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Sustainability of Groundwater for Domestic Uses in Rural Communities of Kogi State, Nigeria

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Abstract: Groundwater is a natural resource that is of immense importance to life and its characteristics are greatly determined by the properties of the immediate geologic formations. Generally, the development of groundwater resource involves three main stages: exploration, evaluation and exploitation. This study focuses on the evaluation stage, which generally encompasses measurement of hydrologic parameters, and estimation of aquifer yield. The analysis of pumping test data collected for 17 wells spread across Kogi state was used to determine the hydraulic parameters of the aquifers within the study area. Transmissivity values ranged from 0.751 – 8.92 m2/day, hydraulic conductivity ranged from 0.0867–1.33 m/day, pumping rates ranged from 1.13 – 8 l/s, while the borehole depths ranged from 11.3 – 202 m. Groundwater maps of the hydraulic parameters were also developed for the study area. These results show that the aquifers within the study area can provide between 5000 to 40,000 litres of water per day. The aquifers can therefore serve as sustainable and dependable sources of water all year round with sufficient water to meet the domestic needs in many small rural communities of Kogi state.

Keywords: groundwater, pumping test, hydraulic parameters, aquifer, sustainability

INTRODUCTION

Groundwater is a natural resource that is of immense importance to life and its characteristics are greatly determined by the properties of the immediate geologic formations. It is naturally stored in the pores spaces within soil compartments and between unconsolidated formations [1]. Its movement is controlled by the force of gravity and it is relatively free from evaporation loss or pollution. As such, the proper development and utilization of this major renewable natural resource is of interest for all water supply requirements. Generally, the development of groundwater resource involves three main stages: exploration, evaluation and exploitation. This study focused on the evaluation stage, which generally encompasses measurement of hydrologic parameters of aquifers and estimation of aquifer yield and sustainability. The determination of aquifer characteristics involves the estimation of its hydraulic conductivity and transmissivity using data obtained from test wells and vertical electrical sounding [2].

To acquire information on the hydrologic parameters, both geologic and hydrologic investigations are required. One of the most important hydrologic studies involves analysing the change, with time of water levels (or total heads) in an aquifer caused by withdrawal through wells. This type of study is referred to as aquifer test or pumping test. This study analysed pumping test data collected from various organizations involved in the development of groundwater in Kogi state, to determine the hydrologic parameters within the study area, and hence the sustainability of the water source for domestic uses.

Sule *et al.* [3] used the Theis residual recovery method to determine the aquifer characteristics of Ilorin, North-Central Nigeria. The result of their analysis showed that the value of hydraulic conductivity ranged between 0.2 and 16.289 m/day with an average of 1.87 m/day and transmissivity ranged between 7.184 and 447.919 m^2/day with an average of 49.12 m^2/day. They were also able to develop maps showing the piezometric surface, the hydraulic conductivity and transmissivity of the aquifer in their study area.

Anomohanran [4] in his work, determined the transmissivity, specific capacity and storativity of the aquifer in Abraka, Nigeria by using the Cooper-Jacobs equations. The values of transmissivity derived showed that the aquifer had high flow rate, hence able to supply sufficient water to the study area. Anomohanran [5] also conducted pumping tests in Central Delta, Nigeria and used the Jacob straight line method to determine the transmissivity and storativity values of the aquifer with average values of 0.022 m^2/min and 0.000133 respectively. In Echi, Delta State, Nigeria, Anomohanran [6] evaluated the aquifer characteristics of the area. Pumping test data were analysed using Jacob's straight line method. The value of the hydraulic conductivity of the aquifer obtained was 0.0058 m/day while the transmissivity and specific capacity were 86.0 m^2/day and 0.258 respectively. From the values obtained from the test well, he inferred that the aquifer contained good quality water suitable for drinking and other purposes.

Olabode *et al.* [7] conducted an analysis of meteorological, drilling, pumping tests and water quality data on over 50 boreholes in the evaluation of groundwater resources of the Middle Niger (Bida) Basin of Nigeria, Theis and Jacob's method of analysis was used for the pumping test data from which results showed that transmissivity values varied between 1.365 and 393 m^2/day. The results from their investigation also showed that depth to water rarely exceeded 50 m, though in some few cases the depth was over 70m.

