# Hydrogeophysical studies for the determination of aquifer hydraulic characteristics and evaluation of groundwater potential: A case study of some selected parts of Imo River Basin, South Eastern Nigeria.

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**ABSTRACT**

**Hydrogeophysical studies of some selected towns in Imo River Basin were carried out to determine the aquifer hydraulic characteristics and evaluate the groundwater potential of the study area. A total of thirty-eight (38) Vertical Electrical Sounding (VES) in fifteen (15) towns in Imo River Basin were conducted to obtain the aquifer resistivity data. The results of the qualitative interpretation of the VES data indicate that 75% of the field curves at the boundary of the aquifers terminated as K-shaped and Q-shaped type curves. The general shapes suggested that transverse resistance of the aquifers is the dominant parameter for the estimation of transmissivity in the study area. The estimation of hydraulic characteristics of the aquifers from the geoelectric parameters showed that the mean hydraulic conductivity values ranged from 1.48 $m/day$ to 135.2 $m/day$ and transmissivity values ranged from 121 $m^2/day$ to 6178.6 $m^2/day$. The results of the correlation between hydraulic and geoelectric parameters showed high coefficient of reliability ($R^2$): Resistivity and hydraulic conductivity with $R^2$ of 0.99; Transverse Resistance and Transmissivity with $R^2$ $of$ $0.81$. The derived analytical relations $\rho_m = 22.65K_m + 182.8$; $R_m = 24.66T_m + 13090$ have presented an empirical relationship to estimate the values of the hydraulic parameters of aquifers in the study area. The analysis of the spatial variation of transmissivity magnitude and variation delineated the study area according to groundwater supply potential ranging from zones without groundwater supply prospect to withdrawal of lesser regional importance. It is envisaged that the parameters utilized in this study will help to reduce the additional expenditures of carrying out pumping tests and offer an alternative approach to pre-drilling estimation of hydraulic parameters for optimum development and proper management of groundwater resources in the study area.**

***Keywords:*** Transverse Resistance, Transmissivity, Hydraulic Conductivity, Type Curves, Coefficient Of Reliability, Dominant Parameters, Hydraulic Parameters, Geoelectric Parameters




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# I. INTRODUCTION

Groundwater can be located very efficiently, and groundwater management made sustainable with modeling and monitoring systems. Geophysical measurements sensitive to hydrogeological variables have the ability to provide information with much higher spatial resolution than hydrogeological measurement methods only.

Different correlation studies between hydraulic and geoelectrical properties have been carried out by many researchers in recent years to estimate aquifer properties such as yield, hydraulic conductivity and transmisivity. (Kelly, 1977; Niwas and Singhal, 1981; Onuoha and Mbazi, 1988; Mazac et al., 1985; Mbonu et al., 1991; Huntley, 1986).

They deduced the relationship between aquifer and geophysical parameters based on the assumption that the geology and groundwater quality remains fairly constant within the area of interest (Niwas and Singhal, 1981; Mbonu et al., 1991). The established relationships between the electrical and hydrological parameters of the aquifer can be used as a possible solution to the problems of wildcat drilling, contamination, pump testing costs, etc. (Laouini G. et al., 2017; Urish, 1981; Yander and Abolfazli, 1998). The conventional method for determining the hydraulic characteristics of an aquifer is the pumping test. However, this method can be expensive, time consuming and yields result that is relevant to a relatively small portion of the aquifer (Massoud et al., 2010). An alternative non-invasive and less expensive approach that provides more regional information is the estimation of the aquifer parameters from geo-electric parameters.

Assessment of aquifer parameters is an effective technique in groundwater resource management considered necessary for planning and economic utilization of groundwater.

There is proliferation of shallow substandard private water wells, poor planning and poor management of public wells in Imo River Basin, Nigeria. Over 60% of water wells developed in the basin is either abortive or not functional (Nwachukwu et al., 2010).

Although numerous boreholes have been drilled at various parts of the Imo River Basin, there has not been any systematic and comprehensive study to establish the nature and distribution of the aquifer beneath the basin. (Uma, 1989).

The objectives of this research are:

i. to determine the geoelectric parameters of the aquifers

ii. to estimate the aquifer hydraulic characteristics from surface geophysics

iii. to establish the empirical relationships between the geoelectrical parameters and hydraulic properties of the aquifers in the study area and

iv. evaluation of groundwater potentials for optimum development and proper management of groundwater resources in the study area.




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## 2. STUDY AREA

The study area lies between latitudes 5°30'N to 6°N and longitudes 7°E to 7°30'E (Fig. 1). It covers about fifteen (15) selected towns in Imo River Basin.

