Available online at https://asric.africa/natural-sciences
ASRIC Journal on Natural Sciences Vol 4(2) (2024) 43-54

Evaluating Groundwater Potential and Hydrogeological Environment By Classification Of Transmissivity Magnitude And Variation In Aquifer Bearing Rocks In Some Communities In Okigwe Local Government Area Southeastern Nigeria

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Received 17 July 2024; revised 21 August 2024; accepted 5 November 2024

Abstract

This report evaluates the groundwater potential and hydrogeological environment of some communities in Okigwe LGA by classification of transmissivity magnitude and variation in aquifer bearing rocks using the methods of statistical testing and Krasny's classification. A total of twelve VES profiles were carried out with the aid of Omega 0198 Terrameter using the Schlumberger array with a maximum current electrode separation of 800m. The VES data were analysed with the aid of IP12Win computer software. Results of the final interpretation were used to generate aquifer hydraulic parameters. Results of the transmissivity analysis based on transmissivity index show that three locations have positive extreme anomalies which indicate zones with high groundwater supply potential. The remaining nine locations have negative extreme anomalies which indicate zones with negligible groundwater supply potential. The Krasny's classification of transmissivity magnitude shows that the coefficient transmissivity for all locations in the study area is greater than 1000 which is designated as very high transmissivity magnitude, implying high groundwater potential. Also, the results of the Krasny's classification of transmissivity variation show that the standard deviation of tansmissivity index of the study area is < 0.2 which indicates that the hydrological environment of the study area is homogeneous.

Keywords: Groundwater, hydrogeological environment, transmissivity magnitude, transmissivity variation, Krasny's classification

Introduction

Aquifer transmissivity is one of the properties that control the movement, storage and extraction of underground water. Aquifer transmissivity is defined as the product of hydraulic conductivity or permeability and thickness of the aquiferous units. It is measured in m^2/day. Aquifer transmissivity is a very important parameter for the assessment of the groundwater potential of any area. The superiority of the electric method over others in groundwater research is confirmed by the work of Pulawaski and

Kurth (1977). Zohdy et al. (1974) reported on the ability of the resistivity method to furnish information on the subsurface geology unobtainable by other methods in groundwater studies. They were able to show the ability of the resistivity method to provide information on the depth of the fresh water/ salt water interface. The geoelectrical method has been successfully utilized in accessing water supply potential in basement aquifers according to Chilton and Foster (1995). Also this method was used in assessment of the groundwater resource potential within the Obudu basement area of Nigeria, Okwueze (1996). Mbonu et al. (1991) carried out a Study for the determination of Aquifer characteristics in parts of Umuahia Area of Nigeria using the geoelectric method. Also Igboekwe et al. (2005) using the geoelectrical method produced the groundwater flow modelling of Kwa- Ibo river watershed in Southeastern Nigeria.

Ahamefule et al. (2023) in their paper titled hydrogeophysical survey and vulnerability assessment of some communities in Okigwe local government area, southeast Nigeria, computed aquifer hydraulic parameters within the study area including transmissiviy values. h x A table showing these parameters for the study area according to Ahamefule et al. (2023) is shown below. Our discussion on classification of transmissivity magnitude and variation in aquifer bearing rocks in the study Area shall be based on the data on Table 1. Meanwhile spatial variation of transmissivity magnitude and variation has been identified as best useful in groundwater management practices (Reddy, 2014).

Materials and Methods

Location and Geology

The study area is Okigwe area with focus on communities such as Aku, Agbobu, Ihube and Umulolo. It is bounded by latitudes 5°40′N to 6°55′N and longitude 7°14′E to 7°16′E. These communities are located in Okigwe Local Government Area in the northern zone of Imo state, southeast, Nigeria. They can be assessed through Enugu-Portharcout expressway, Okigwe-Owerri express roads with other secondary and minor roads.

The study area geologically lies within the Anambara sedimentary basin which constitutes a major depocenter of classtic sediments in the southern portion of the lower Benue Trough. The geological Formations of Anambra Basin are Nkporo Formation, Mamu Formation, Ajali Formation, Nsukka Formation, Imo Shale, Ameki Formation and Ogwashi Asaba Formation. Soils of the area are identified to originate from the false bedded sandstones of the Ajali Formation. The Nsukka Formation is underlain by the Ajali Formation. The Ajali Formation overlies the Mamu formation.