The results of pumping test analyses by Guideal *et al*. [8] on 26 boreholes in the Chad Republic showed values of hydraulic conductivity ranging between 0.12 m/day to 0.00546 m/day. Transmissivity values ranged from 0.599 m^2/day to 0.000269 m^2/day while specific yield ranged between 0.006 and 0.052. From these values they were able to infer that the aquifer was heterogeneous, has permeability but with a low storage.

Amah *et al.* [9] presented the results of groundwater site evaluation scheme and quality assessment of coastal aquifers in Calabar, South-eastern Nigeria based on ground water potential index (GWPI) scale. Among the input parameters for the GWPI was transmissivity, and the results showed that the values of transmissivity recorded for the central, southern and northern zones were 2640 m^2/day, 2150 m^2/day and 750 m^2/day respectively.

DESCRIPTION OF STUDY AREA

The study area is Kogi State, Nigeria. The State lies between Longitudes 5°18E to 7°54E and Latitudes 6°30N to 8°42N with a total land area of approximately 28,312 Km^2.Kogi State is made up of 21 Local Government Areas and has its capital at Lokoja. The State is divided into three Senatorial Districts namely: Western, Central and Eastern Senatorial Districts. The Western Senatorial District is made up of 7 Local Government Areas (East Yagba, KabbaBunu, Kogi, Lokoja, MopaAmuro and WestYagba). The Central Senatorial District is made up of 5 Local Government Areas (Adavi, Ajaokuta, OgoriMangogo, Okehi and Okene). The Eastern Senatorial District is made up of 9 Local Government Areas (Ankpa, Basssa, Dekina, Ibaji, Idah, Igalamela-Odolu, Ofu, Omala andOlamaboro).

Kogi State has an average maximum temperature of 33.2 ^{0}C and average minimum of 22.8 ^{0}C. The State has two distinct weathers, the dry season, which lasts from November to February and the rain season that lasts from March to October. Annual rainfall ranges from 1016mm to 1524mm. The vegetation of the state consists of mixed leguminous (guinea) woodland to forest savannah. Wide expanse of Fadama exists in the river basin and long stretches of tropical forest in the Western and Southern belt of the state.

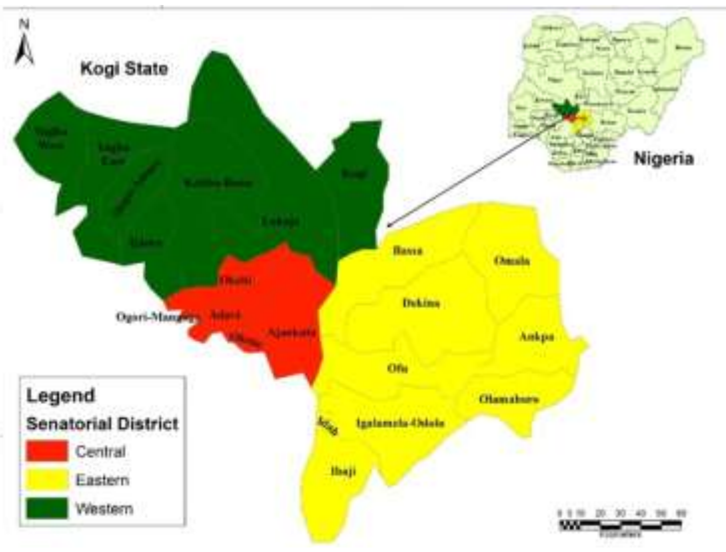

Fig-1: Map Showing Study Area

Geographically, the study area lies within the Benin-Nigeria shield, situated in the Pan-African mobile zone extending between the ancient Basement of West African and Congo Cratons in the region of Late Precambrian to early Palaeozoic origins. The Basement complex rocks of Nigeria are composed predominantly of migmatite gneiss; slightly migmatised to unmigmatisedpara-shists and meta-igneous rocks; charnockitic, older granite suites and unmetamorphosed dolerite dykes [10].