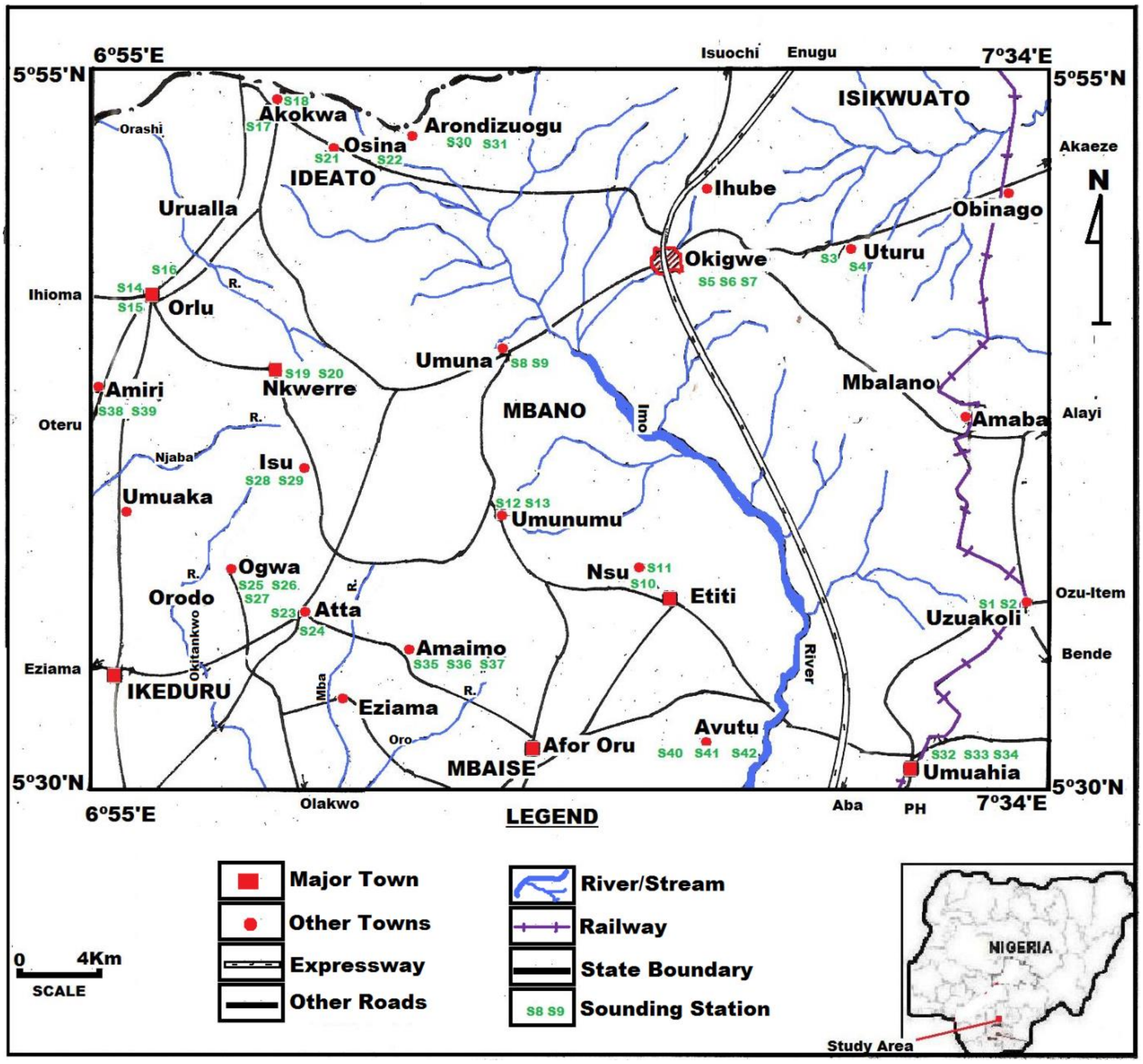


**Fig. 1. Map of Study Area.**

The basin is a 140km N-S trending sedimentary syncline located at the mid South-Eastern part of Nigeria. The basin has rich deposit of clay minerals, sand, gravel and lignite. Based on near surface lithology, the Imo River Basin was divided into two zones (Nwachukwu et al., 2010). The northern zone consisting of a group of shaly formations which have greater drainage density than the Southern zone belonging to the sandy Benin formation. Age of the shaly zone range from Paleocene to Albian and the sandy zone is Oligocene to recent. Table 1 summarizes the general geology of the study area (after Uma and Egboka, 1985)




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**Table 1. Stratigraphic succession in the area**

| Tertiary | Age | Formation | Lithology |
|---|---|---|---|
| | Maocene-recent | Benin formation | Medium-coarse grained poorly consolidated sands with clay lenses and stringers |
| | Oligocene-Miocene | Ogwashi/Asaba | Consolidated sands with lignite seams at various layers |
| | Eocene | Ameki formation | Clayey sandstone and sandy claystones |
| | Paleocene | Imo Shale | Laminated clayey shale |
| | Paleocene | Nsukka formation | Sandstones intercalated with shales and coal beds |
| | Maestrichtian | Ajalli formation | White coloured sandstone |
| | Maestrichtian | Mamu formation | Sandy shale and coal seams |

The geology of the Benin formation has been given by Uma and Egboka, 1985 among others. The Benin formation is made up of friable sands and minor intercalation of clay. The sand units are mostly coarse grained, pebbly, poorly sorted and contain lenses of fine grained sands . The formation starts as a thin edge at its contact with Ogwashi/Asaba formation in the north of the area and thickens seawards. The Benin formation conformably overlies the Ogwashi/Asaba formation. The Ogwashi/Asaba formation (Lignite series) is also predominantly sandy with minor clay units. The formation is characterized by lignite seams at various levels. The lignite formation has thickness of about 300m. This is underlain by the Ameki formation with thickness of 1460m, which is inturn underlain by Imo Shale, Nsukka formation, Ajalli formation and Mamu formation successively.

## 3 THEORETICAL BACKGROUND

Hydraulic and electric conductivities are dependent on each other since the mechanisms of fluid flow and electric current conduction through porous media are generally governed by the same physical parameters and lithological attributes.

When current flows parallel to the geoelectrical boundaries of a geoelectrical section, the parameters that influence current flow is longitudinal conductance $L_C$ and when current flows normal to the bed boundaries, the transverse resistance ($T$) is significant.

Relationships between fluid transmissivity, transverse resistance and longitudinal conductance are based on the nature of relationships between hydraulic conductivity (Permeability, $K$) and electrical resistivity ($\rho$).

For a terminal H-shaped or A-shaped segment of the muitilayer resistivity curves, the resistivity of the aquifer formation is lower than the resistivity of the layer below it at the boundary of the aquifer. Both the current flow and hydraulic flow for any of the two curve segments are dominantly horizontal in the aquifer substratum (Frohlick and Kelly, 1985). Thus the relationship between hydraulic conductivity ($K$) and electric resistivity ($\rho$) is inverse and the dominant dar Zarrouk parameters for estimation of transmissivity is longitudinal conductance $L_C$:

$$k \propto \frac{1}{\rho} \quad (1)$$




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$$L_C = h/\rho \quad (2)$$

The transmissivity of the aquifer is

$$T = k\rho L_C \quad (3)$$

Substituting eqn. (2) into eqn. (3)

$$T = k\rho\left(\frac{h}{\rho}\right) = kh \quad (4)$$

According to Heigold et al., (1979), the hydraulic conductivity value determined from geoelectrical technique is

$$k = 386.4\rho^{-0.93283(m/day)}$$

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

For the terminal K-shaped or Q-shaped segment of the multi-layer resistivity curves, the resistivity of the aquifer is higher than the resistivity of the layer below it at the boundary of the aquifer substratum. Thus for either curve types, the relationship between $k$ and $\rho$ is direct and the dominant dar Zarronk parameter for the estimation of transmissivity is transverse resistance ($R$):

$$k \propto \rho \quad (5)$$

$$R = h\rho \quad (6)$$

The transmissivity of the aquifer substratum for a transverse current flow and lateral hydraulic flow is

$$T = (k/\rho)R \quad (7)$$

Substituting eqn. (6) into eqn. (7)

$$T = \left(\frac{k}{\rho}\right)(h\rho) = kh \quad (8)$$

In a porous aquifer according to Johasen (1977), the hydraulic conductivity value determined from geoelectrical technique is given by the equation.

