Hydraulic Conductivity Estimates of Imo River Basin's Aquiferous layers, Southeastern Nigeria Using Empirical Equations Derived from Electrical Resistivity Data

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Abstract: **This study was carried out to determine the equation (model) that fits best to the hydraulic conductivity values measured directly from pumping test data from monitoring wells. Three different electrical resistivity empirical equations were used to estimate aquifer hydraulic conductivity of Imo river basin, southeastern Nigeria, using surficial geo-sounding data. Two hundred (200) vertical electrical sounding (VES) data were obtained with forty-five (40) available pumping test data that were acquired from monitoring wells within the study area. Similarly, forty of the two hundred VES data were acquired close to the monitoring wells for parametric and correlation purposes. Three empirical resistivity model equations (N_ Model, H_ Model, and M_ Model) were used to estimate aquifer hydraulic conductivity across the study area. Estimates of the aquifer hydraulic conductivity from the three models revealed that the hydraulic conductivity ranges between 0.23- 26.43m/day with a mean value of 6.15 m/day for N_ Model. For H_ Model it ranged between 0.07 and 5.22m/day with a mean value of 1.03m/day and for M_ Model it ranged between 1.03 and13.42m/day with a mean value of 4.19m/day . The Aquifer hydraulic conductivity values estimated from the M_model when compared with the values from the pumping test showed a strong coefficient of determination (R^2 = 0.82) while N_ Model and H_ Model revealed very poor correlations with the pumping test data, with negative correlations of -0.03 and -0.3 respectively. The results of the t _test revealed that there is no significant difference between the estimated hydraulic conductivity values from M_Model and pumping test data. These findings have therefore revealed that geologically constrained empirical resistivity equations are reliable for the estimation of aquifer hydraulic conductivity from surface resistivity data. The reason for the poor correlation of the N_Model and H_Model with the pumping test data in the study area is because local geology of the study area was not considered by the models.**

Keywords**: Vertical Resistivity Sounding, Pumping Test, Dar Zarrouk parameters, hydraulic conductivity, N_model**

I. INTRODUCTION

Groundwater is one of the natural resources needed for industrial, domestic, and agricultural purposes. Presently, nearly fifty percent (50%) of the global population without access to potable water lives in Sub-Saharan Africa and approximately 700 million people in the region lack access to improved sanitation (UNICEF 2015). Access to safe drinking water is a key ingredient for environmental sustainability, better health, and poverty reduction. However, more than half of the rural people in countries in Sub-Saharan regions like Nigeria do not have access to a safe and reliable water supply [41]. Faced with this reality, the international community has set the Millennium Development Goals (MDGs) and the Sustainable Development Goals (SDGs) to help focus on activities that will address poverty and pursue sustainable development. One of these targets is to reduce by half the the population without access to safe reliable water supplies that by 2015 (MDGS 2015). This was also captured in the Vision 2020 Action Plan of the Federal Government of Nigeria which unfortunately was far from been achieved. This problem has led to serious environmental challenges with far-reaching socio-economic consequences including the prevalence of water-borne diseases in parts of the study area. The scarcity of potable water in most parts of the study area is often linked to the poor quality of most of the exploration studies carried out to delineate productive aquifers and their hydraulic characteristics [9], [36], [32].Besides, the exploration and exploitation of groundwater resources are most often carried out by contracting firms with little or no experience of the hydrological, hydro-geological, and aquifer vulnerability characteristics of the area.

Thus groundwater resources are most often extracted without a sound knowledge of aquifer hydraulic characteristics of the various hydro-stratigraphic units. This has led to several abandoned and abortive water boreholes in the study area and its environs [44], [9], [36]. As the demand for freshwater increases worldwide, delineation of groundwater potential zones and their protective capacities has, therefore, become very necessary for effective groundwater exploration/exploitation, protection, and sustainable management [25],[3]. However, the problem of potable water scarcity in most developing countries like Nigeria is most often further complicated by indiscriminate waste disposal and other human activities, which has resulted to anthropogenic contamination of groundwater resources from these surface sources [5].

The direct current resistivity methods especially the use of vertical electrical sounding is one viable way that has been extensively used with great success worldwide for groundwater exploration[15], [27], [37], [6], [3]. Resistivity methods have been used in delineating the aquifer systems in addition to the evaluation of their geometrical parameters like depth, thickness, and curve types. Several scholars have used resistivity methods to estimate the geo-hydraulic characteristics of the aquifers [20], [37], [6],[4].

