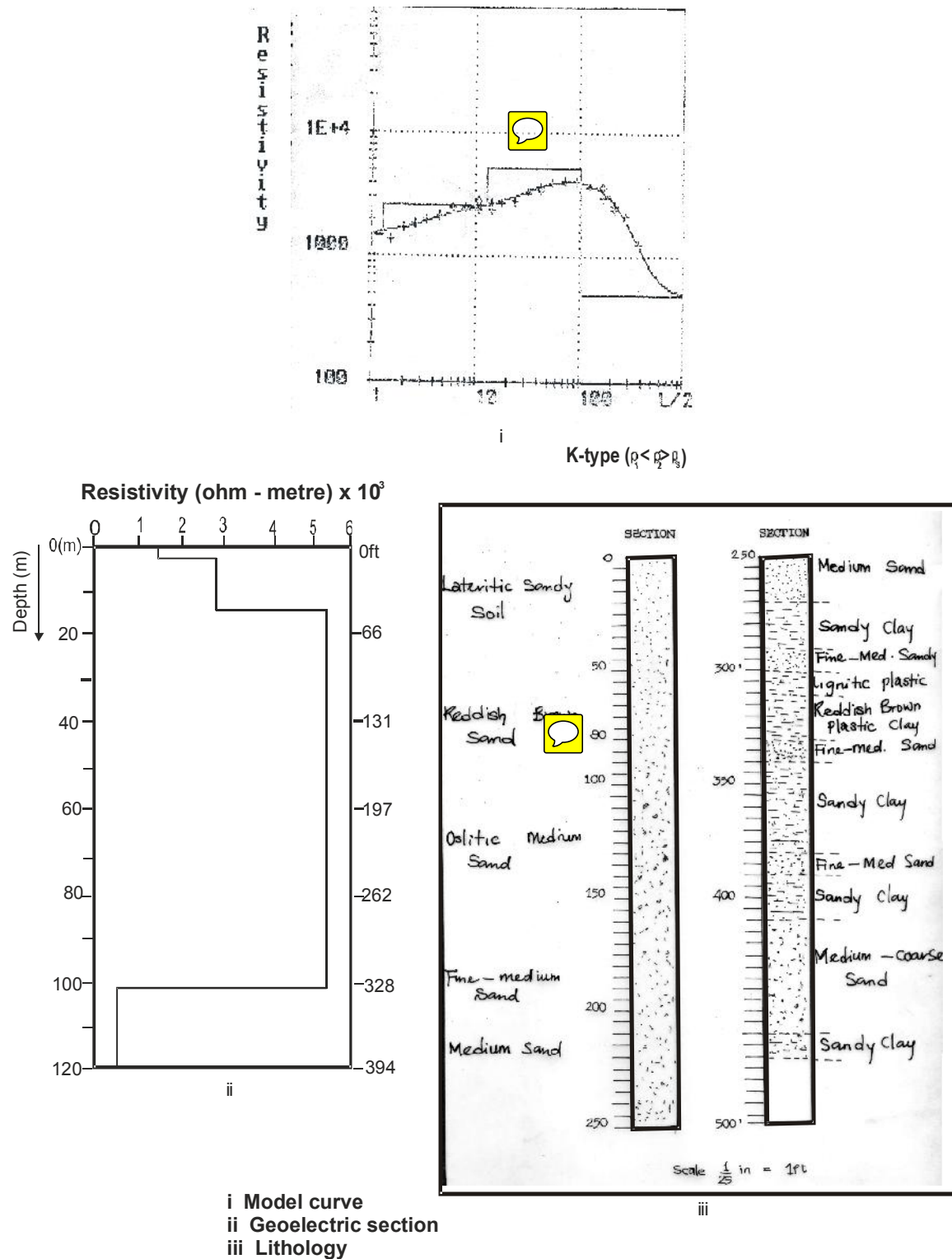
