Determination of Aquifer Characteristics in Okija, Anambra State, Nigeria

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Abstract- Knowledge of hydraulic properties of groundwater aids economic and environmentally friendly exploitation of water resources in water-scare rural area such as Okija. In this study therefore, the aquifer constants are evaluated for Okija town in Ihiala Local Government Area of Anambra State, Nigeria to facilitate efficient and effective exploitation of the water resources in the area. The drawdown test involved pumping down the water level and monitoring the response of hydraulic head in the surrounding aquifer. The computation of formation constants is performed in three ways: Theis method, Cooper-Jacob method and Chow method. Model Selection Criterion (MSC was used to evaluate the discharge predictions from the three methods. The results show that transmissivity and storage coefficient for Theis method are 256. 37 m^2/day and 146.67 m^2/day; Cooper-Jacob method are 251.71 m^2/day and 131 m^2/day, and chow method are 2 67.87 m^2/day and 146.67 m^2/day respectively. This work represents a practical and novel approach to the determination of a key hydrogeological parameter for a highly transmissive aquifer.

Keywords-.Aquifer constants, Theis method, Cooper-Jacob method, Chow method, Okija

1 INTRODUCTION

In quantitative studies of groundwater hydrology for the development of water resources in an aquifer, it is essential to determine the field values of transmissivity and storage coefficient. This is so because they are generally considered as the physical indices of the aquifer characteristics, and are used as the basis for the theoretical prediction of the future yield of groundwater storage (Aguado et al., 2012; Amadi et. al, 2010). This fact has been strongly recognized in the application of the science of groundwater hydrology to engineering problems. The coefficient of transmissivity, T indicates the rate at which an aquifer will transmit water under a unit hydraulic gradient. Aguado et al. (2011) defined transmissivity as the number of m3/s of water which will move in one day through a vertical string of the aquifer one metre wide and having the height of one metre when the hydraulic gradient is unity. The coefficient of storage characterizes the ability of the aquifer to release water from storage as the head declines.

Amadi et al. (2010) defined S as the volume of water of a certain density released from storage within the column of aquifer underlying a unit-surface area during a decline of head of unity. Robust estimates of the rate at which the water is transmitted through the aquifer are essential if over extraction is to be avoided. The consequences of over-extraction can be include lower water tables and decreased access to groundwater supplies, decreasing environmental flows to groundwater dependent ecosystems, movement of poor quality (saline) water into the aquifer, the possibility of land subsidence and a decline in the contribution of groundwater to the base flow of river systems (Anazoo, 2008).

The Okija area is one of the communities that satisfy the definition of a rural community in Anambra State. The poor development and management of surface and groundwater resources in the area has been linked to the deplorable conditions of the populace in this community (Bear and Verruijt, 2011).

Reliable surface water resources are relatively nonexistent and communities rely on surface impoundments, dugouts and manually dug shallow wells which in most cases are not protected from surface contamination and are not able to provide water all year through (Ehirim and Nwankwo, 2010). Furthermore, high evapotranspiration rates, high temperatures and low humidity drys up the few surface impoundments shortly after the end of the rainy season. Groundwater has been identified as the solution to most of the economic and social problems in Okija area and other rural communities in Anambra State (Anazoo, 2008). Sustainable exploitation of groundwater can help develop irrigation industry. The use of groundwater for irrigation has been successful in other developing countries (Delleur, 2010; Charbeneau, 2010), and has the potential to be equally successful in Anambra State as well. However, a good understanding of the hydrogeology is needed to properly assign any productive use to the resource. In this research, the aquifer parameters of the groundwater resources in this Okija community were studied to determine its sustainability for domestic and irrigation uses.