Generally, aquifer hydraulic parameters are measured directly from monitoring wells using the pumping test technique. However, the nearly prohibitive cost of pumping test measurements within the study area has resulted in the paucity of accurate and authentic data on hydraulic characteristics of the aquifers in the study area [9], [8], [4]. Only little authentic information of specific yield, transmissivity, hydraulic conductivities, etc of the aquifers within the study area exists and is readily available mostly at government-owned institutions, agencies, and universities. Aquifer hydraulic conductivity may also be estimated from grain size analysis test which requires the granulometric analysis of grain size samples obtained from the drilling of water boreholes [21], [44], [38], [2]. This approach is also very expensive and unaffordable for most research studies, estimates of the hydraulic conductivity must involve the drilling of boreholes to the total drill depth (TDD). Therefore, detailed regional studies that require dense data set of aquifer hydraulic parameters in the study area are not readily available and affordable. The estimation of hydraulic conductivity using pumping test and grain size analysis is very expensive and as such, surface electrical investigation techniques are commonly used by researchers to investigate groundwater hydraulic characteristics [27], [1], [20], [29], [14], [30], [10]. However, the accuracy of these estimates depends on the hydraulic behavior of the fractures and the hydraulic connectivity of the pores in addition to the predictive capabilities of the empirical model equations used [40].

The geo-hydraulic characteristics of aquifers are therefore most often estimated from resistivity data [34]. Several analytical and empirical equations have been used over the years for estimating hydraulic characteristics of aquifers from direct current resistivity measurements. These model equations include those of [27], [15], among others. These equations have been used by several authors worldwide to estimate aquifer transmissivity and hydraulic conductivity values with a relatively good degree of success [8], [36]. Many Scholars have shown that the aquifer hydraulic conductivity is inversely proportional to aquifer resistivity [15], [Niwas and 26], [31] [18] [22].

Estimates of aquifer hydraulic characteristics employing Dar-Zarrouk parameters have also been widely discussed by many scholars [19], [17], [27]. Studies on aquifer hydraulic parameter estimations carried out using Dar-Zarrouk parameters in several locations in the Southeastern part of Nigeria have also recorded varying degrees of successes [35], [23], [9], [8], [36]. Thus estimation of aquifer hydraulic conductivity using surface resistivity data is the cheapest option especially when the study is of the regional extent and only a few well data are available in the area.

There is, therefore, the need to explore models that will yield results that will be close enough to the pumping test result. Despite the obvious achievements and gains of the spatial estimation of aquifer hydraulic parameters from surficial resistivity data, most of the time, the accuracy of the equations used especially geologically complex environments is uncertain. [39] showed that experimental data can be used to calibrate models for estimation of recharging rate of groundwater and determined the better model for prediction of natural recharge rate. In this study, a comparative analysis of the new formation specific models, the [15] model equations were made to evaluate their various degrees of accuracy.

II. LOCATION, PHYSIOGRAPHY, GEOLOGY, AND HYDROGEOLOGY OF THE STUDY AREA

The study area is in the Imo River Basin which lies between Latitudes $4^o\ 45' - 6^o 00' N$ and Longitudes $6^o\ 40' - 7^o 45' E$ (Figure 1). The Imo River Basin is located in the tropical, equatorial rainforest belt of West Africa. It is a 140 km north-south trending hydro-geological and hydrological syncline located within Southeastern Nigeria stretching across three states.

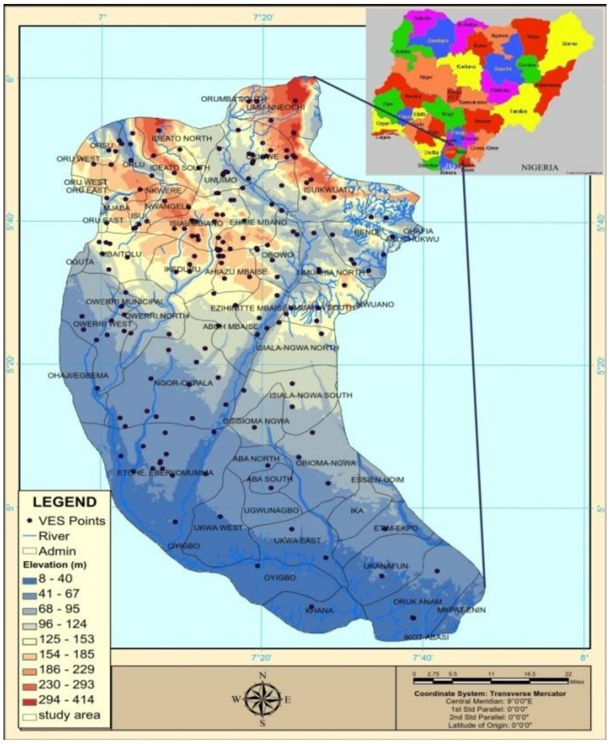


Fig. 1 Location map of the study area showing the vertical electrical sounding points.

The climatic condition of the study area is characterized by uniformly high temperatures and seasonal distribution of precipitation. Its average maximum temperature is 34°C while its average minimum temperature is 25^{0}C, with heavy rainfall of about 2400 mm/year increasing southwards. There are two seasons prominent in the study area namely: dry and rainy seasons. The rainfall regime is rather simple and runs intermittently from May to October and sometimes to November. The area is densely populated with fast-growing cities characterized by urbanization and industrialization which pose a serious challenge to the quantity and quality and status of the groundwater [11], [33].