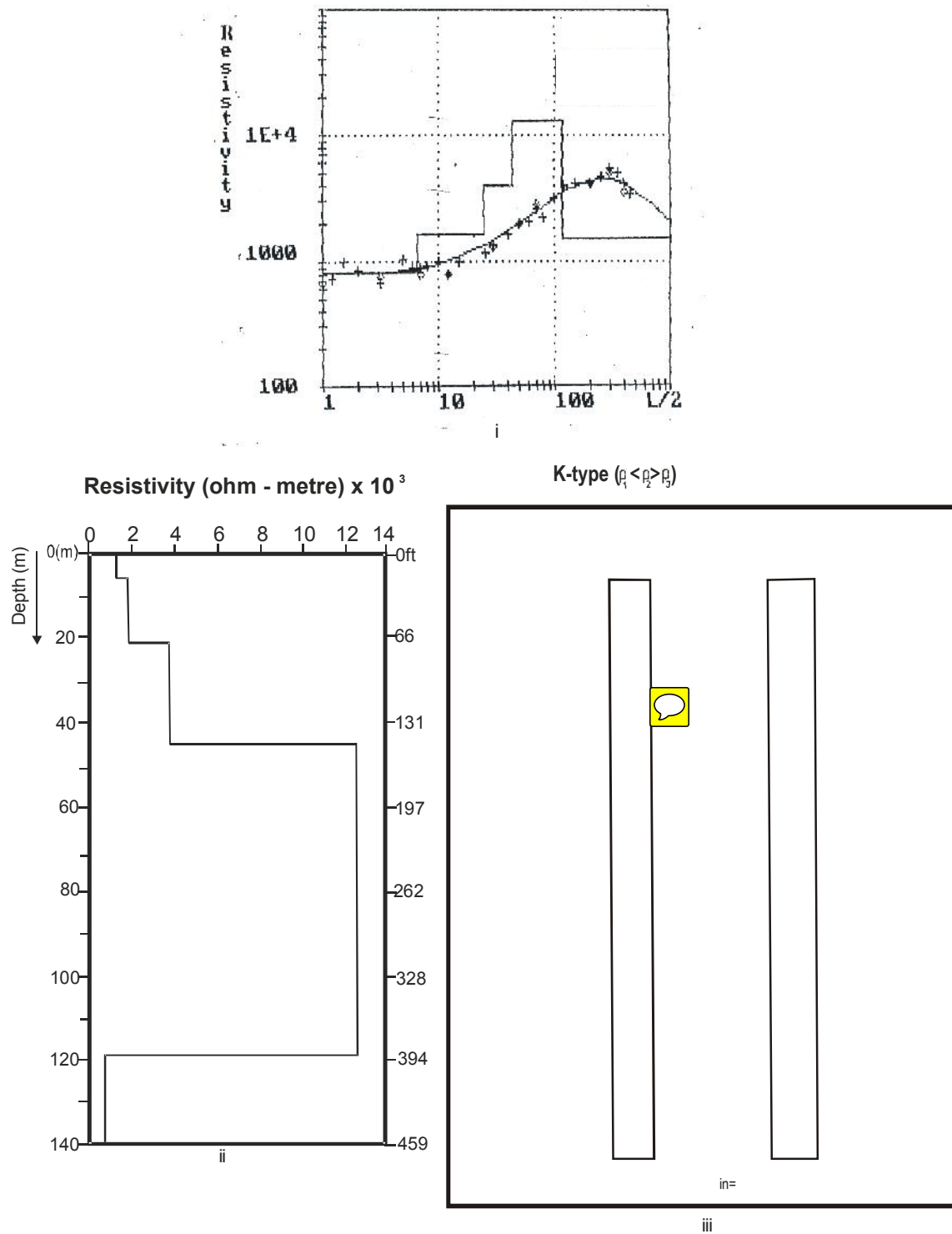