2 METHODOLOGY

The site is situated in Okija community along Onitsha-Owerri express road in Anambra state and bounded at the rear by the Ulasi stream. The site is about 5 Kilometres from Ihiala, the local government headquarters, 15km from Nnewi and 25km from Onitsha. Anazoo (2008)reported that Okija town is located in Ihiala local government area in south-western Anambra State, between longitude 6°49‟52″E and 6° 47‟ 14″E and latitude 5°55'59"N and 5° 50‟ 39″ N. The entire area of south-western Anambra State has gentle rolling topography with some pronounced high grounds. On a general term, the topography rises west to east. The drainage in the area is marked by three drainage basins. These are the Njaba River Basin, the Orashi River Basin and the Niger River Basin. The Orashi River drains Ihiala, Azia, Amorka, Okija and Isieke towns. Uli is drained by the Njaba River. All the above mentioned rivers drain into the River Niger which in turn drains into the Atlantic Ocean (Anazoo, 2008).

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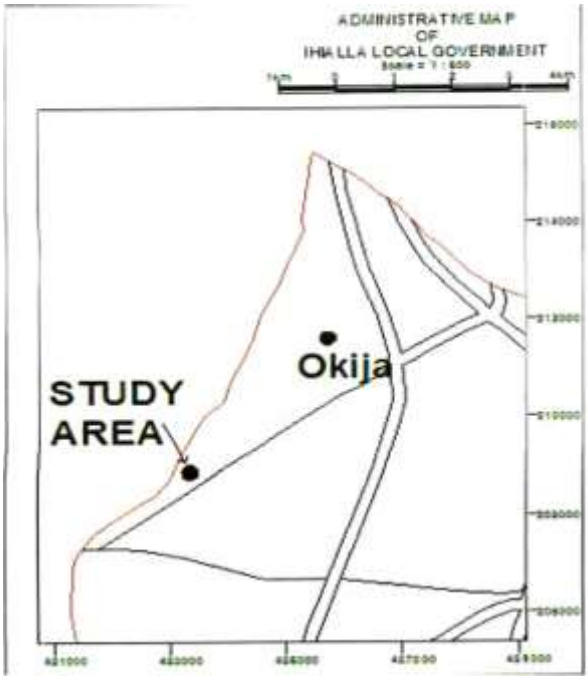

Fig. 1: Location Map of Okija town (Okija-in-home club, 2010)

The area lies on the middle Eocene sediment of the tertiary period called the Bende-Ameki Formation. It constitutes the main bulk of the Eocene strata overlaying the Imo shale group. Ameki formation consists of a series of highly fossiliferous greyish green sandy clay with calcerous concretions and white clayey sandstone. Two lithological groups have been identified in parts, the lower with fine to coarse sandstone and thin shaley limestone, the upper with coarse cross-bedded sandstone bands of fine greyish green sandstone and sandy clay. The climate is tropical with two distinct seasons, the rainy season and the dry season. The rainy season begins around the first of May and continues into September while the dry season runs from November to April. Rainfall reaches its highest monthly maximum of 300-400mm during the month of June through September and drops to 0.0-1.0mm during the months of December and January (Mbajiorgu, 2003).

2.1 Evaluation of Aquifer Constants

According to Domenico (2012), the following inherent assumptions were emphasized in order to avoid erroneous results:

1. The aquifer is homogeneous, isotropic, of uniform thickness and of infinite areal extent;
2. Before pumping the piezometric surface is horizontal;
3. The well is pumped at a constant discharge rate;
4. The pumped well penetrates the entire aquifer and flow is everywhere horizontal within the aquifer to the well
5. The well diameter is infinitesimal so that storage within the well can be neglected
6. Water removed from storage is discharged instantaneously with decline of head

Hardly were these assumptions strictly satisfied, but recognition of them can create an awareness of the approximations involved for employing the non-equilibrium equation under field conditions. Average values of S and T were obtained in the vicinity of pumped well by measuring in one or more observation wells the change in drawdown with time under the influence of a constant pumping rate.