$$k(m/s) = 10^{-5} \times 97.5^{-1} \times \rho^{1.195} \quad (9)$$

$$k(m/day) = 60 \times 60 \times 24 \times k(m/s) \quad (10)$$




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# 4. MATERIAL AND METHODS

## 4.1. Data Acquisition and Interpretation

Thirty-eight (38) Schlumberger Vertical Electrical Soundings (VES) were carried out in the study area (Fig. 1) using Omega 1000 resistivity meter. The array spread for the current electrode spacing in the VES profiles range between 300m to 700m across the area.
The apparent resistivity ($\rho_a$) values were determined by taking the product of the resistance ($R_a$) as measured by the Terrameter and the geometric factor ($k$) which is dependent on the potential and current electrode spacing:

$$\rho_a = \pi\left(\frac{\left(\left(\frac{AB}{2}\right)^2-\left(\frac{MN}{2}\right)^2\right)}{mn}\right)R_a \qquad (11)$$

where AB is the distance between the two current electrodes and MN is the distance between the potential electrodes. The equation can be simplified to

$$\rho_a = kR_a \qquad (12)$$

where $k$ is the geometric factor.

The field curves were generated by plotting the apparent resistivity values against the electrode spacing $\left(\frac{AB}{2}\right)$. The curves were interpreted using partial curve matching techniques. The geoelectric parameters obtained from the manual interpretation of VES data were refined or modified using the AGI-1D and Schlumberger Automatic analysis interpretation software.

The softwares require that the operator introduce the number, thickness and resistivities of the subsurface layers. The method of iteration was performed until the fitting error between the field data and the synthetic model curve became minimal and constant to generate the data for the estimated model (figure 2). According to Johasen (1977), the hydraulic conductivity can be determined from the geoelectrical technique using the equation

$$k(m/s) = 10^{-5} \times 97.5^{-1} \times \rho^{1.195} \qquad (13)$$

$$k(m/day) = 60 \times 60 \times 24 \times k(m/s) \qquad (14)$$

Transmissivity analysis was carried out using two methods: (i) descriptive statistical testing for identification of background transmissivity and anomalies and (ii) classification scheme introduced by Krasny (1993) for appraisal of groundwater supply potential.

The statistical testing method requires that all the transmissivity values in a particular region be pooled using transmissivity index '$Y$'. According to Jetal and Krasny (1968), the relationship between transmissivity ($T$) and logarithmic transmissivity index ($Y$) is

$$T = 10^{y-8.96} \times 86400 \qquad (15)$$

$$Y = \log\left(\frac{\tau}{86400}\right) + 8.96 \qquad (16)$$

where $T$ is the transmissivity in $m^2/day$.




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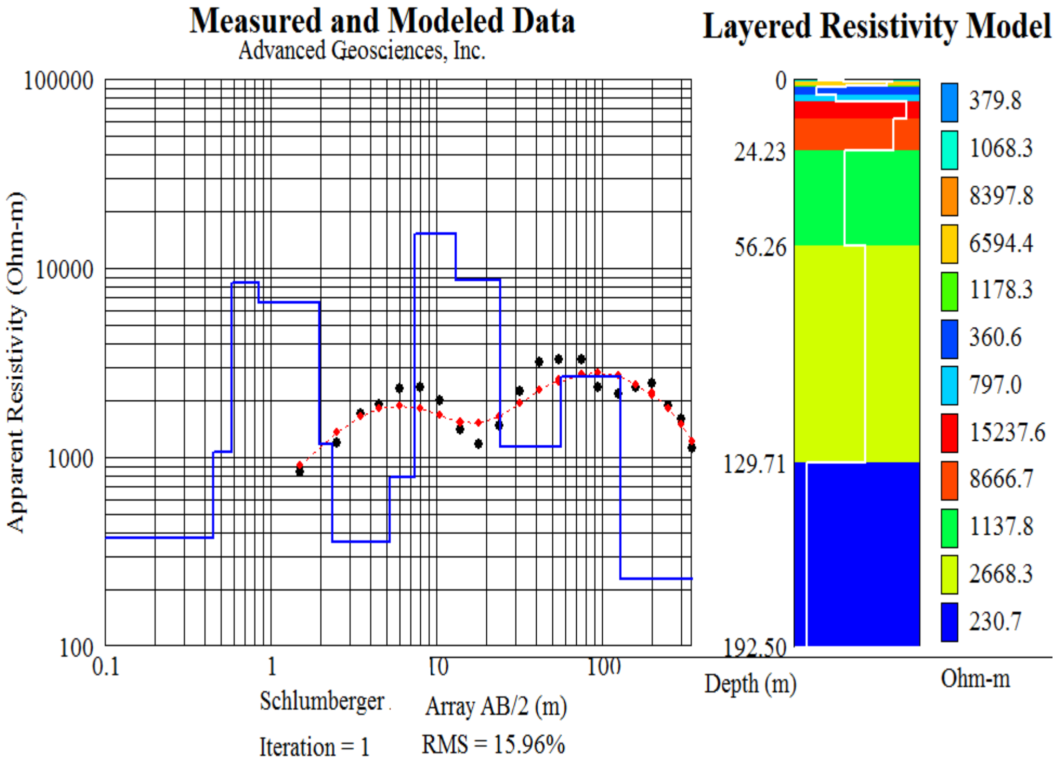


**AFOR-OGIDI SQUARE AMAIFEKE, ORLU VES**

Analytical result presented by the AGI 1D Software and the Schlumberger Automatic analysis package reveals nine sub-layers as follows:

| LAYER | DEPTH (m) | RESISTIVITY (Ohm-m) | LITHOLOGY | COLOR |
|---|---|---|---|---|
| 1 | 0.5 | 380 | Topsoil- Lateritic | Mixed Blue |
| 2 | 2 | 8397 | Sand | Red-Brown |
| 3 | 7 | 1178 | Shale-Sandstone | Green |
| 4 | 13 | 797 | Mixed sand | Blue |
| 5 | 20 | 15237 | Shale-Sandstone | Red |
| 6 | 24 | 8666 | Sandstone | Off red |
| 7 | 56 | 1137 | Shally sand | Green |
| 8 | 130 | 2668 | Siltstone | Orange |
| 9 | >192 | 230 | Prospective unit | Blue |

**Fig. 2. Typical iterated sounding curve of the study area at VES 22**

The transmissivity classification systems for the study area based on the magnitudes and variations of the transmissivity index ($Y$) as proposed by Krasny (1993) are given in tables 2 and 3.