The Imo river basin consists of a bedrock of a sequence of sedimentary rocks of about 5.480km thick and with the geological ages ranging from Upper Cretaceous to Recent [42], [43]. The basin stretches across six geologic formations within the study area. The formations that cut across the study area include the Benin, Ogwashi, Ameki, Imo Shale, Nsukka, and Ajali Formations [42].

The geological map of the study area (Figure 2) shows the different formations in the study area. The analysis of the geology and stratigraphy of the study area is very important because the occurrence of groundwater, the extent, and distribution of aquifers and aquitards in a region are determined by the lithology, stratigraphy, and structure of the geological strata present [16].

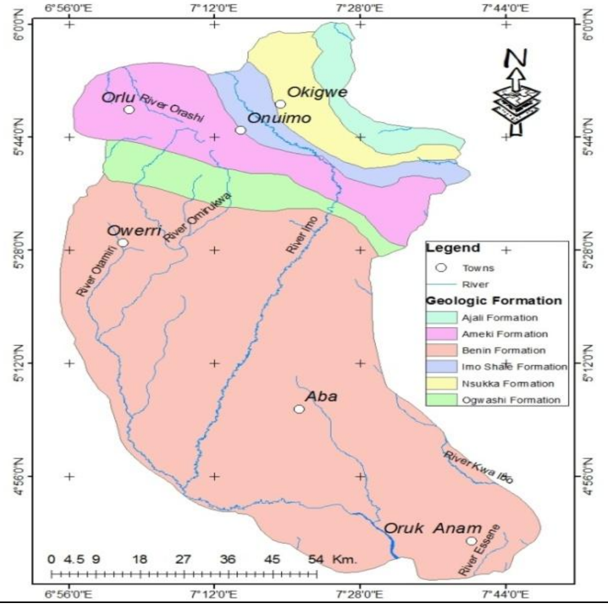


Fig. 2 Geology map of the study area

The Benin and Ajali Formations have a multi- aquifer system which is hydraulically connected and are associated with very high groundwater productivity. The Benin Formation (also known as the Coastal Plain Sands) within the Imo River basin consists of unconsolidated yellow and white sands/sandstones and is occasionally pebbly with grey sandy clay lenses. Reference [42] identified three aquifer units within the Imo River Basin which consist of a shallow unconfined aquifer, a confined aquifer, and a deep unconfined aquifer system.

In the study area, shallow unconfined aquifers are the major sources of water for both domestic and industrial wells within the basin. These near-surface aquifers with high hydraulic characteristics are especially prolific along the southern flank of the Imo River basin and usually occur at depths of about 70-100 m.

III. METHODOLOGY

Two hundred (200) vertical electrical soundings (VES) were carried out in the study area using ABEM^{TM}Terrameter SAS 4000 with the data points shown in Figure 2. The Schlumberger electrode array was employed for the vertical electrical sounding data acquisition with a maximum half current electrode separation (AB/2) of 500 m as shown in Figure 3.

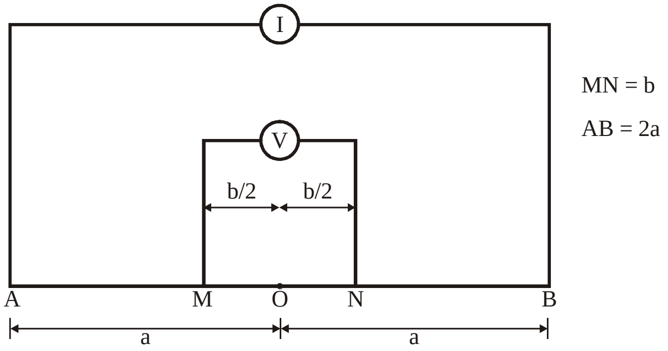


Fig. 3 Schematic representation of the Schlumberger electrode array

The observed field data were converted to apparent resistivity using the appropriate geometrical factor k given by

$$k = \frac{(a^2-b^2)}{2b}\pi \tag{1}$$

Where k is a geometric factor, a is half current electrode separation and b is half potential electrode separation. The field data was reduced to their equivalent geological models using a combination of curve matching and computer modeling techniques [45]. WinResist^{TM}software which took care of the effects of the lateral inhomogeneities and other forms of noisy signatures were used to generate smooth VES curves using the apparent resistivity and the electrode distance as the input data. Layer parameters representing the hydro-stratigraphy of the study area were later generated from the interpreted geo-electric curves.