2.1.1 Theis Method

Amadi et al. (2010) used Theis method in which the drawdown produced by a well pumping at a constant rate from an a really extensive artesian aquifer of uniform thickness and physical properties was given by

$$S = (114.6\,Q/T)\,W(u) \tag{1}$$

where s drawdown in metre , Q constant discharge of the pumped well in m^3/s, T = coefficient of transmissibility in m^3/s per day per metre, and W (u) is called well function. The well function is an exponential integral and can be expanded in the form of an infinite series as

$$w\,(u) = \int_u^{\infty} (e^{-u}/u)\,du = -0.577216 - \log_e u + u - \frac{u^2}{2} - 21 + \frac{u^3}{3.31} \tag{2}$$

where e = base of natural logarithm and u is an argument expressed as

$$u = 1.87r^2S/Tt \tag{3}$$

where r = distance of the observation well from the pumped well in metre, S coefficient of storage a ratio or fraction, and t = time since pumping began in days.
A plot on logarithmic paper of W(u) versus u, known as a type curve, was prepared. Values of drawdowns were plotted against values of r^2/t on 1ogarithmic paper of the same size as the type curve. With values of W(u), u, s, and r^2/t thus determined according to Amadi et al. (2010), S and T was obtained from Eqs. 1 and 3.

2.1.2 Cooper-Jacob's Method

According to Hantush and Jacob (2015) a plot of the drawdown s against the logarithm of the elapsed time t since pumping began From the slope of this straight line, or the drawdown difference per log cycle of time, Δ_s , and the time intercept on zero-drawdown axis, to, the formation constants, T and S, may be easily computed by the following equations

$$T = 264\,Q/\Delta s \tag{4}$$

Specific Capacity, S is discharge divided by drawdown. If this calculated value is plotted against the well discharge, the slope yields a value, C and the point of contact with the y-axis yields a value, B.

2.1.3 Chow's Method

Yen Te Chow (1958) developed a method of solution with the advantage of avoiding curve fitting. According to this method, the data on time-drawdown in an observation well was plotted on a semi-logarithmic paper and arbitrary chosen point a tangent was drawn to the drawdown curve and the drawdown difference, Δs , in m per log cycle was determined Then, the value of the new function F(s) was computed from

$$F(u) = \frac{s}{\Delta s} \tag{5}$$

since the relation between F(u), W(u) and u is given by.

$$F(u) \quad \frac{w(u).e^{u}}{2.3} \tag{6}$$

2.2 Error Measures

The commonly used error measure, therefore, was used employed in this study to evaluate the model predictions. The Model Selection Criterion (MSC) defined as follows:

$$MSC = \ln\left(\frac{\sum_{i=1}^{n}(Q_i-\bar{Q}_i)^2}{\sum_{i=1}^{n}(Q_i-\tilde{Q}_i)^2}\right) - \frac{2p}{n} \quad (7)$$

where Q_i is the observed discharge, $\tilde{Q}_i$ is the simulated discharge, $\bar{Q}$ is the mean of the observed discharges, $\tilde{Q}$ is the mean of the simulated discharges, p, number of parameters and n is the length of the observed/simulated series.

3 Results and Discussion

The values obtained from the pumping tests carried out in the area are shown in Table 1. The pumping time, pumping rate, pumping level and drawdown are all indicated in Table 1. For the first 30mins, the pumping rate remained constant at 1.2litres/second and the drawdown increased from 2.53 to 2.69m. As shown in Table 1, this remained constant for the next 35mins at 1.7 litres/second, causing the drawdown to increase from 2.71m to 2.77m. From the 66th min to 130th min, the pumping rate changed from 1.7 litres/second to 2.6 litres/second. The pumping rate however changed to 3.5 litres/second at the 131th min; resulting in a constant drawdown 3.10m which lasted for several hours which was not shown in Table 1.

Figures 2 and 3 show the design of the pumping well and lithologic log section of the observation well in the study area. The arrangement of the soil layers depicts a varve type geological deposition whereby repetitive depositional layers were observed. There was a cyclic occurrence of clay and gravelly sand. The gravelly sand layers were aquiferous and confined repetitively by top and bottom clayey layers. This arrangement caused the piezometric surface to rise up to 2.53 metres, giving rise to a sub-artesian condition.