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**Table 2: Krasny's Classification of Transmissivity of Magnitude and Variation**

**Classification of Transmissivity $T$ magnitude**

| Coefficient of $T(m^2/d)$ | Class of $T$ magnitude | Designation of $T$ magnitude | Groundwater Supply Potential |
|---|---|---|---|
| $> 1000$ | I | Very high | Withdrawal of great regional importance |
| 1000-100 | II | High | Withdrawals of lesser regional importance |
| 100-10 | III | Intermediate | Withdrawals for local water supply (small communities and plants) |
| 10-1 | IV | Low | Smaller withdrawals for local water supply (private consumption) |
| 1-0.1 | V | Very low | Withdrawals for local water supply with limited consumption |
| $< 0.1$ | VI | Negligible | Sources for local water supply are difficult |

**Table 3: Classification of Transmissivity ($T$) Variation**

| Standard Deviation of $T$ Index ($Y$) | Class of $T$ Variation | Designation of $T$ Variation | Hydrogeological environment |
|---|---|---|---|
| $< 0.2$ | a | Insignificant | Homogenous |
| 0.2-0.4 | b | Small | Slightly heterogeneous |
| 0.4-0.6 | c | Moderate | Fairly heterogeneous |
| 0.6-0.8 | d | Large | Considerably heterogeneous |
| 0.8-1.0 | e | Very large | Very heterogeneous |
| $> 1.0$ | f | Extremely large | Extremely heterogeneous |

The standard deviation of the Transmissivity Index ($Y$) vrariations represents the degree of heterogeneity of the hydrogeological environment.

By using the transmissivity analysis based on transmissivity Index ($Y$) classification (table 4), the groundwater supply potential designation for the various localities in the study area was identified as given in table 5.

**Table 4: Transmissivity Analysis based on Transmissivity Index ($Y$) Classification**

| S/N | Classification | Description | Range of $Y$ | Groundwater Supply Potential |
|---|---|---|---|---|
| 1 | Negative Extreme Anomalies | Less than (mean - (2× standard deviation)) | $< 6.37$ | Negligible |
| 2 | Negative Anomalies | Between (mean - standard deviation) and (mean – (2× standard deviation)) | 6.79 and 6.37 | Very low |
| 3 | Background Anomalies | Between (mean – standard deviation) and (mean - (2× standard deviation)) | 6.79 and 7.63 | Low |
| 4 | Positive Anomalies | Between (mean + standard ddeviation) and (mean + (2× standard deviation)) | 7.63 and 8.05 | Moderate |
| 5 | Positive Extreme Anomalies | Greater than (mean + (2× standard deviation)) | $> 8.05$ | High |

Negative Extreme Anomalies – Zones without groundwater supply prospect; Negative Anomalies – withdrawal for local water supply with limited consumption; Background Anomalies – smaller withdrawal for local water supply (private consumption); Positive Anomalies – withdrawal for less regional importance; Positive Extreme Anomalies – Zones with high groundwater supply prospect




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**Table 5: Results of summary Statistics of Transmissivity Index ($Y$), Krasny's Transmissivity ($\tau$)**

| S/N | Locality | $T_{(m^2/day)}$ | $T$ Index ($Y$) | Results of $T$ Index ($Y$) | Results of $T$ Magnitude | Results of $T$ Variation |
|---|---|---|---|---|---|---|
| 1 | Uzuakoli UZ | 2114.2 | 7.34 | Background Anomalies (Low) | Smaller withdrawal for local water supply | Fairly Heterogeneous |
| 2 | Uturu UT | 1394.8 | 7.16 | Background Anomalies (Low) | Smaller withdrawal for local water supply | Fairly Heterogeneous |
| 3 | Okigwe OK | 1947.9 | 7.31 | Background Anomalies (Low) | Smaller withdrawal for local water supply | Fairly Heterogeneous |
| 4 | Umuna UM | 1350.6 | 7.15 | Background Anomalies (Low) | Smaller withdrawal for local water supply | Fairly Heterogeneous |
| 5 | Nsu NS | 121 | 6.10 | Negative Extreme Anomalies (Negligible) | Zone without groundwater supply prospect | Fairly Heterogeneous |
| 6 | Umunumo UMN | 817.9 | 6.93 | Background Anomalies (Low) | Smaller withdrawal for local water supply | Fairly Heterogeneous |
| 7 | Orlu OR | 2429.9 | 7.40 | Background Anomalies (Low) | Smaller withdrawal for local water supply | Fairly Heterogeneous |
| 8 | Akokwa AK | 2403.3 | 7.40 | Background Anomalies (Low) | Smaller withdrawal for local water supply | Fairly Heterogeneous |
| 9 | Nkwerre NK | 2424.9 | 7.40 | Background Anomalies (Low) | Smaller withdrawal for local water supply | Fairly Heterogeneous |
| 10 | Isu IS | 2871.5 | 7.48 | Background Anomalies (Low) | Smaller withdrawal for local water supply | Fairly Heterogeneous |
| 11 | Atta AT | 6178.6 | 7.81 | Positive Anomalies (moderate) | Withdrawal for lesser regional importance | Fairly Heterogeneous |
| 12 | Ogwa OG | 2328.1 | 7.39 | Background Anomalies (Low) | Smaller withdrawal for local water supply | Fairly Heterogeneous |
| 13 | Isuochi ISC | 940.9 | 6.99 | Background Anomalies (Low) | Smaller withdrawal for local water supply | Fairly Heterogeneous |
| 14 | Arondizuogu AR | 440.3 | 6.66 | Negative Anomalies (Very Low) | Withdrawal for local water supply with limited consumption | Fairly Heterogeneous |
| 15 | Umuahia UMH | 4439.8 | 7.67 | Positive Anomalies (Moderate) | Withdrawal for lesser regional importance | Fairly Heterogeneous |

## 5. RESULTS AND DISCUSSION

Thirty-eight (38) Vertical Electrical Soundings (VES) were interpreted qualitatively and quantitatively. The terminal shape of the vertical electrical sounding curve types identified in the study area at the boundary of the aquifers include 53%Q, 22%K, 14%H and 11%A types (table 6). Approximately, 75% of all the resistivity curves are of the terminal $K$ and $Q$ curve types whereas, the remaining 25% belong to the terminal $H$ and $A$ types within the study area. Therefore, terminal $K$ and $Q$ curve types are the most dominant sounding curve types.