The study area is largely drained by the Imo River. The drainage path is mainly dentritic. Its topography is slightly undulating and punctuated by low hills with evidences of sandstone and siltstone deposits. The climate of the area is tropical with a mean annual temperature range of 27° - 28°C (Whiteman, 1982).

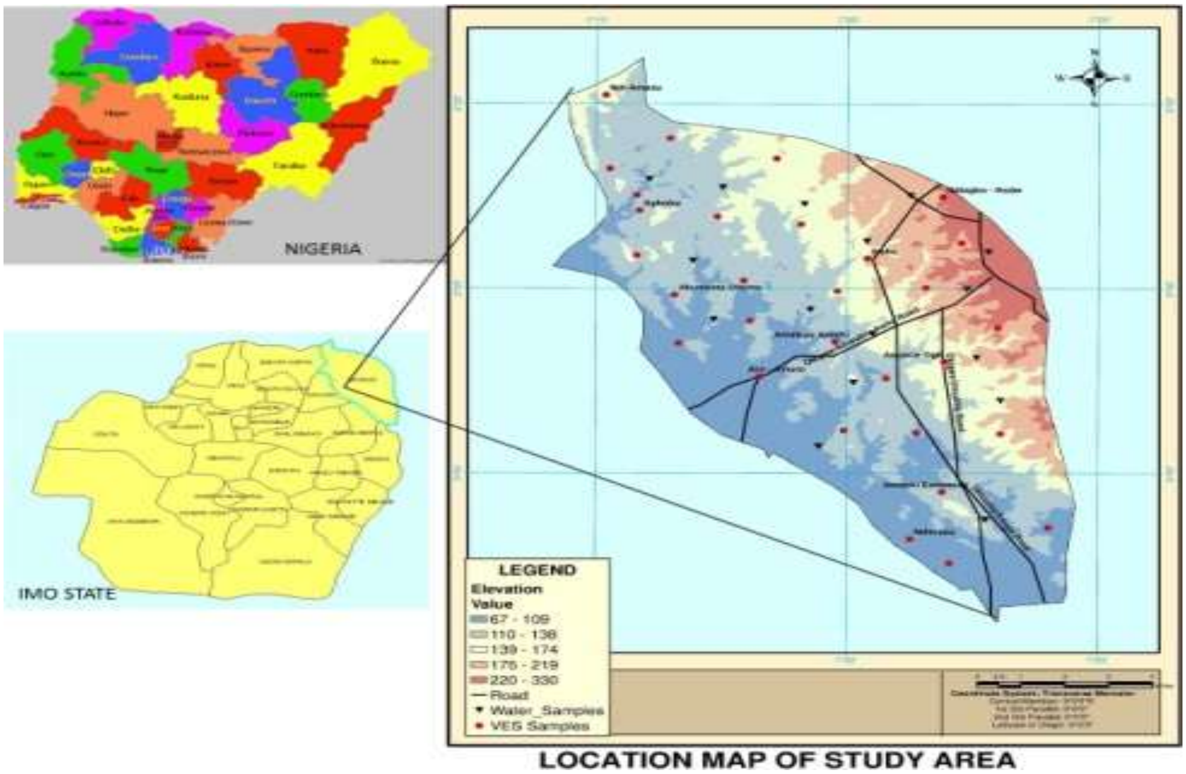

Figure 1: Location map of the study area

Figure 2: Geology map of the study area

Geophysical investigation was carried out in the field using Vertical Electrical Sounding Method. The instrument used is the Omega Terrameter with model number 0198. A total of twelve (12) vertical electrical sounding profiles were carried out within the survey area using the Schlumberger array with a maximum current electrode separation of 800m. The terrameter reads directly the resistance of the subsurface which is a measure of the voltage (V) to the imposed current (I). The resistance measured is used to compute the corresponding apparent resistivity by multiplying the geometric factor values.

$$\rho_a = \pi R \left\{ \frac{\left|\frac{AB}{2}\right|^2 - \left|\frac{MN}{2}\right|^2}{MN} \right\} \qquad (1)$$

Where, AB is the current electrode separation, MN is the potential electrode separation and

$\pi \left\{ \frac{\left|\frac{AB}{2}\right|^2 - \left|\frac{MN}{2}\right|^2}{MN} \right\}$ is the geometric factor