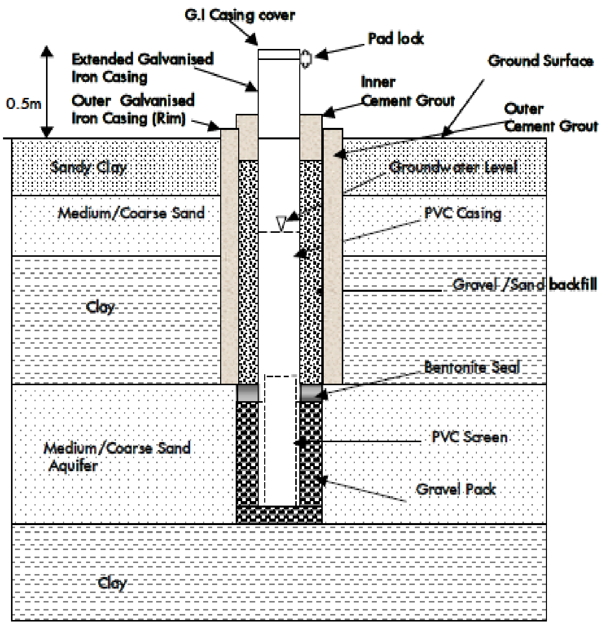

Fig. 2: Design of the Well

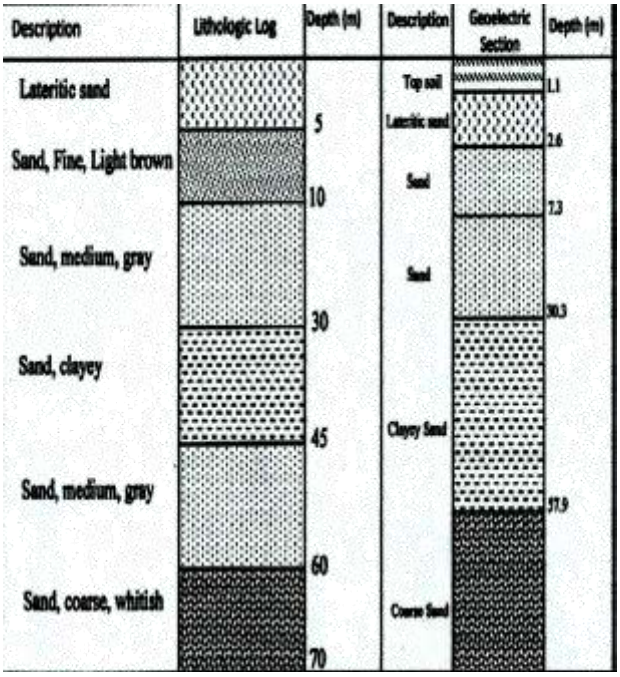

Fig. 3: Lithologic Log Section of the Study Area

Table 1. Pumping Test Data

TIME (Min)	Pumping rate (L/S)	Pumping level (Mb.G.L)	Draw down (b.St.W.L)
05	1.2 L/S	2.53	2.53
06	1.2 L/S	2.54	2.54
07	1.2 L/S	2.55	2.55
08	1.2 L/S	2.56	2.56
09	1.2 L/S	2.57	2.57
10	1.2 L/S	2.58	2.58
11	1.2 L/S	2.59	2.59
12	1.2 L/S	2.60	2.60
13	1.2 L/S	2.61	2.61
14	1.2 L/S	2.62	2.62
15	1.2 L/S	2.63	2.63
17	1.2 L/S	2.64	2.64
19	1.2 L/S	2.65	2.65
21	1.2 L/S	2.66	2.66
23	1.2 L/S	2.67	2.67
25	1.2 L/S	2.68	2.68
30	1.2 L/S	2.69	2.69
35	1.7 L/S	2.71	2.71
40	1.7 L/S	2.72	2.72
55	1.7 L/S	2.75	2.75
60	1.7 L/S	2.76	2.76
05	1.7 L/S	2.77	2.77
15	2.6 L/S	2.80	2.80
25	2.6 L/S	2.81	2.81
35	2.6 L/S	2.82	2.82
45	2.6 L/S	2.83	2.83
55	2.6 L/S	2.85	2.85
05	2.6 L/S	2.86	2.86
15	2.6 L/S	2.87	2.87
45	3.5 L/S	2.90	2.90
15	3.5 L/S	2.92	2.92
45	3.5 L/S	2.94	2.94
15	3.5 L/S	2.97	2.97
45	3.5 L/S	2.98	2.98
15	3.5 L/S	3.10	3.10