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The general shape of the resistivity curves (table 6) suggests that transverse resistance ($\mathcal{R}$) of the aquifers can be considered as the dominant dar-Zarrouk parameters for the estimation of transmissivity in the study area.

Equations 8, 9 and 10 were used to calculate the hydraulic conductivity and transmissivity values for the thirty-eight (38) VES stations. Table 7 is a summary of the mean values of aquifer parameters of the locations in the study area. The geoelectric parameters estimated mean values are apparent resistivity ($\ell_m$) 72.7 in Nsu to 3170 Ohm-m in Atta, Depth ($d_m$) $28.9m$ in Umuna to 148.8m in Arondizuogu, transverse resistance ($\mathcal{R}_m$)144869 ohm-$m^2$ in Atta to 360 ohm-$m^2$ in Nsu. For hydraulic parameters, the estimated mean values are hydraulic conductivity ($K_m$) 1.48 in Nsu to 135.2 $m/day$ in Atta and transmissivity ($T_m$) 121 in Nsu to 6178.6 $m^2/day$ in Atta.

**Table 6: Summary of the Results Obtained from Interpreted VES Data**

| VES No. | Location | Aquifer Thickness $h(m)$ | Aquifer Depth $d(m)$ | Aquifer Resistivity $\ell(Ohm-m)$ | Curve Type | No. of layers |
|---|---|---|---|---|---|---|
| 1 | Uzuakoli Bd I | 166.9 | 53 | 654.3 | AKHAAKQQ | 10 |
| 2 | Uzuakoli Bd II | 106 | 86.5 | 383 | HAAAKQHAK | 11 |
| 3 | ABSU Uturu I | 23.4 | 66.4 | 1990 | HKQ | 5 |
| 4 | ABSU Uturu II | 52.3 | 35.6 | 148.2 | KHKQQHAKQ | 11 |
| 5 | Isiokwe Okigwe | 4.4 | 0.9 | 1490 | H | 3 |
| 6 | Amogu Okigwe | 41 | 30 | 2340 | KHAA | 6 |
| 7 | Agbala Okigwe | 49 | 172 | 3800 | AKQHAK | 8 |
| 8 | Umualumoke Okigwe | 42 | 65 | 800 | HAKQHA | 8 |
| 9 | Umulolo Okigwe | 21.1 | 27.4 | 207 | KQQ | 5 |
| 10 | Ogbugbe Okigwe | 24.2 | 74.6 | 1600 | QKQ | 5 |
| 11 | Okai Umuna I | 27.6 | 53.2 | 2770 | AK | 4 |
| 12 | Okai Umuna II | 17.9 | 4.7 | 420 | K | 3 |
| 13 | Ezeoke Nsu I | 135.7 | 84.2 | 30.4 | HAAKQ | 7 |
| 14 | Ezeoke Nsu II | 28 | 86 | 115 | AKQQQ | 7 |
| 15 | Umunumo I | 25.9 | 71.2 | 1310 | KHKQQH | 8 |
| 16 | Umunumo II | 50.9 | 29 | 39.8 | KQQ | 5 |
| 17 | Okporo Orlu | 106.5 | 86 | 436.1 | KHAKQQQ | 9 |
| 18 | Umuowa Orlu | 85.5 | 107 | 308.6 | KQHAAKQ | 9 |
| 19 | Umudioka Orlu | 97 | 95 | 866 | HAKHAKQ | 9 |
| 20 | Owerre Nkworji Orlu | 105 | 87 | 2063 | AAAAKQQ | 9 |
| 21 | Amaifeke Orlu | 48.7 | 67.3 | 505 | AAKQ | 6 |
| 22 | Akokwa Orlu | 67.7 | 124.8 | 1035.2 | HAKQHKQ | 9 |
| 23 | Alaekwe Nkwerre | 93 | 72 | 482 | HAKHAAKQ | 10 |
| 24 | Ugara Nkwerre | 18.1 | 32.9 | 1310 | HA | 4 |
| 25 | Umudi Nkwerre | 30.1 | 24.6 | 2460 | K | 3 |
| 26 | Umulolo Isu | 104.1 | 88.3 | 409.1 | AAKQQ | 7 |
| 27 | Umudike Isu | 107.8 | 84.2 | 760 | KHAAKQ | 8 |
| 28 | Atta Ikeduru | 45.7 | 72.5 | 3170 | KHK | 5 |
| 29 | Umueze Ogwa | 41 | 108 | 2960 | KHKQQ | 7 |
| 30 | Alaeze Ogwa | 44 | 62 | 788.6 | KQQHAKH | 9 |
| 31 | Ochi Ogwa | 49 | 46.7 | 539 | KQ | 4 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 32 | Umunneochi Isuochi | 15.1 | 43.2 | 54.5 | HKH | 5 |
| 33 | Ndiawa Isuochi | 138 | 82 | 804 | AKHAKHAK | 10 |
| 34 | Nwangele Isu | 117 | 75 | 1246 | HAKHAKQQ | 10 |
| 35 | Ndiawa Arondizuogu | 66 | 202 | 301 | KQHAAK | 8 |
| 36 | Akaeme Arondizuogu | 96.8 | 95.6 | 127.9 | AAAAKQQ | 9 |
| 37 | Isieke Umuahia | 21.7 | 49.6 | 1200 | KH | 4 |
| 38 | Uzuakoli Rd. Umuahia | 46.6 | 37.7 | 4940 | HAA | 5 |