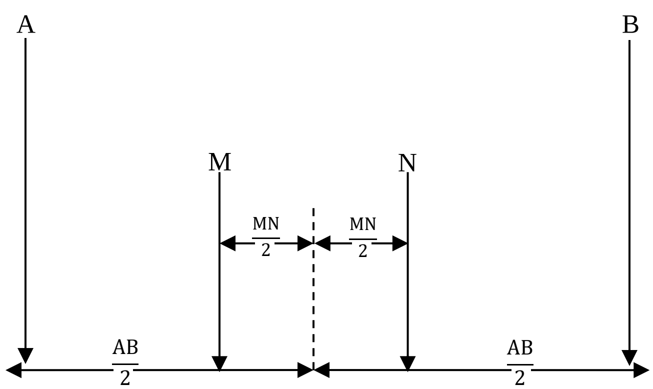

Figure 3: Schlumberger electrode

The resistivity is constant in a homogenous and isotropic ground irrespective of surface location and electrode spread. However, in the presence of subsurface inhomogeneities, the resistivity varies with the relative positions of electrodes. The computed value in this case is called apparent resistivity. With the aid of IPI2 win computer software, computer iterations were carried out. Results of the final interpretation were used to generate Aquifer hydraulic parameters

Aquifer Parameters from Geo-Electric Data

The transmissivity *(T)* and hydraulic conductivity (*K*) of the aquifer, has a direct relationship to the resistivity and thickness of the aquiferous medium. The integration of these parameters give an indication of the groundwater potential of an area (Maillet, 1947). For the assessment and evaluation of the aquifer hydraulic properties of an area, the concept of Dar-Zarrouk parameters: Transverse resistance R and Longitudinal conductance S are applied.

$$R = h\rho \qquad (2)$$

$$S = \frac{h}{\rho} \qquad (3)$$

Where ρ and h are resistivity and thickness of each layer respectively.
The relationship between transmissivity and hydraulic conductivity is:

$$T = kh \quad (4)$$

From Equation 3, $h = s\rho = \frac{s}{\sigma}$ (5)

Where σ is layer conductivity

From Equation 4, $h = \frac{T}{k}$ (6)

Therefore, Equation 5, is equal to equation 6
$\frac{S}{\sigma} = \frac{T}{k}$

$$T = \frac{KS}{\sigma} = kh = \frac{KR}{\rho} = K\sigma R \quad (7)$$

In areas of similar geologic setting and water quality, the product Kσ remains fairly constant. (Niwas and Singhal, 1981). Transmissivity values and its variation from one VES point to another can be determined by using parameters 'R' and 'S' in areas where borehole data is unavailable (Igbokwe et al; 2006). The Tables 1 and 2 are respectively Tables of aquiferous layer parameters and aquifer hydraulic parameters.

Table 1: Aquiferous layer parameters

VES	VES STATION NAME	ELEVATION(m)	LATITUDE	LONGITUDE	LAYERS	RESISTIVITY(Ω m)	THICKNESS(m)	DEPTH(m)	LITHOLOY
1	Ndi-agbo Ihube	254	5°52.502′	7°22.506′	1	773	0.9	0.9	Top soil
					2	106	0.97	1.87	Laterite
					3	8360	2.01	3.88	Laterite
					4	311	4.18	8.06	Laterite
					5	7568	36.5	44.56	Sand
					6	1552	37.4	81.96	Sandstone
					7	2.8	-	-	Sandstone
2	Amano-Ihube	282	5°52′10.604″	7°22′35.251″	1	2148	0.9	0.9	Top soil
					2	1463	0.97	1.87	Laterite
					3	88.4	2.01	3.88	Laterite
					4	10145	4.18	8.76	Clay Laterite
					5	1414	8.68	17.44	Silt Stone
					6	55475	55.6	73.04	Sand Stone
					7	12297	-	-	
3	Apugo-Ihube	231	5°52′45.642″	7°21′54396″	1	366	0.9	0.9	Top soil
					2	608	0.97	1.87	Laterite
					3	9.27	2.01	3.88	Laterite
					4	345	12.9	16.78	Sand: Laterite
					5	249	18.0	34.78	Sand
					6	4439	37.4	72.18	Sand Stone
					7	19521	-	-	
4	Uhuala-Aku	225	5°53′.966″	7°20.422′	1	538	0.9	0.9	Top soil
					2	1561	3.21	4.11	Laterite
					3	12163	4.56	8.67	Sand Stone
					4	498	75.6	84.27	Sand: Shaly
					5	246	-		Sand: Shaly
5	Umuno-Aku	86	5°42.462′	7°17.729′	1	18.4	0.29	0.29	Top soil
					2	19.4	2.03	2.32	Laterite
					3	0.5	2.66	4.98	Shale
					4	8.6	0.05	5.03	Shale
					5	209	6.71	11.74	Shale
					6	958	11.7	23.44	Shale
					7	86249	22.6	46.04	Shale
					8	214	43.7	39.74	Shale
					9	13.4	-	-	
6	Umuele Umulolo	144	5°49′26.574″	7°20′3.435″	1	466	0.41	0.41	Top soil
					2	1777	0.78	1.19	Laterite
					3	96.3	588	7.07	Laterite
					4	12.3	2.93	10.00	Clay: Laterite
					5	70.0	49.5	59.50	Silt stone
					6	1035	36.4	95.90	Sand Stone
					7	1.88	-	-	