A Aquifer Hydraulic Conductivity Estimation using Different Empirical Resistivity Model Equations

The layer parameters which are related to the different combination of thickness and resistivities of the geo-electric layers are very important for the analysis and understanding of the geologic model [45]. These parameters were used to calculate the Dar Zarrouk Parameters. The Dar Zarrouk Parameters (longitudinal conductance S, and transverse resistance R) are very important hydro-geophysical parameters and have found great application in groundwater vulnerability and aquifer hydraulic estimation studies. The Dar Zarrouk Parameters are given as:

$$S = \frac{h}{\rho} = \sigma h \qquad (2)$$

$$R = h\rho \qquad (3)$$

Where S is the longitudinal conductance in Ω^{-1}, ρ is the layer resistivity in Ωm, and h, layer thickness in m and R is the transverse resistance in Ωm^2.

[27], considered a prism of an aquifer material having a unit cross-sectional area A, and thickness h, and then combined the Darcy equation and Ohms law to get the relationship given as:

$$K = k\sigma\rho \qquad (4)$$

Where K is the hydraulic conductivity,$k\sigma$ is the diagnostic constant (product of hydraulic conductivity measured from well and the aquifer conductivity from the geophysical survey) andρ is the aquifer resistivity. In this study, the empirical equation used by [27] for the estimation of the aquifer hydraulic conductivity was referred to as the N_ Model.

[15] fitted a least-square line to the cross plot of the aquifer hydraulic conductivity values measured from available monitoring wells and aquifer resistivity values acquired by carrying out parametric vertical electrical soundings close to the locations of the monitoring wells with a resulting correlation of determination, R given as 0.94. This fitted least-square line resulted in an exponential relationship between hydraulic conductivity and aquifer resistivity as given in Eq. 6:

$$K = 386.40\, \boldsymbol{\rho}_w^{-0.93283} \qquad (5)$$

Where K = hydraulic conductivity from Heigold equation in cm/sec, $\boldsymbol{\rho}_w$ = resistivity of the water-saturated aquifer in Ωcm. Equation 5 is hereby referred to as the H_ Model equation in he present study.

Earlier studies on aquifer hydraulic estimation from surficial resistivity data used the empirical equations of [15] and [27] to estimate aquifer geo-hydraulic characteristics from surficial resistivity data. However, the use of these empirical equations has most of the time resulted in computational errors in the values of the estimated aquifer parameters especially in areas where the geology is complex. To solve this problem, a new empirical equation similar to the [15]model equation but further constrained by the local geology was developed using VES data collected around the monitoring wells. Reference [4] developed (6) empirical equations for six different geological formations in the study area to further improve the predictive capacity of the empirical equation as shown.

$$K = c\rho_w^d \qquad (6)$$

Where c and d are constants that depend on the geological formation overlying the aquifer unit, K is hydraulic conductivity and ρ is the aquifer resistivity.

B. Result and Discussion

The analysis of the geo-electric curves revealed five to six geo-electric layers with the aquifer zones lying mainly between the third and sixth layers and several primary curve types and their combination types were identified in line with the complex geology of the study area (Table 1) . The interpreted VES curves showed that the resistivity values of the shallow aquifers across the study area ranged between 101 Ωm and 8900 Ωm (Table 2.)

The aquifer hydraulic conductivity of the study area was estimated for each VES location with the three model equations. The aquifer hydraulic estimates from N_Model ranged from a minimum value of 0.23 m/day at VES EF in Ogwashi Formation to a maximum value of 26.43m/day at VES DO in Ameki Formation The average aquifer hydraulic value of 6.15m/day was estimated (Table 2). The aquifer hydraulic estimates from H_Model ranged between 0.08 m/day at VES A in Ogwashi Formation to 5.22 m/day at VES CV in Ameki Formation with a mean value of 0.68m/day. The aquifer hydraulic values estimated with M_Model showed minimum value of 1.03 m/day, maximum value of 13.42m/day and mean value of4.19 m/day (Table 2).From the well data the minimum aquifer hydraulic conductivity measured was 1.9 m/day, the maximum value was 8.12 m/day, and the average aquifer hydraulic conductivity as measured from wells in the study area was 4.07 m/day.

Table II: A Sample of the Layer Parameters of the Study Area.

VES NO.	VES Locations		Layer Resistivity						Layer Thickness						
	LONG.	LAT.	ρ1	ρ2	ρ3	ρ4	ρ5	ρ6	d1	d2	d3	d4	d5	d6	Curve Type
A	7.01	5.663	3510	16700	160000	8900	56500	34401	0.6	24.7	57.9	108	155		KK
AE	7.4	5.816	586	752	119	447	980	1530	0.6	2.3	9.3	53.2	116	171	KK
M	7.061	5.809	3060	8100	2220	3110	4000	4020	8.5	21	45	74	96.2		KA
AF	7.383	5.816	900	129	740	228	1560		0.4	3.9	15.4	31	99		KK
AI	7.383	5.833	196	327	375	208	511		5.4	53	97.7	109			AQ