Fig. 3: Model curve, geoelectric section and lithology of VES 79 near Isinweke Borehole.



i Model curve
ii Geoelectric section
iii Lithology

Fig. 4: Model curve, geoelectric section and lithology of VES 32 near Anara borehole

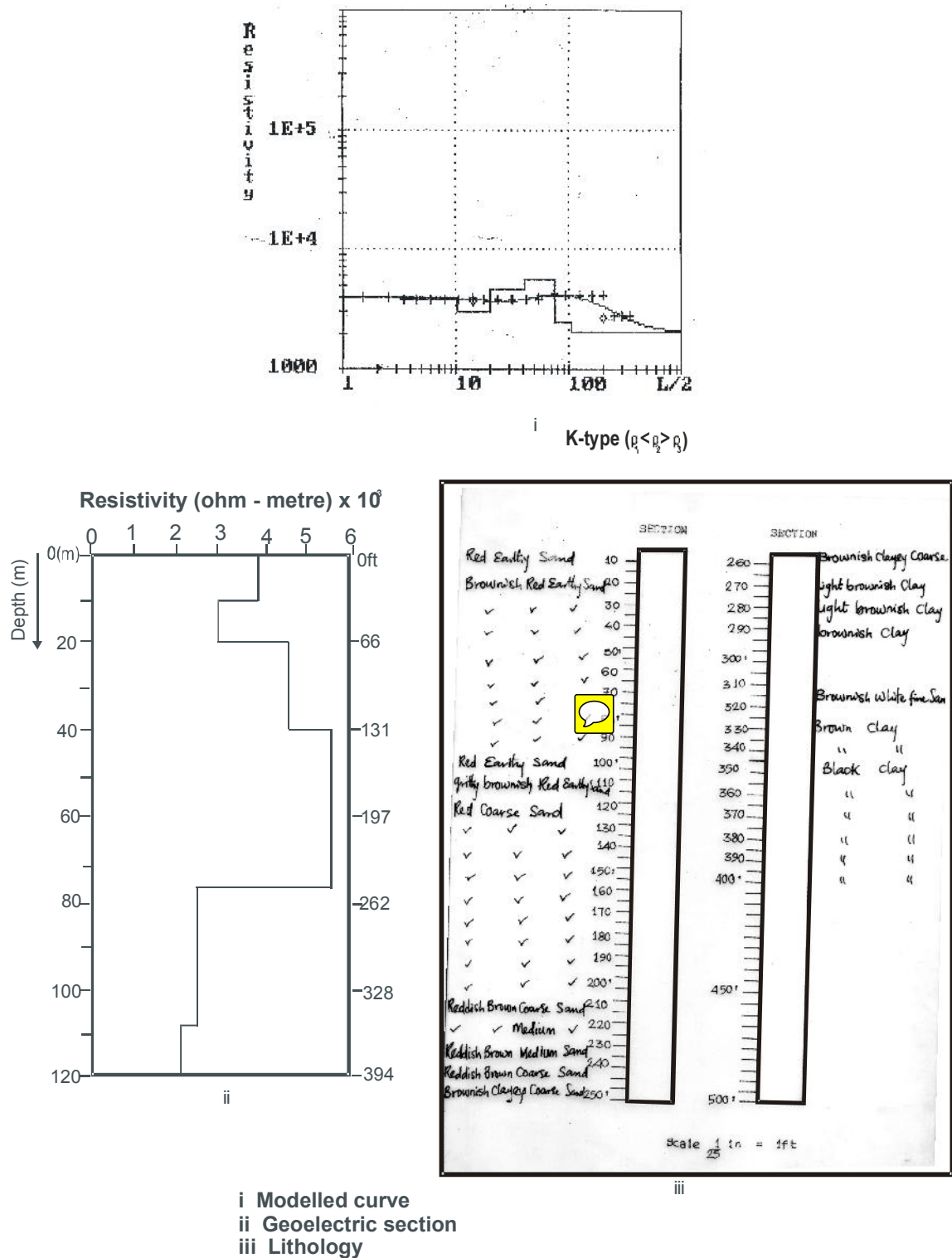


Fig. 5: Modelled curve, geoelectric section and lithology of VES 110 near Okigwe Borehole.