**Table 7: Mean Values of Aquifer Parameters of the Localities in the Study Area**

| S/No. | Location | $Y$ | $K_m$ | $\ell_m$ | $h_m$ | $d_m$ | $\mathcal{R}_m$ | $T_m$ |
|---|---|---|---|---|---|---|---|---|
| 1 | Uzuakoli | 7.34 | 15.5 | 518.6 | 136.4 | 69.7 | 74929 | 2114.2 |
| 2 | Uturu | 7.16 | 36.9 | 1069.1 | 37.8 | 15 | 27162 | 1394.8 |
| 3 | Okigwe | 7.31 | 64.5 | 1706.1 | 30.2 | 16.6 | 60897 | 1947.9 |
| 4 | Umuna | 7.15 | 59.5 | 1595 | 22.7 | 28.9 | 41985 | 1350.6 |
| 5 | Nsu | 6.10 | 1.48 | 72.7 | 81.8 | 85.1 | 3680 | 121.0 |
| 6 | Umunumo | 6.93 | 21.3 | 674.9 | 38.4 | 50.1 | 17977 | 817.9 |
| 7 | Orlu | 7.40 | 27.4 | 835.5 | 88.5 | 88.4 | 123798 | 2424.9 |
| 8 | Akokwa | 7.40 | 35.5 | 1035.2 | 67.7 | 124.8 | 70083 | 2403.3 |
| 9 | Nkwerre | 7.40 | 51.7 | 1417.3 | 47 | 43.1 | 47527 | 2429.9 |
| 10 | Isu | 7.48 | 26.2 | 805 | 109.6 | 82.5 | 90109 | 2871.5 |
| 11 | Atta | 7.81 | 135.2 | 3170 | 45.7 | 46.3 | 144869 | 6178.6 |
| 12 | Ogwa | 7.39 | 52.2 | 1429.2 | 44.6 | 72.2 | 60823 | 2328.1 |
| 13 | Isuochi | 6.99 | 12.3 | 429.2 | 76.5 | 62.6 | 55887 | 940.9 |
| 14 | Arondizuogu | 6.66 | 5.41 | 214.4 | 81.4 | 148.8 | 16125 | 440.3 |
| 15 | Umuahia | 7.67 | 130.2 | 3070 | 34.1 | 43.5 | 128122 | 4439.8 |

$K_m$ - Mean hydraulic conductivity; $\ell_m$ - Mean resistivity; $h_m$ - Mean thickness; $d_m$ - Mean depth; $\mathcal{R}_m$ - Mean transverse resistance; $T_m$ - Mean transmissivity

Correlation analysis was applied to establish the empirical relationships between geoelectric parameters and hydraulic parameters. The results of the analysis (Figs.3 and 4) for the fifteen locations showed high coefficient of reliability $\mathcal{R}^2$:

(i) $\ell_m$ and $k_m$ with $\mathcal{R}^2$ of 0.99

(ii) $\mathcal{R}_m$ and $T_m$ with $\mathcal{R}^2$ of 0.81.