7	Amosu Umulolo	116	5°48.479′	007°19.294′	1	484	0.9	0.9	Top soil
					2	954	1.01	1.91	Laterite
					3	25.5	6.72	8.63	Siltstone
					4	41.7	9.67	18.30	Clay e.g Siltstone
					5	785	20.5	38.80	Sandstone
					6	856	43.6	82.40	Sand
					7	48.7	-	-	Shale
8	Agbobu	112	05°51.717	007°15.628″	1	85.5	0.9	0.9	Top soil
					2	1043	0.97	1.87	Laterite
					3	177	6.22	8.09	Laterite
					4	1656	26.7	34.79	Siltstone
					5	178	-		Siltstone
9	Umuedi Agbobu	121	05°49.797"	07°16.052"	1	309	0.9	0.9	Top Soil
					2	50.6	1.01	1.91	Laterite
					3	27.6	2.15	4.06	Laterite
					4	3.17	4.56	8.62	Laterite
					5	19.1	9.67	18.29	Shale
					6	11.8	66.9	85.19	SaltStone
					7	5151	-	-	
10	Umudike Agbobu	108	5°.86750"	007°.25989"	1	315	0.92	0.92	Top soil
					2	5299	0.99	1.91	Laterite
					3	1548	1.49	3.40	Laterite
					4	72.8	2.68	6.08	Laterite
					5	229	11.2	17.28	Clay
					6	68.8	21.8	39.08	Shale
					7	39796	-		
11	Ofoishi Aku	144	5°49"25.574"	$7^0$20'3.425'	1	460	0.41	0.41	Top soil
					2	1775	0.78	1.19	Laterite
					3	46.1	5.88	7.07	Laterite
					4	12.3	2.93	10.00	Clay:Laterite
					5	70.0	49.5	54.50	SiltStone
					6	1038	36.4	95.90	Sand Stone
					7	1.80	-	-	
12	Odomi Aku	178	05°50.593"	07°19.182"	1	131	0.9	0.9	Top Soil
					2	141	0.97	1.87	Laterite
					3	702	6.31	8.18	SandStone: Laterite
					4	238	8.68	16.86	Sand Stone
					5	33.52	18.0	34.86	Silt Stone
					6	2220	37.4	72.26	SandStone
					7	4.67	-	-	

Table 2: Results of aquifer hydraulic parameter

VES	VES STATION NAME	TRANSVERSE RESISTANCE (Ω)	LONGITUDINAL CONDUCTANCE(mho)	TRANSMISSIVITY m^2/day	LAYER CONDUCTIVITY (Ωm)	AQUIFER THICKNESS (m)
1	Ndi-agbo Ihube	58044.8	0.0241	2352.5	0.0006	374
2	Amano-Ihube	3084410	0.0010	3497.2	0.0010	55.6
3	Apugo-Ihube	166018.6	0.0084	23525	0.0002	37.4
4	Uhuala-Aku	37648.8	0.1518	4755.2	0.0020	86.3
5	Umuno-Aku	9351.8	0.0204	2748.7	0.0047	63.1
6	Umuele Umulolo	38195.5	0.0360	2321.0	0.0010	36.9
7	Amosu Umulolo	84.3	16.070	2314.7	0.4367	43.6
8	Agbobu	44215.2	0.0161	1679.4	0.0006	25.2
9	Umuedi Agbobu	15313.5	0.0274	1289.5	0.0013	66.9
10	Umudike Agbobu	867552.8	0.0005	1371.2	0.0003	21.8
11	Ofoishi Aku	38195.5	0.0360	2321.0	0.4367	36.9
12	Odomi Aku	83028	0.0168	2352.5	0.0005	37.4

Results

Theory of Spatial Analysis of Transmissivity

The transmissivity analysis is carried out using two methods. One method is based on descriptive statistical testing by identifying transmissivity and anomalies and the other method is based on a classification scheme introduced by Krasny in 1993