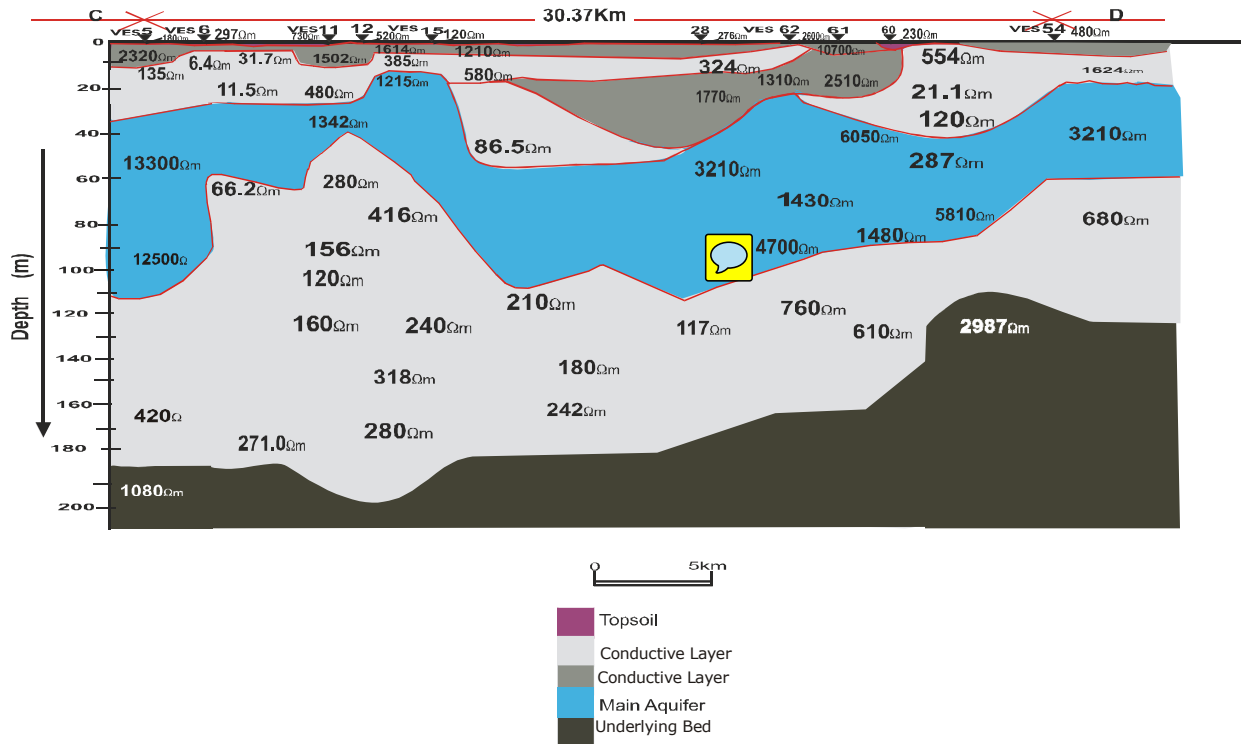


Fig.6: Interpretative Goelectric Cross-Section (IGCS) along profile line CD

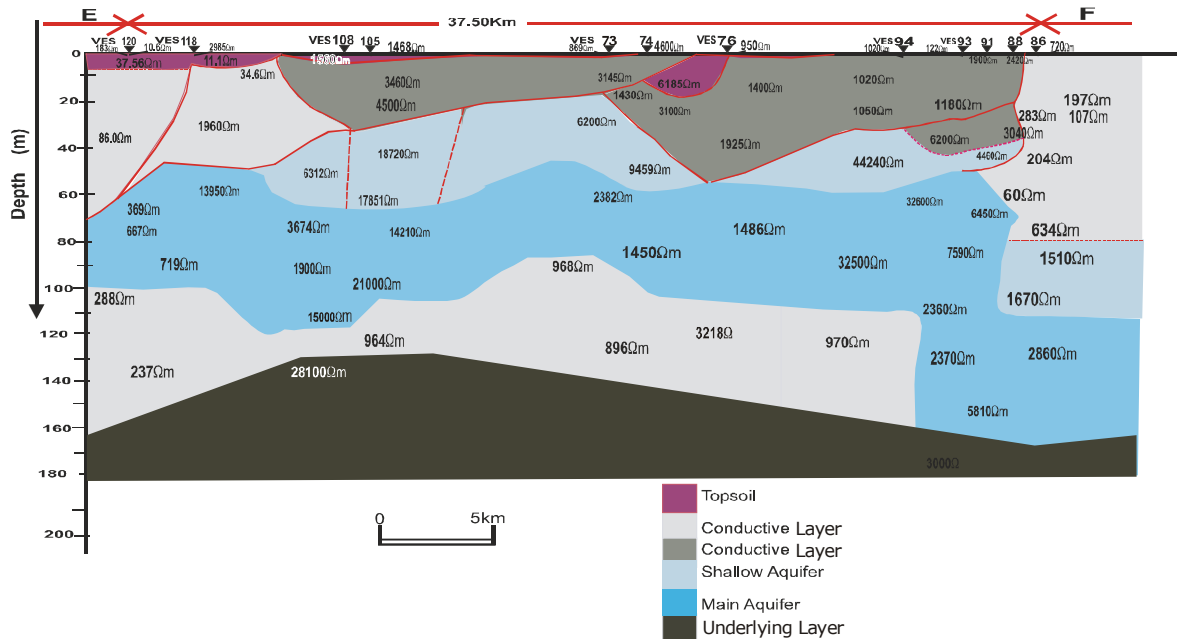


Fig.7: Interpretative Goelectric Cross-Section (IGCS) along profile line EF

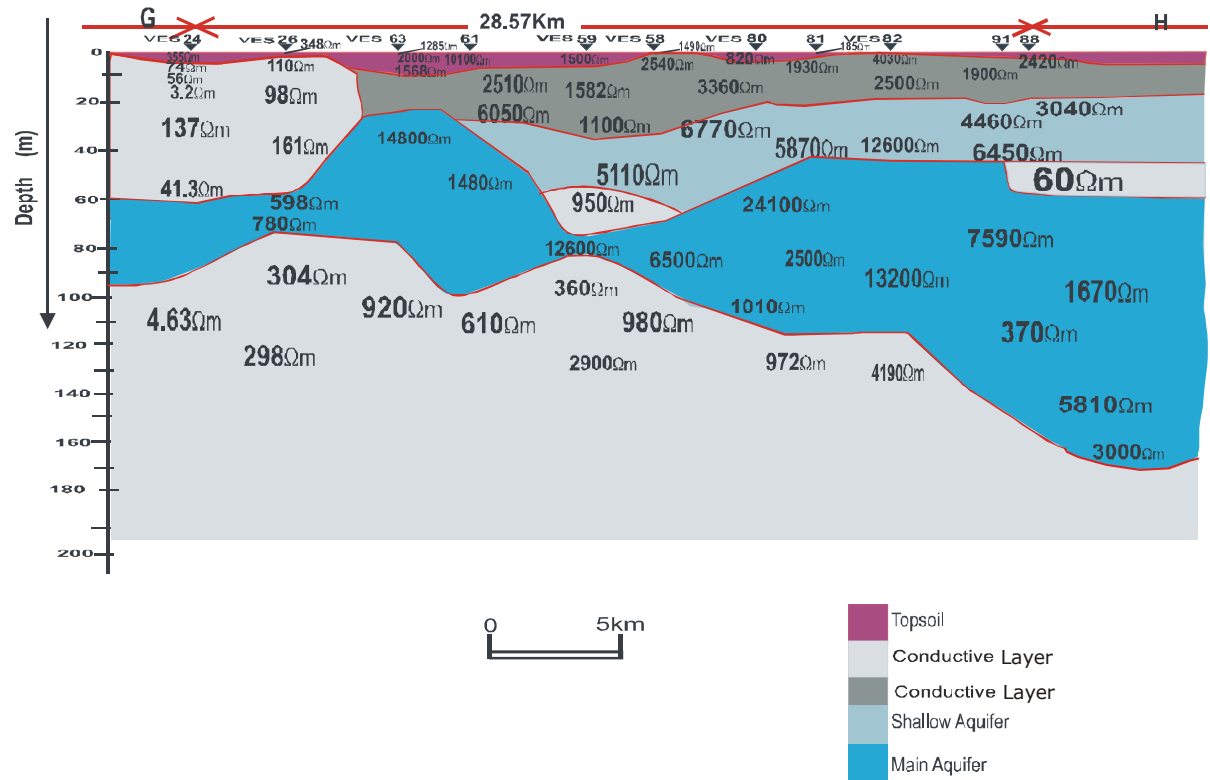


Fig.8: Interpretative IGEOelectric Cross-Section (IGCS) along profile line GH

(ii). The Bende Ameki sandstone/shale aquifer (Zone B) which covers the least area in the district located around parts of Ihitte Uboma and the Northern part of Ehime Mbano and Isiala Mbano LGAs. The Formation is aquiferous but not to the extent of the coastal plain sands with transmissivity being lower due to higher percentage of shales. Groundwater exploitation is sometimes difficult in this zone (IWADA 2002). The $K\sigma$ values range from 0.00831 to 0.23787.

(iii). The False bedded sandstone aquifer (Zone D) covers the Northeastern part of the study area in Okigwe L.G.A. This area falls within the Ajali Formation (False