GROUNDWATER HYDRAULICS

Aquifer properties and parameters

Well hydraulics assists in evaluating aquifer properties, defining boundaries and predicting yields and future effects of pumping. Some of the important aquifer properties and parameters are [11] hydraulic conductivity (K), transmissivity (T) and storage coefficient (S), specific storage (S_c) and specific yield (S_y). Hydraulic conductivity (K) is the capacity of rock or soil to transmit water. It is the measure of the quantity of water (Q) that will flow through a unit cross-sectional area (A) of a porous medium per unit time under a unit hydraulic gradient (dh/dl). The porosity of a rock or soil has no direct relation to the permeability or water yielding capacity. Thus, K is related to the size and degree to which the pores are interconnected. If the pores are small, the rock will transmit water slowly, but if large and interconnected, they will transmit water readily. K is obtained from Darcy's law of groundwater flow as

$$Q = KA\frac{dh}{dl} \qquad (1)$$

Where,
Q = the quantity of water per unit time,
A = the cross sectional area of the aquifer through which the flow occurs,
dh/dl = hydraulic gradient,
K = hydraulic conductivity.

Transmissivity (T) is the capacity of the rock to transmit water of prevailing kinematic viscosity through a unit width of the aquifer under a unit hydraulic gradient. It embodies the saturated thickness of the aquifer and the properties of the contained liquid. Thus, T of an aquifer is equal to the product of the hydraulic conductivity (K) and the saturated thickness of the aquifer (B).

$$T = KB \ \ (\text{m}^2/\text{day}) \qquad (2)$$

Storage coefficient (S) is defined as the volume of water that an aquifer releases from storage or takes into storage per unit surface area of the aquifer per unit change in hydraulic head. It is a dimensionless unit. The size of the storage coefficient is a function of whether the aquifer is confined or unconfined. Storage coefficients are much lower in confined aquifer as compared to unconfined units. This is because the pressure is reduced in the case of confined aquifer during pumping without dewatering the aquifer. For unconfined aquifer, S ranges between 0.1 to 0.30, while for confined unit it is between $10^{-5}$and 10^{-3}. Specific storage (Ss): this is the volume of water released from storage from a unit volume of aquifer per unit decline in hydraulic head while specific yield (Sy) is the volume of water by gravity drainage to the volume of the aquifer. The specific yield is dimensionless and typically ranges from 0.01 to 0.3.

Theory of aquifer tests

Aquifer tests are controlled experiments in which the rock hydraulic properties are determined in the field. It includes pumping a well at a constant rate for a period ranging from minutes to several hours and even for several days and measuring the change in water level in one or more observation wells spaced at suitable distance from the pumped well. Several solutions methods have been developed for the analysis of aquifer tests. (Deep,2005), classified the methods as follows:

a. Pumping Test Solution Methods: these methods estimates aquifer properties including single and multiple well tests. They include:

i. Theis Solution for Confined Aquifers
ii. Cooper-Jacob Solution (Time-Drawdown) for Confined Aquifers
iii. Cooper-Jacob Solution (Distance-Drawdown) for Confined Aquifers
iv. Hantush and Jacob Solution for Leaky-Confined Aquifers
v. Neuman Solution for Unconfined Aquifers
vi. Moench Solution for Unconfined Aquifers/Partially Penetrating Wells
vii. Moench for Fracture Flows

b. Step Test Solution Methods: these methods are used to determine well performance and efficiency. They include:

i. Theis Solution for Confined Aquifers
ii. Cooper-Jacob Solution for Confined Aquifers

c. Recovery Test Solutions Methods: are frequently conducted after pumping is stopped to estimate aquifer properties. The major method of analysis used here is the Theis-Jacob solutions.