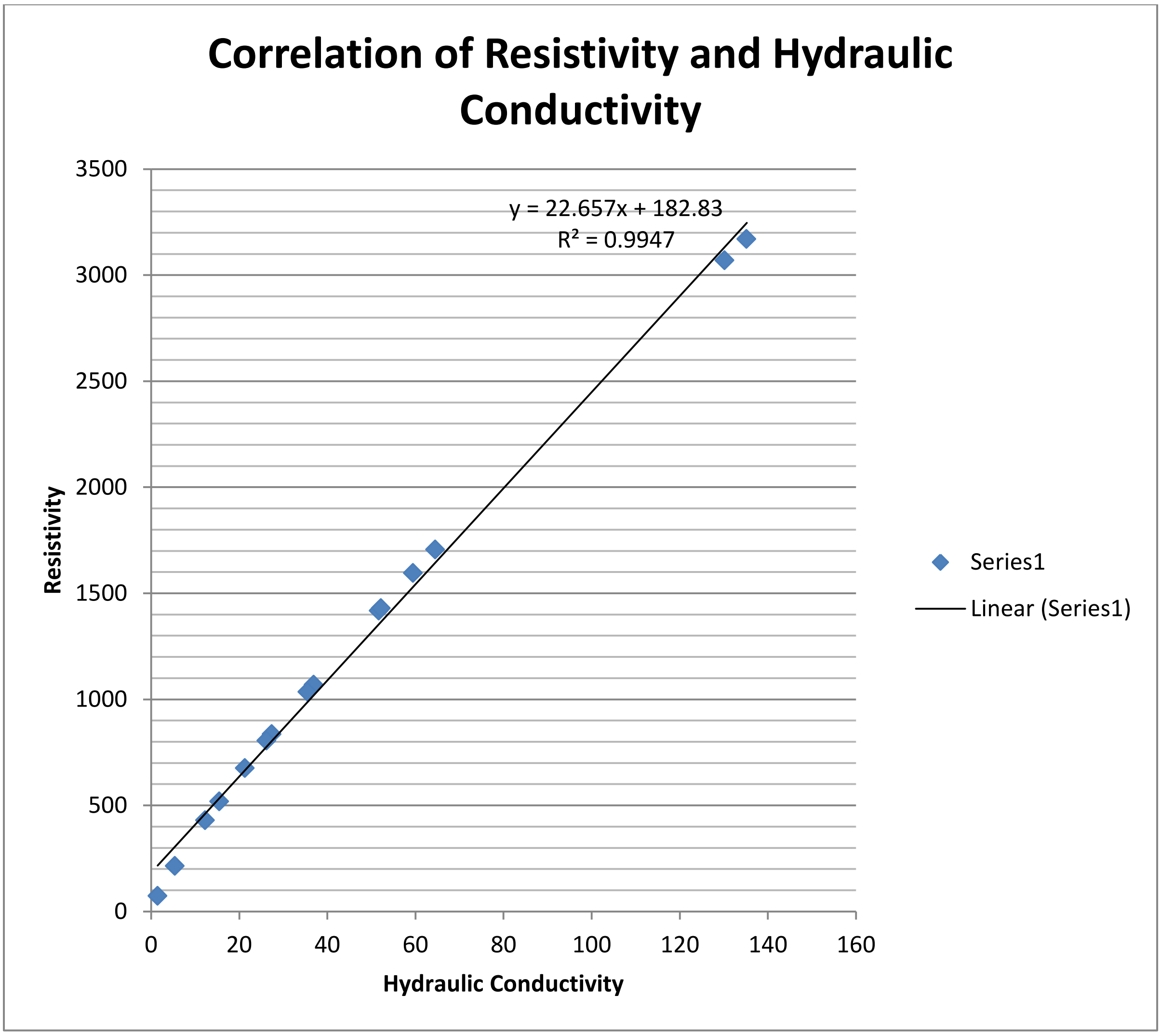


**Fig. 3. Correlation of Resistivity and Hydraulic Conductivity of the fifteen locations in the study area.**

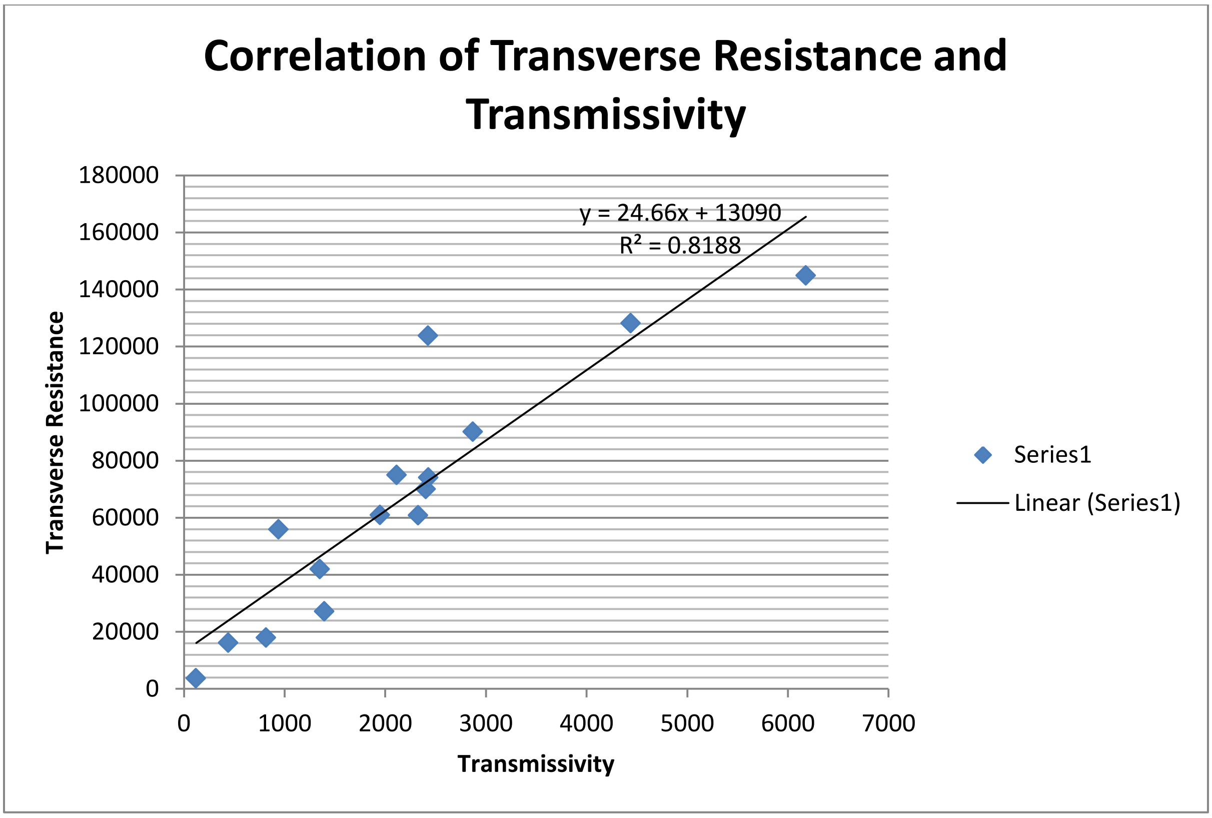


**Fig. 4. Correlation of Transverse Resistance and Transmissivity of the fifteen (15) locations in the study area.**

The regression equations of the hydraulic and geoelectric parameters from the study area are:

$$\ell_m = 22.65K_m + 182.8 \quad (17)$$

$$\mathcal{R}_m = 24.66T_m + 13090 \quad (18)$$

Equations (17) and (18) can be used to estimate the aquifer hydraulic characteristics in the study area where the survey did not cover.

Comparisons of resistivity map (fig.5) with hydraulic conductivity map (fig.6) transverse resistance map (fig.7), and transmissivity map (fig.8) show that areas underlain by relatively higher resistive aquifer materials have higher transverse resistance, hydraulic conductivity, and transmissivity values respectively. These relationships are expected because resistivity is directly proportional to the three parameters which are used to define target areas of good groundwater potential.


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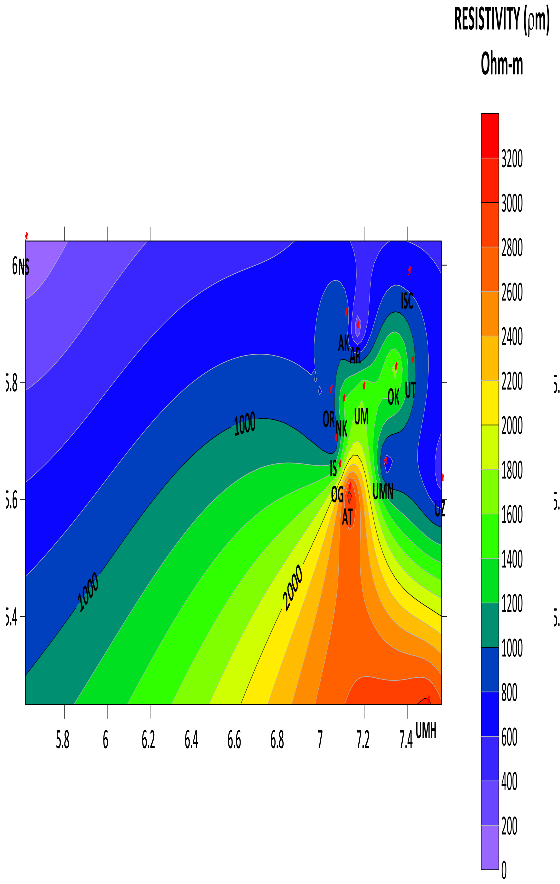