Aquifer constants from Theis method involved plotting logarithms of S and T. This is shown in Figure 4. Values of W(u) and u were plotted on another sheet of logarithmic paper and a curve was draw through the points. The two curves were superposed and shifted with alternate coordinate axes parallel until the curve of the observational points (data curve) coincided with the type curve, For convenience a match point was selected with W(u) = 1.00 and u = 1 x 10^{-2} for which log S = -0.0273 and $\log_{10} r^2/t$ =-1.1555 respectively. The antilog values gave S= 0.939m and r^2/t=0.0699m^2/min.

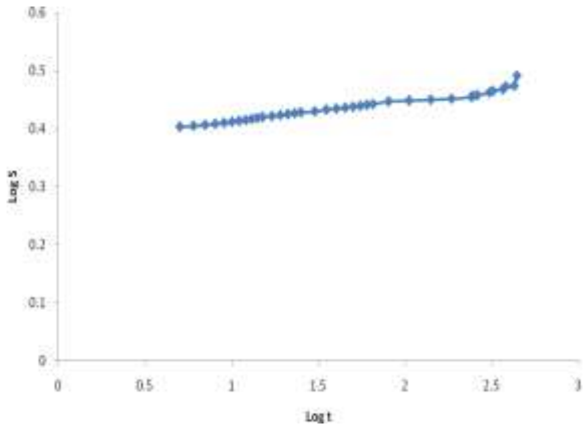

Fig. 4: The Graph of Log S versus Log (r^2/t)

Average discharge: Q = 3.5 L/s = 3.5×10^{-2} m^3/s = 3024 m^3/day

Now from Eq. 1:

$$T = \frac{Q}{4\pi s} w(u) = \frac{3024 \; x \; 1.00}{4\pi x \; 0.939} = 256.37 \; m^2 day^{-1}$$

Now from Eq. 3:

$$S = \frac{4Tu}{r^2/_t} = \frac{4 \times 256.37 \times 1 \times 10^{-2}}{0.0699} = 146.67 \; m^2 day^{-1}$$

This is consistent with the findings of Fitts (2012); Oborie and Nwankwoala (2012). Aquifer constants from Cooper-Jacob method are estimated by plotting time-drawdown data on a semi-log graph as shown in Figure 5. From this graph, at log t = 1, s= 2.58; when log t = 2, s = 2.80 thus Δs = 0.22, which is the drawdown difference per log cycle of t.

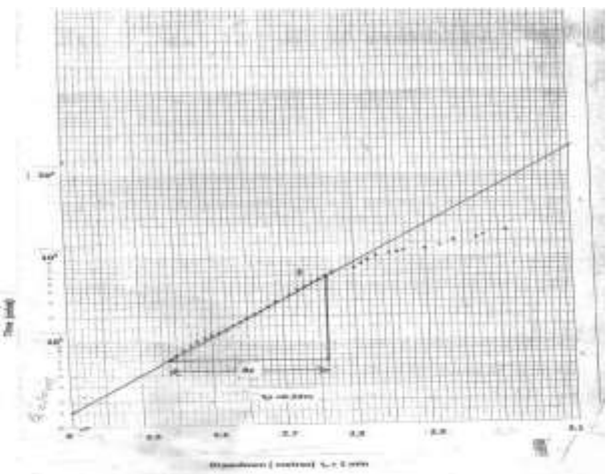

Fig. 5: Graph of S versus $\log_{10} t$

Similarly, average discharge:

Q = 3.5 L/s = 3.5×10^{-2} m^3/s = 3024 m^3/day

$$T = \frac{2.3026x3024}{4\pi x 0.22} = 251.71 m^2 day^{-1}$$

The Specific Capacity,

S=$B \times Q + C \times Q^2$.