bedded sandstones) and underlain by Mamu Formation. The clay and shale members of this Formation are thick which makes ground water exploitation difficult (IWADA, 2002). Water is available through cracks and fissures.

Each zone is fairly homogenous in terms of geologic setting, hydraulic properties and water quality. This observation suggests possible variation in water quality across the area. The dividing lines correspond to possible groundwater divides. Niwas and Singhal (1981) showed that in areas of similar geologic setting and water quality, the product $K\sigma$ remain fairly constant. This assumption has also been adopted by Ekine and Iheonunekwu (2007) and Nwosu et al (2011) in identifying the aquifer systems in Mbaitoli L.G.A and Isiala Mbano L.G.A of Imo State respectively.

On the bases of longitudinal conductance, four zones are also identified corresponding to the location identified using $K\sigma$ product values (Fig. 10). The areas covered by Zone D are underlain by relatively high resistive (low longitudinal conductance aquifer materials). These areas may not be good prospects for drilling boreholes with high yield expectation (Mbonu et al., 1990). The dividing lines between Zone A and C runs almost parallel to the channels of Nterere and Odioma Rivers that join to drain southwards into the Imo River. Similarly, the dividing line between Zone A and B runs along the channels of Efuru River and Eze River which are tributaries of Imo River that terminate at Abadaba lake. These lines indicate possible groundwater divide.

CONCLUSION

This work has successfully delineated the aquifer systems in Okigwe district. Based on the VES results, the Southern and Northeastern parts of the district are more promising for siting borehole with high yield expectations than the North Western part as there is no well defined sand body that constitute aquifer there. The occurrence of aquifer in this area is linked to the presence of fracture in the shale members.