Fig. 5. Resistivity map

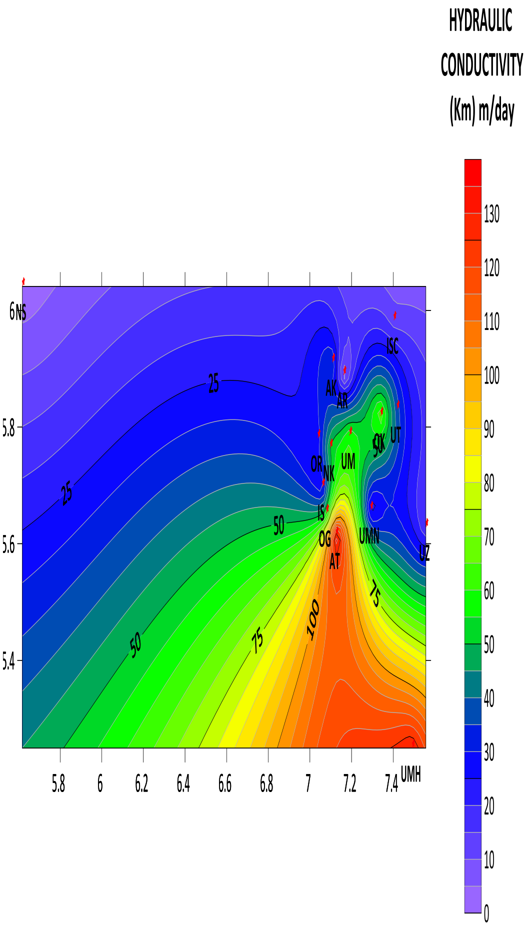


Fig. 6 Hydraulic Conductivity map

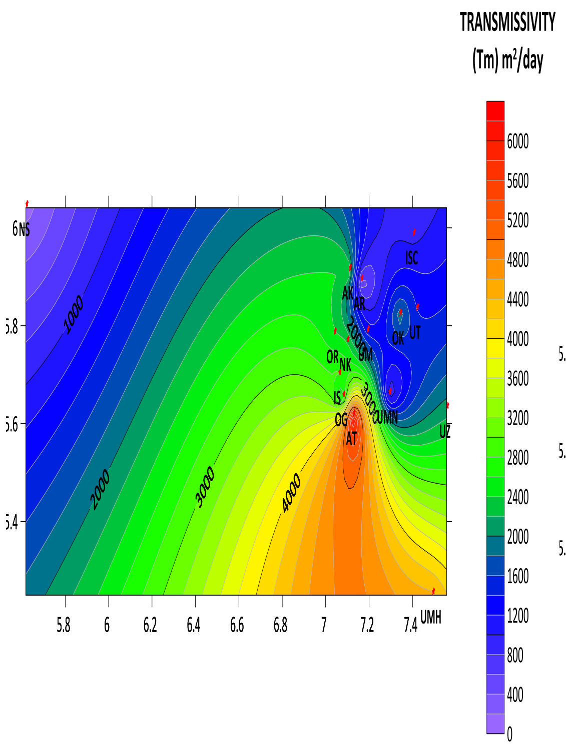


Fig.7. Transmissivity map

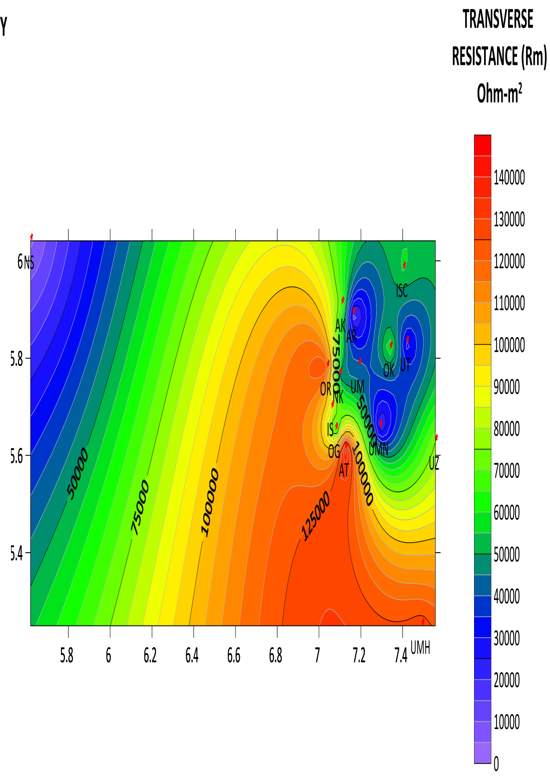


Fig. 8. Transverse Resistance map


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The result of the classification based on the Transmissivity Index (Y) (Fig. 9) shows that approximately 13% of the study area are under moderate magnitude (withdrawal of lesser regional importance),73% low (smaller withdrawal for local water supply), 7% very low (withdrawal for local water supply with limited consumption) and 7% negligible (zone without groundwater supply prospect).

From Krasny's Classification Scheme, the standard deviation value of 0.42 observed in Transmissivity Index $(Y)$ values of the area represents a moderate transmissivity variation and a fairly heterogeneous environment.

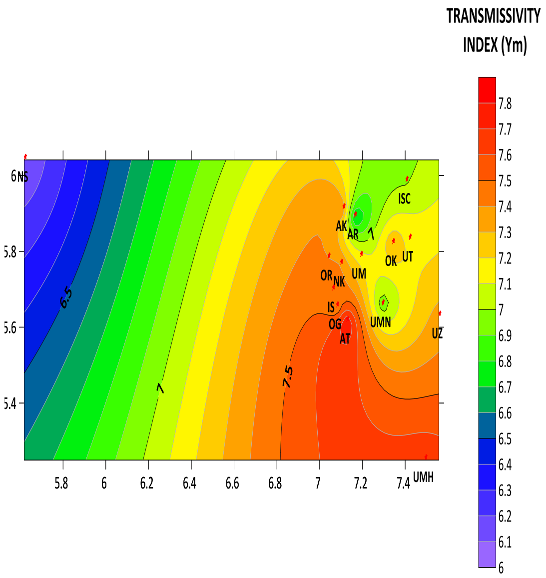


**Fig. 9. Transmissivity Index Map**

## 6. CONCLUSION

The application of VES technique has provided detailed information on the hydrogeoelectrical characteristics of the aquifers in the study area. The general terminal shapes of the vertical electrical sounding curves revealed that transverse resistance is the dominant Dar- Zarrouk parameter for the estimation of transmissivity in the study area.

The results of the correlation between hydraulic and geoelectric parameters showed high coefficient of reliability. Thus the regression equations of these parameters can be used to estimate the hydraulic conductivity and transmissivity values in the area the survey did not cover.

The analysis of spatial variation of transmissivity magnitude and transmissivity variation has classified the study area according to their groundwater supply potential ranging from zone without groundwater supply prospect to withdrawal of lesser regional importance. The standard deviation in the transmissivity index identified the study area as fairly heterogeneous hydrogeological environment.

The overall implication of the data analysis in this research is that transmissivity index classification has been applied successfully to assess the groundwater resources potential of the study area. The results of the study are



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reliable and consistent with the geology of the study area. Hydraulic parameters are of crucial importance in groundwater prospecting. The parameters utilized in this study will help to reduce the additional expenditures of carrying out pumping tests and offer an alternative approach to pre-drilling estimation of hydraulic parameters for optimum development and proper management of groundwater resources in the study area.

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