From Figure 6,

$$C = \frac{0.094}{81.25} = 1.16 \times 10^{-3}; B = 8.38 \times 10^{-4}$$

$$\therefore S = 8.38 \times 10^{-4} \times 3024 + 1.16 \times 10^{-3} \times 3024^2 = 131 m^2 day^{-1}$$

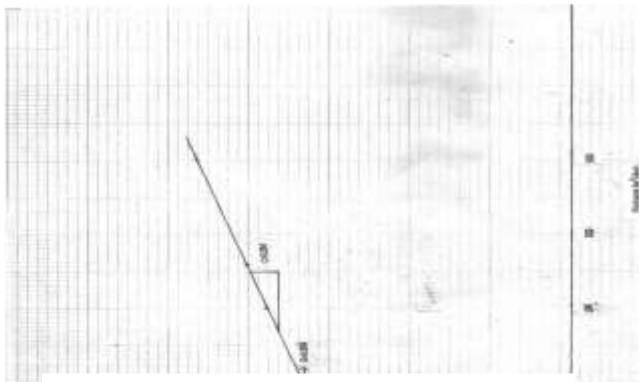

Fig. 6: Discharge-drawdown versus Discharge

Aquifer constants from Chow method are computed as plotting drawdown, s versus time, t data on a semi-logarithmic paper. At a selected point, with co-ordinates of s = 2.58 m and log t = 4.323, a tangent was drawn which gave Δs = 0.22 m for one log cycle.

t= antilog t = antilog (4.323) = 21, 059.29 days.

$$\therefore F(U) = \frac{S}{\Delta S} = \frac{2.58}{0.22} = 11.73$$

Thus, when F(u) = 11.73 then, W(u) = 2.85 and u = 0.065

From Eq. (1),

$$T = \frac{100 \; x \; 2.85}{4\pi \; x \; 2.58} = 267.87 \; m^2/day$$

From Eq. (3),

$$S = \frac{4 \; x \; 267.87 \; x \; 21{,}059.29 \; x \; 0.065}{100 \; x \; 100} = 146.67 m^2/day$$

This is consistent with the findings by Ehirim and Nwankwo (2010).

Table 2. Model Selection Criterion

Plotting Positions	Theis	Copper-Jacob	Chow
1	4.04	3.39	4.38
2	4.46	4.48	4.74
3	5.64	5.76	6.26
4	4.96	4.38	6.59
5	4.91	4.48	5.47
6	4.45	4.46	5.03
7	4.80	4.75	5.41

The result for the model selection criterion is shown in Table 2. Its drawback is that it gives a larger error due to the discrete estimation of the slope which is made at each point. However, Theis method revealed a near constant slope values, followed by Chow method while the least accurate method was Copper-Jacob method. The use of more than one curve in the estimation of aquifer parameters in Theis method explains while it produced the most accurate result as errors are reduced.

4 Conclusion

The computation of formation constants is performed in three ways: Theis method, Cooper-Jacob method and chow method. The methods for determining the formation constants as described in this study have several significant features. During the pumping test, the values of T and S gradually changed, depending on the method of computation. For F (u) greater than 1.74, or u less than 0.01, the Chow's method was observed to give practically the exact theoretical values of T and S. For F (n) less than 1.13, or n greater than 0.05, the Chow's method resulted in error greater than five percent.

In Theis method, the superposition of two curves involved personal error, however a satisfactory fit between the observed curve and the type curve cannot be easily obtained, particularly when the apparent values of T and S are varying with the time of pumping at a remarkable degree. The least accurate method was Copper-Jacob method. It is therefore recommended that for further verification of the results of this study, same coordinate graphs of the $T - \log_{10} t$ and $S - \log_{10} t$ curves should plotted to obtain horizontal straight lines as an affirmation of the non-equilibrium theory which is based on the assumption of constant T and S.

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