Statistical Testing

In this approach, all the transmissivity values collected are pooled in a particular region using transmissivity index Y. The relationship between transmissivity T and logarithmic transmissivity index Y is

$$T\ (m^2/day) = 10^{Y-8.96} \times 86400 \qquad (8)$$

Found by Jetal and Krasny in 1968, it is used to calculate the logarithmic transmissivity index Y from transmissivity T values. The above stated equation can be modified as, logarithmic transmissivity index:

$$Y = \mathrm{Log}\ [T/86400] + 8.96 \qquad (9)$$

Where T is transmissivity in m^2/day. The Logarithmic transmissivity index Y values are calculated using the modified equation.

Table 3: 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 xstandard deviation))	<0.95367790	Negligible
2	Negative anomalies	Between (mean –standard deviation) and mean –(2 standard deviation))	0.95367795 and 0.95367790	Very low
3	Background anomalies	Between(mean – standard deviation) and (mean+(standard deviation)	0.95367795 and 0.95367805	low
4	Positive anomalies	Between(mean +standard deviation) and (mean +(2x standard deviation)	0.95367805 and 0.9536781	Moderate
5	Positive Extreme anomalies	Greater than(mean +(2xstandard deviation)	>0.9536781	High

Table 4: Krasny's classification of transmissivity magnitude (T)

Coefficient of T (m^2/Day)	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	Verylow	Withdrawals for local water supply with limited consumption
<0.1	VI	Negligible	Sources for local water supply is difficult

Table 5: Krasny's classification of transmissivity (T) variation

Standard Deviation Index	Class of Variation	Designation of Variation	Hydrogeological Environment
< 0.2	A	Insignificant	Homogenous
0.2—0.4	B	Small	Slightly heteregenous
0.4-0.6	C	Moderate	Fairly heterogenous
0.6-0.8	D	Large	Considerably heterogenous
0.8-1.0	E	Very large	Very heterogenous
>1.0	F	Extremely large	Extremely heterogenous

The Standard deviation of the transmissivity index as calculated for the twelve VES locations and obtained as 5.02 x 10^{-8}.

Considering Table 3 above in relation to the results obtained from the study area we generate the following table:

Table 6: Transmissivity analysis based on transmissivity index classification from available results

VES	Location	Range of Y	Description	Classification	Groundwater Supply Potential
1	Ndi agbo Ihube	<0.95367790	Less than mean-(2 x standard deviation)	Negative extreme anomaly	negligible
2	Amano Ihube	>0.9536781	Greater than mean + (2 x standard deviation)	Positive extreme anomaly	High
3	Apugo Ihube	<0.95367790	Less than mean – (2 x standard deviation)	Negative extreme anomaly	negligible
4	Uhuala- Aku	>0.9536781	Greater than mean +(2 x standard deviation)	Positive extreme anomaly	High
5	Umuano Aku	>0.9536781	Greater than mean +(2 x standard deviation)	Positive extreme anomaly	High
6	Umuele Umulolo	<0.95367790	Less than mean- (2 x standard deviation)	Negative extreme anomalty	Negligible
7	Amosu Umulolo	<0.95367790	Less than mean-(2 x standard deviation)	Negative extreme anomaly	Negligible
8	Agbobu	< 0.95367790	Less than mean –(2 x standard deviation	Negative extreme anomaly	negligible
9	Umuedi Agbobu	<0.95367790	Less than mean –(2 x standard deviation)	Negative extreme anomaly	negligible
10	Umudike Agbobu	<0.95367790	Less than mean-(2 x standard deviation)	Negative extreme anomaly	negligible
11	Ofoishi Aku	<0.95367790	Less than mean –(2 x standard deviation	Negative extreme anomaly	negligible
12	Odomi Aku	<0.95367790	Less than mean-(2 x standard deviation)	Negative extreme anomaly	negligible

Table 7: Coefficient of transmissivity from Krasny's classification of transmissivity magnitude

VES	Location	Transmissivity Magnitude (m^2/Day)	Coefficient of Transmissivity Magnitude	Class of Magnitude	Designation	Groundwater Supply Potential
1	Ndi Agbo Ihube	2352.5	> 1000	I	Very high	Withdrawal of great regional importance
2	Amano Ihube	3497.2	>1000	I	Very high	Withdrawal of great regional importance
3	Apugo Ihube	2352.5	>1000	I	Very high	Withdrawal of great regional importance
4 to 12	Every other location		>1000	I	Very high	Withdrawal of great regional importance