AR	7.299	5.646	394	1382	436	347	550	1770	1.6	3.2	5	8.4	11.8	24.7	HKA
AT	7.163	5.889	368	649	8	3860	2880	463	2.6	3.9	22.6	99	174		KK
BF	7.188	5.668	214	1030	4270	7110	3410	234	0.4	19.9	53.2	76.9	122		AQ
BP	7.252	5.779	84	621	12.9	101	12.1		1.6	4.1	17.6	74	142		AHQ
BM	7.673	5.798	320	630	420	55			0.5	4.7	52.6				KQ
DN	7.517	5.579	726	118	2990	2783			1.4	5.4	35.5				HQ
DG	7.631	5.535	202	519	477	27.7	155	39.6	0.8	3.7	22.3	68	133		KHQ
DR	7.584	5.591	47.3	2610	507	900	345	100	0.5	2.1	9.8	38	104		KK
DZ	7.503	5.519	1520	561	6270	8600	4210	684	6.1	12.6	31.2	80.1	102		HK
EI	7.043	5.469	518	577	190	273	682	752	1	1.5	3.6	7.9	12.6		KK
FF	7.25	5.683	276	1770	3210	4700	117		12.9	33.6	52.9	117			KK
AR	7.299	5.646	394	1382	436	347	550	1770	1.6	3.2	5	8.4	11.8	24.7	HKA
HM	7.291	7.292	292	706	498	23568	2589		0.4	3.3	9.9	18.2	20.5	35.6	KK
HO	7.306	5.538	2020	1390	4260	28800	1040	6190	13.9	40.4	87.6	103	135		HKQ
HF	7.078	5.66	980	2340	565	539	1740		0.7	3.5	14.8	72.5	118		KH

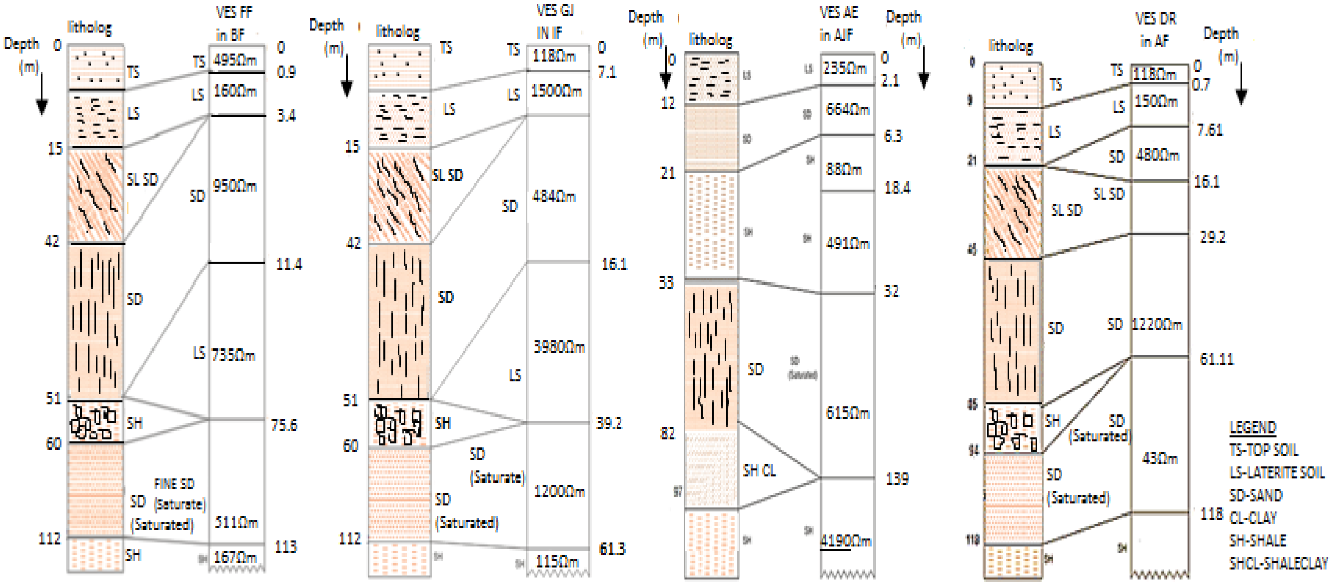


Fig. 4 Correlation of sampled litho-log from some boreholes with VES from the study area

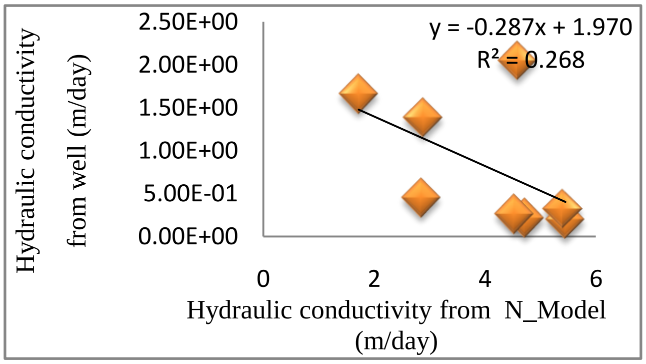
Correlations of litho-logs obtained from boreholes drilled within the study area and geo- electric sections obtained from vertical electrical sounding data revealed that the depths of the saturated zones in the wells correlated well with the results obtained from surface resistivity data (Figure 4). The saturated zones were found to be within the depth ranges of 65 - 112 m in the interpreted litho-logs while the geo-electric section showed that the saturated zones were within the depth range of 75 - 113 m (Figure 4). The strong relationships between the litho-log and geo-electric sections suggest that the estimated depths as shown in Table 2 are reliable. Similarly, five main geo-electric layers were generally encountered and are interpreted as topsoil, lateritic sand, silty sand, sands and clay in that sequence (Figure 4).