TABLE 2: EXISTING BOREHOLE /PUMPING TEST DATA - CONVERTED VALUES
(SOURCE: IMO STATE WATER BOARD, OWERRI, IMO STATE)

S/No	LOCATION	DRILL DEPTH (m)	CASING DIAMETER (m)	SCREEN DIAMETER (m)	CASING DEPTH (m)	SCREEN LENGTH (m)	SWL (m)	DRAW DOWN (m)	YIELD (m ³ /day)
1	Avutu No. 2 BH	170.69	0.34	0.20	146.30	21.34	53.04	10.68	4364.24640
2	Anara 1	73.15	0.30	0.20	54.86	15.24	52.43	Abortive	218.21232
3	Umunumo 1	73.15	0.30	0.20	54.86	15.24	23.78	28.65	618.99450
4	Umunumo 2	79.25	0.30	0.20	67.06	9.15	21.56	27.13	392.78218
5	Amaraku 1 Amaraku 2	99.36 118.87	0.20 0.30	0.15 0.25	76.20 83.52	1.52 6.10	31.10 74.37	- 1.83	1091.06160
6	Madona 1 Ihitte Uboma	128.02	0.34	0.25	97.54	30.48	95.07	6.25	654.63696
7	Madona 2 Ihitte Uboma	182.88	0.34	0.25	151.79	21.95	93.27	6.40	2618.54784
8	Nsu	143.26	0.20	0.15	125.58	17.68	35.3	Collapsed	781.95544
9	Ugiri	121.92	0.25	0.20	103.63	15.24	71.32	6.10	1745.69656
10	Mbano	91.44	0.13	0.12	73.76	6.10	46.02	20.12	78.55644
11	Mbano Hospital	85.65	0.25	0.15	78.94	9.75	44.81	3.66	1854.80472
12	Umuelemai	140.21	0.30	0.20	121.92	15.24	30.91	3.78	5237.09568
13	Isiweke LGA H/Q	155.45	0.30	0.20	121.92	12.19	87.57	2.04	8292.06816
14	Okigwe	94.49	0.17	0.13	85.34	5.39	23.17	-	327.31848

TABLE 3: AQUIFER CHARACTERISTICS CALCULATED FOR SOME BOREHOLES LOCATED IN THE STUDY AREA

S/No	PARAMETER	AVUTU BH	ANARA BH	UMUNUMO 2 BH	AMARAKU 2 BH	MADONNA 2 IHITTE UBOMA BH	NSU BH	UGIRI BH	MBANO HOSP. UMUELEMAI BH	ISIWEKE BH	OKIGWE BH
1	Screen Length (m)	21.34	15.24	15.24	6.10	21.95	17.68	15.24	9.75	12.19	5.39
2	Average field hydraulic conductivity K (m/day)	22.5957	-	1.6729	115.3321	21.9952	-	22.158	61.333	393.463	-
3	Transmissivity (m ² /day)	482.1922	-	25.4950	703.5285	482.7946	-	136.272	597.997	4796.314	-
4	Storativity	0.000257	-	0.000210	0.000375	0.000226	-	0.000073	0.000319	0.02588	-
5	Specific Storage	0.000012	-	0.000014	0.000061	0.000010	-	0.000005	0.000033	0.000210	-
6	Specific capacity (m ³ /day)	409.8634	-	21.6707	577.997	410.3754	-	287.035	508.297	4076.867	-
7	Resistivity of Aquifer(Ω m)	5810	13400	12600	15000	16200	2430	6080	14800	4368	13950
8	Aquifer thickness h (m)	24.80	18.20	16.00	35.50	38.20	23.6	24.50	71.70	18.40	16.40
9	Conductivity σ ($\Omega^{-1}m^{-1}$)	0.000172	0.000746	0.000079	0.000067	0.000062	0.00412	0.000164	0.000068	0.000229	0.000072
10	Longitudinal Conductance S	0.0043	0.0014	0.0013	0.0024	0.0024	0.0097	0.0040	0.0048	0.0042	0.0012
11	Transverse Resistance	1440.88	1243880	201600	532500	618840	57348	148960	1061160	80371.20	228780
12	K σ value	0.007158	0.042304	0.005096	0.001948	0.001675	0.018018	0.006909	0.000979	0.012845	0.004531
13	K/ σ	241955.23	76106.01	816522.78	433,907.46	435,772.58	106,146.60	619,498.53	211,683.82	244,611.35	874,055.56
14	Transmissivity of aquiferous zone Tr (m ² /day)	1031.382	10317.141	1027.337	1037.245	1036.625	1033.282	1029.112	1038.691	1032.366	1036.626
15	Hydraulic conductivity	41.6163	56.7080	64.5053	29.0728	27.0179	43.7324	42.1259	14.3945	56.0916	62.9320