Table 8: Krasny's classification of transmissivity variation within the study area

VES	Location	Standard Deviation of T Index	Class of T Variation	Designation of T Variation	Hydrogeological Environment
1	Ndi agbo Ihube	< 0.2	A	Insignificant	Homogenous
2	Amano Ihube	<0.2	A	Insignificant	Homogenous
3	Apugo Ihube	<0.2	A	Insignificant	Homogenous
4 to 12	Every other location	<0.2	A	Insignificant	Homogenous

Discussions

Considering the table 6 where transmissivity analysis based on transmissivity index (Y) within the study area has been displayed, we discover that about three locations out of the twelve locations had positive extreme anomalies which indicate zones with high groundwater supply potential. Other locations had negative extreme anomalies which indicate zones with negligible groundwater supply potential. However using the krasny's classification of transmissivity, T, magnitude we realize as in Table 7 that the coefficient of transmissivity for all locations in the study area is greater than 1000 which is designated as very high transmissivity magnitude with a corresponding groundwater supply potential expressed as withdrawal of great regional importance which implies high groundwater potential.

Also using the krasny's classification of transmissivity variation as displayed on Table 8, we discover that the hydrogeological environment of the study area is homogenous.

Conclusion

The standard deviation value of 5.02×10^{-8} in the transmissivity index (Y) classification represents an insignificant transmissivity variation characterizing the study area as a homogenous hydrogeological environment. Transmissivity analysis based on transmissivity index(Y) classification (Table 7) delineated the study area into two groundwater supply potential zones 75% negligible and 25% very high groundwater potential rating. However following the Krasny's classification of transmissivity magnitude, the entire study area has transmissivity magnitude with a coefficient greater than 1000 designated as very high with groundwater supply potential expressed as withdrawals of great regional importance.

References Cited

Chilton, P. J. and Foster, S. (1995). Hydrogeological characterization and water-supply potential of basement aquifers in tropical Africa. Hydrogeology journal, 3, 36-49.

Igbokwe, M. U., Gurunadha Rao, V. V. S., and Okwueze, E. E. (2005). Groundwater flow modelling of Kwa-Ibo River watershed, southern Nigeria. Global Journal of Geological Sciences, vol. 3, No. 2, 2005: 169-177.

Igboekwe, M.U., E.E Okwueze, and C.S. Okereke, (2006). Delineation of potential aquifer zones from geoelectric soundings KWA IBO River watershed, southeastern, Nigeria. Journal of Engineering and Applied Sciences. 1(4): 410-421.

Jetal, J., and Krasny, J. (1968). Approximative aquifer characteristics in regional hydrogeological study. Vest. Ustr.Ust. Geol. Praha 43 (5), 459-461.

Krasny, J. (1993). Classification of transmissivity magnitude and variation. Groundwater journal of Association of Groundwater Scientists and Engineers, 31,230-236.

Maillet, R. (1947). The fundamental equations of electrical prospecting. Geophysics, 12, 529-556.

Mbonu, P. D. C, Ebeniro, J. O., Ofoegbu, C. O., and Ekine, A. S. (1991). Geoelectric sounding for the determination of aquifer characteristics in parts of the Umuahia area of Nigeria. Geophysics, vol. 56, No. 2, 284-291.

Niwas, S, and Singhai, D.C., (1981). Estimation of aquifer transmissivity from Dar-Zarrouk parameters in porous media. Journal of Hydrology, 50, 393-399.

Okwueze, E. E. (1996). Preliminary findings of the groundwater resources potentials from a regional geo-electric survey of the Obudu basement area. Nigeria Global Journal of Pure and Applies Sciences, vol. 2, (2), pp. 201-211.

Pulawaki, B. and Kurth, R. (1977). Combined use of resistivity and seismic refraction methods in groundwater prospecting in crystalline areas. Study project, Kenya, DANIDA, pp. 5-33.

Reddy, S. K. (2014). Classification of transmissivity magnitude and variation in calcareous soft rock of Bhaskar Rao Kunta watershed, Nalgonda District, India. International Journal of Water Resources and Environmental Engineering, 6 (3): 106-111.

Whiteman, A. J. (*1982*). Nigeria: Its petroleum geology, resources and potentials. (1) 176, (2) 238. Graham and Trotman, London, U.K..

Zohdy, . A., Eaton, C. P., and Mabey, D. R. (1974). Application of surface geophysical to groundwater investigation technology. Water Resources Investigation, Washington, U.S Geological Survey.