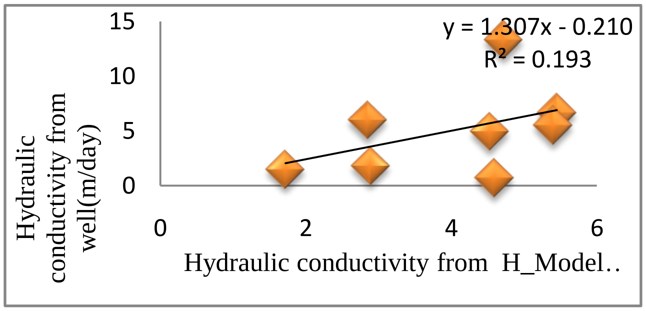
Table II Some Aquifer Hydraulic Conductivity Estimates From the Three Models

VES NO	Long.	Lat.	ρ (Ωm)	d (m)	h (m)	S= h/ρ	(σ)	R=ρh	K	Kσ	N model	H model	M model
A	7.011	5.663	8900	108	50.1	0.00563	0.000112	445890			17.3889	0.0799701	6.72659
AE	7.4	5.816	1530	171	55	0.03595	0.000654	84150			9.84883	0.4132962	2.74431
M	7.061	5.809	3110	74	29	0.00932	0.000322	90190	4.72	0.0015177	13.3138	2.13E-01	5.47521
AF	7.383	5.816	1560	31	15.6	0.00684	0.000439	35568	8.12	0.0035614	10.0419	0.40587724	2.7506
AI	7.383	5.833	511	97.7	44.9	0.08787	0.001957	22943.9	7.12	0.0139335	3.28938	1.14958437	2.4112
AQ	7.297	5.648	2530	160	145.1	0.05735	0.000395	367103	4.53	0.0017905	4.94313	0.25852599	4.71195
AT	7.7	5.851	1400	99	76.4	0.05457	0.000714	106960	2.85	0.0020357	5.99336	4.49E-01	3.71185
BF	7.187	5.668	3410	122	45.1	0.01323	0.000293	153791	5.45	0.0015982	6.66247	0.19569415	5.12728
BP	7.252	5.779	101	74	54.6	0.54059	0.009901	5514.6			2.50232	0.56178049	1.80502
BM	7.312	5.804	420	22.6	17.9	0.04262	0.002381	7518	2.89	0.006881	1.79801	1.38E+00	2.06514
CD	7.305	5.824	275	140	17	0.06182	0.003636	4675	4.59	0.0166909	0.66785	2.0490587	4.03945
DG	7.683	5.533	155	133	65	0.41935	0.006452	10075			0.66355	3.50E+00	1.27092
DS	7.7	5.73	1400	10.5	11.2	0.008	0.000714	15680			0.7492	0.448988	3.71185
DR	7.679	5.596	345	104	66	0.1913	0.002899	22770	1.72	0.0049855	1.47694	1.66E+00	1.87648
DZ	7.21	5.343	4210	102	21.9	0.0052	0.000238	92199			8.22552	1.61E-01	5.44238
EI	7.043	5.468	682	12.6	4.7	0.00689	0.001466	3205.4			1.83867	8.78E-01	2.3698
FF	7.241	5.733	2040	52.9	19.3	0.00946	0.00049	39372	5.4	0.0026471	5.49984	0.31602017	6.65107
AR	7.303	5.648	3040	53.8	24.7	0.00813	0.000329	75088			13.0142	2.18E-01	5.41484
HM	7.23	5.499	2589	20.5	2.3	0.0009	0.00039	5954.7			6.9799	0.253026	
HO	7.31	5.537	1040	199	42	0.0404	0.00096	43680			2.8038	0.592458	3.375
HF	7.06	5.574	539	57.7	72.5	0.1345	0.00186	39077.5			1.0531	1.093778	3.04198

A cross plot of the aquifer hydraulic conductivity measured from well and estimations from the three models gave a root mean square values (r) of 0.193 for N_model, 0.268 M_model and 0.808 M_models (Figure 5 a,b, and c).