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TABLE 4: SUMMARY OF AQUIFER CHARACTERISTICS FOR ALL THE SOUNDING STATIONS

VES Station	Resistivity of Aquifer(Ωm)	Thickness (m)	Conductivity σ ($\Omega^{-1} m^{-1}$)	Transverse Resistance R (Ωm)	Longitudinal Conductance S ($m \Omega^{-1}$)	Hydraulic conductivity K (m/day)	Transmissivity T_r (m ² /day)	Conductivity Product $K\sigma$	Storativity	Specific Capacity (m ³ /day)
61	1480	50.3	0.000676	74444.00	0.033987	20.5186	1032.58	0.013871	2.48x10 ⁻³	877.273
62	1430	72.0	0.000699	102960	0.050350	14.3345	1031.64	0.010020	3.55x10 ⁻³	877.271
63	14800	71.7	0.000068	1357160.00	0.004845	14.3945	1328.48	0.000988	3.08x10 ⁻³	877.273
64	4860	64.1	0.000206	311526.00	0.013189	16.1012	1033.28	0.003168	3.16x10 ⁻³	877.274
65	12500	34.2	0.000080	427500.00	0.002736	30.1779	1032.08	0.002414	1.69x10 ⁻³	877.272
66	1360	25.0	0.000735	34000.00	0.018382	41.2834	1031.67	0.030343	1.23x10 ⁻³	877.272
67	1362	42.4	0.000734	57748.80	0.031131	24.3416	1031.78	0.017868	2.09x10 ⁻³	877.271
68	2185	34.2	0.000478	74727.00	0.015652	30.1779	1077.94	0.014425	1.69x10 ⁻³	877.272
69	1268	47.8	0.000789	60610.40	0.037697	21.5913	1032.55	0.017036	2.36x10 ⁻³	877.255
70	2430	23.6	0.000412	64638.00	0.009719	43.7324	1164.63	0.018018	1.16x10 ⁻³	877.272
71	2800	62.0	0.000357	173600.00	0.022143	16.6465	1031.67	0.005928	3.06x10 ⁻³	877.271
72	1400	50.0	0.000714	70000.00	0.035714	20.6417	1031.67	0.014738	2.47x10 ⁻³	877.272
73	2382	35.9	0.000420	85513.80	0.015071	28.7489	1032.54	0.012075	1.77x10 ⁻³	877.273
74	1450	62.0	0.000690	8990000	0.042759	16.6465	1032.60	0.011486	3.06x10 ⁻³	877.271
75	2125	58.5	0.000471	124312.50	0.027529	17.6425	1032.99	0.008310	2.88x10 ⁻³	877.273
76	1486	54.0	0.000673	80244.00	0.036339	19.1127	1032.17	0.012863	2.66x10 ⁻³	877.273
77	1470	68.3	0.000680	100401.00	0.046463	45.1111	1031.67	0.010276	3.37x10 ⁻³	877.275
78	2500	8.6	0.000105	81700.00	0.000905	120.0099	1029.51	0.012201	4.24x10 ⁻⁴	877.272
79	5110	90.1	0.000196	460411.20	0.01763	11.4549	1033.37	0.002245	4.44x10 ⁻³	877.274
80	24100	55.0	0.000042	1325500.00	0.00228	18.7652	1044.68	0.000788	2.71x10 ⁻³	877.273

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