Furthermore, statistical analysis was carried out to rank the different models used in the present study. The Pearson product-moment correlation coefficient, r, was computed to assess the strength and direction of the linear relationships that exist between the estimation (Table 3). A strong positive correlation of r = 0.6 was observed between the M_model and the pumping test values (k). The calculated t is 0.76 and at the α significance level of 0.1, while the tabulated t is 1.68 (Table 4). Thus, there is no significant difference between the M_model and the pumping test values. There is however a weak negative correlation (r = - 0.07) between the N_model and k values from the pumping test. Also, a negative weak correlation of r = -0.25 exists between the H_model and the k values from the pumping test (Table 3).





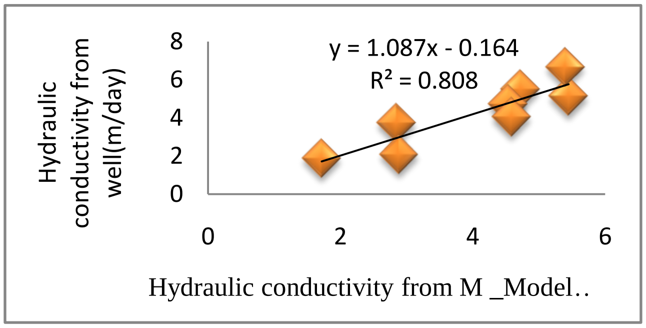


Fig. 5 Scatter plots of K form well and the estimates

Table III Correlation matrix of the different models used for hydraulic conductivity Estimations

		N_ model	H _model	M_ model	K_ model
N_ model	Pearson Correlation	1	-0.562	0.098	-0.026
	Sig.		0.000	0.000	0.590
	N	45	45	45	45

H_ model	Pearson Correlation	0.0562	1	-0.280	-0.025
	Sig.	0.000		0.000	0.004
	N	45	45	45	45
M_ model	Pearson Correlation	0.098	-0.28	1	0.824
	Sig.	0.000	0.000	0.000	0.76
	N	45	45	45	45
K_ model	Pearson Correlation	-0.026	-0.025	0.824	1
	Sig.	0.590	0	0.590	
	N	45	45	45	45

The spatial variation of aquifer hydraulic conductivity estimated using H_model (Figure 7), also showed three distinct areas. There were relatively low, moderate and high aquifer hydraulic conductivity regions. The northwestern part of the study area within Ameki and Imo Shale Formations were identified as area with relatively low aquifer hydraulic conductivity while the southern part of the study area was identified with relatively moderate to high aquifer hydraulic conductivity. The spatial variation of aquifer hydraulic conductivity as estimated with M_model equations (Figure 8) show that the Northern part of the study area; within some parts of Nsukka Formation and the whole of Ajali Formation were identified with relatively low aquifer hydraulic conductivity. This is in agreement with the well information from these two formations. The southern part of the study area that mprises of Benin Formation, Ogwashi Formation and Ameki Formation was identified with relatively moderate to high aquifer hydraulic conductivity.

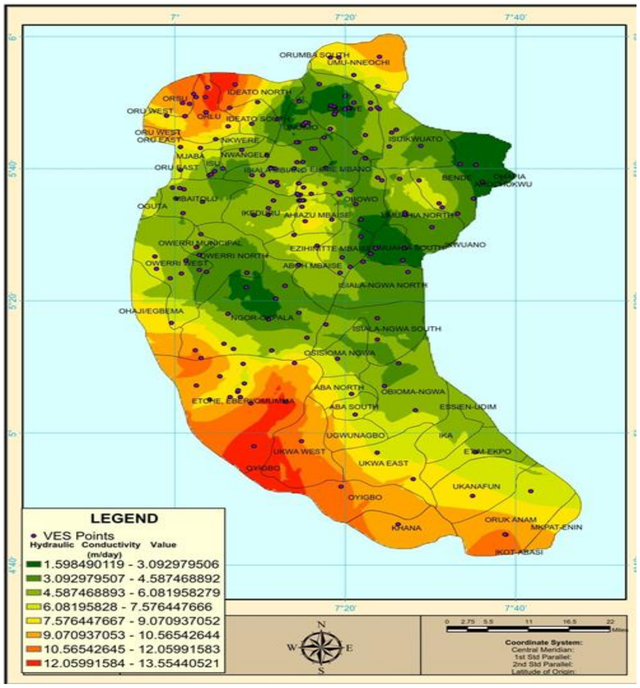


Fig. 6 Contour maps showing the distribution of the estimated hydraulic conductivity using N model.

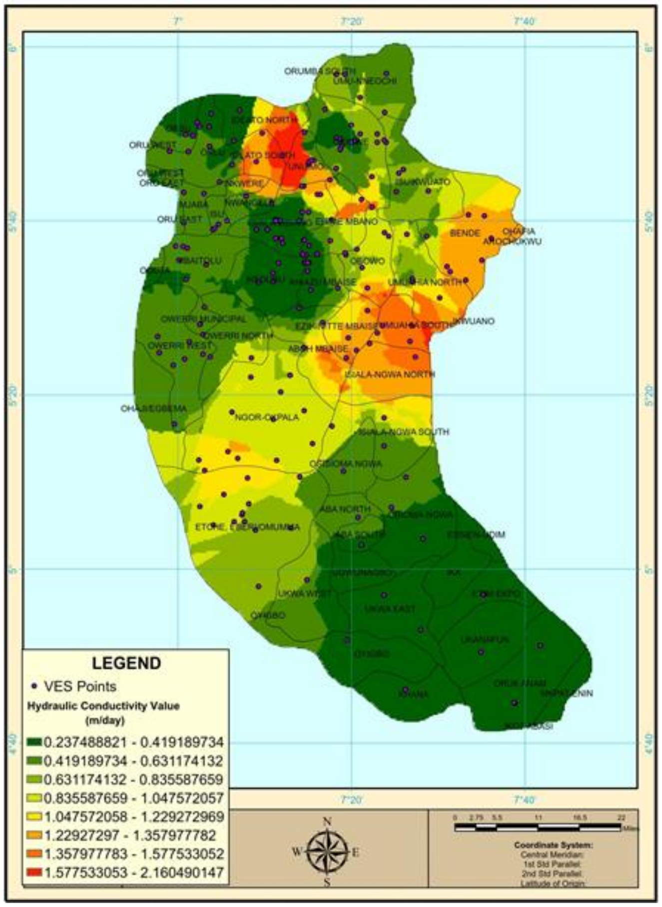


Fig. 7 Contour maps showing the distribution of the estimated hydraulic conductivity using H model

IV. SUMMARY, CONCLUSION, AND RECOMMENDATION

Aquifer hydraulic conductivity values estimated from the M_model when compared with the values from the pumping test using the Pearson product-moment correlation coefficient, showed a strong correlation coefficient while N_ Model and H_ Model revealed very poor correlations with the pumping test data.

The results of the t _test revealed that there is no significant difference between the estimated hydraulic conductivity values from M_Model and pumping test data. Estimates of the aquifer hydraulic conductivity using the M_Model revealed that the hydraulic conductivity ranges between 0.93 - 6.495 m/day with a mean value of 3.64 m/day. Similarly, the contour maps of the aquifer hydraulic conductivity across the study area show that the three models differ from each other. There is however no significant difference between the aquifer hydraulic conductivity estimated with the M_ model and the aquifer hydraulic conductivity measured from pumping well tests.

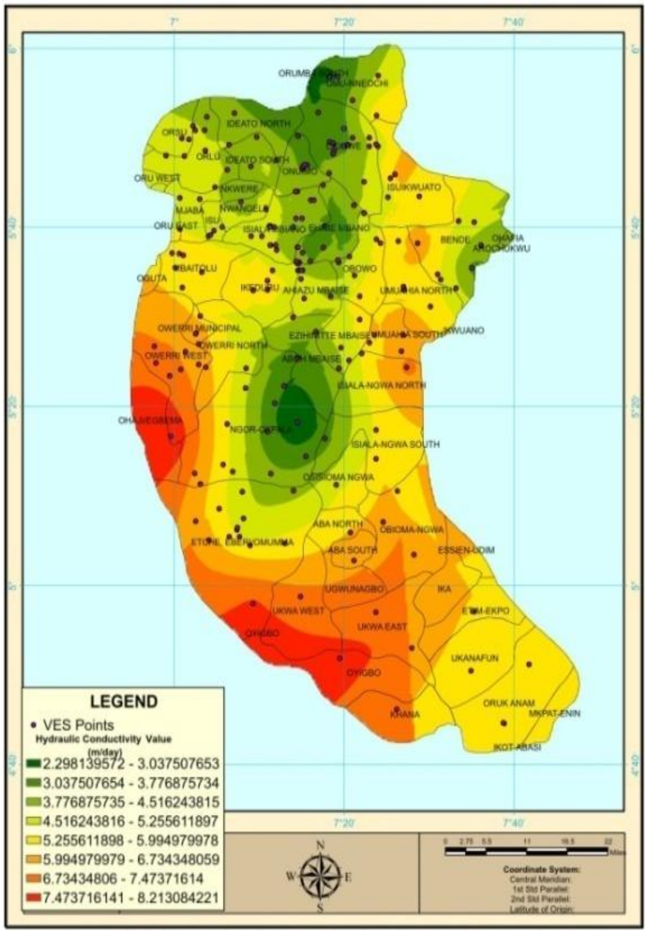


Fig. 8 Contour maps showing the distribution of the estimated aquifer hydraulic conductivity in m/day using M model.

This study present a formation-specific aquifer hydraulic conductivity estimation model (M_model) as an alternative means of accurately estimating hydraulic conductivity of an area with complex geology using surface resistivity data. The M_Model therefore can be used to estimate aquifer hydraulic characteristics when there is a dearth of pumping test data.

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