Here the Cooper-Jacob Solution (Time-Drawdown) for confined aquifers will be used as it is the most common method used to evaluate aquifer characteristics from field data. This method is actually the modified version of Theis equation (Todd and Mays, 2005). Theis equations are given by:

$$s = \left(\frac{Q}{4\pi T}\right) W(u) \qquad (3)$$

$$S = \frac{4Ttu}{r^2} \qquad (4)$$

$$u = \frac{r^2 S}{4Tt} \qquad (5)$$

Where:
Q = Pumping rate (m^3/s),
s = Drawdown in the observation well located at a given radius to the test well at a specific time (m),
T = Transmissivity of the aquifer (m^2/day),
S = Storage coefficient of the aquifer
t = time from start of pumping (sec),
r = distance from centre of pumping well to the observation well
W (u) = well function of u
u = is a dimensionless quantity

When r is small and t is large, u is small and hence all terms after the second term of the series of exponential function of W(u) are negligible. The modified non-equilibrum equation becomes

$$s = \frac{Q}{4\pi T}(-0.5772 - \ln u)$$

$$s = \frac{Q}{4\pi T}\left(-0.5772 - \ln \frac{r^2 S}{4Tt}\right) \qquad (6)$$

Rearranging equation (6) and using common logarithm (base 10) gives,

$$s = \frac{2.303\ Q}{4\pi T}\log_{10}\left(\frac{2.25\ Tt}{r^2 S}\right) \qquad (7)$$

Equation (7) plots as a straight line on semi-logarithm paper. Time is plotted along the logarithm x-axis, while drawdown is plotted along the linear y-axis. Transmissivity and storativity are estimated as follow:

$$T = \frac{2.303\ Q}{4\pi \Delta s} \qquad (8)$$

When s = 0, and t = t_0, equation (7) becomes

$$\left(\frac{2.25\ Tt_0}{r^2 S}\right) = 1 \qquad (9)$$

Therefore,

$$S = \frac{2.25\ Tt_0}{r_0^2} \qquad (10)$$

Where Δs is drawdown ($s_2 - s_1$), t_0 and r_0 are time and distance at zero drawdown interception from the plotted graph.

The general procedure for Cooper-Jacob Solution (Time-Drawdown) analysis is described below:

a. Prepare a graph on semi-log graph paper, with water levels or drawdown on the (linear) y-axis, in metres below datum, and time on the (logarithmic) x-axis (time since the start of pumping, in minutes).

b. Plot the water levels against time for the duration of the test. The data should plot roughly as a straight line. Draw a best-fit line through the data, ignoring the early data and concentrating on middle to late data.

c. From this line, measure a parameter known as Δs, which is the difference in water levels (in meters) over one log cycle.

d. Calculate the average pumping rate for the duration of the test, Q, in m^3/day.

e. Insert the values of Q and Δs into equation (2.8) to calculate the Transmissivity T. Make sure that the correct units have been used, in which case the units of T will be m^2/day.

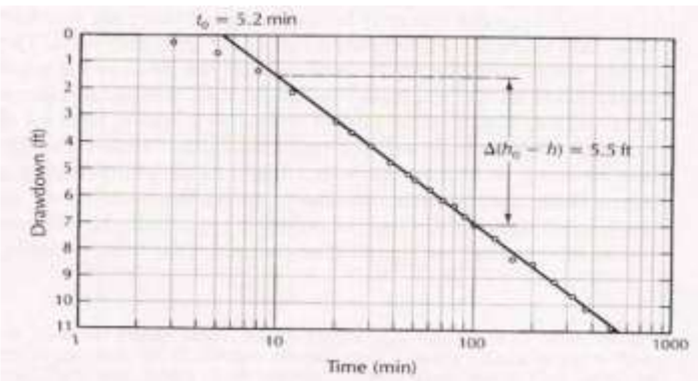

Fig-2: Cooper-Jacob's Method of Analysis (Deep, 2005)

METHODOLOGY
Data collection
The data required for this study was collected from the Kogi State Ministry of Water Resources and the Kogi State Rural Water Supply and Sanitation Agency (RUWASSA), Lokoja. The data obtained were mainly pumping test results in tabulated form. The tables showed the time since pumping started, pumping water levels, calculated drawdowns, pumping rate, well location, borehole depth, etc. Table 1 shows a typical summary of test results for the well drilled at Ologba village, Dekina LGA, Kogi state.

Data Analysis
Analysis of the data obtained was done using a Pumping Test and Slug Test Data Analysis Computer Software called Aquifer Test Pro 4.It was developed by Schlumberger Water Services and was downloaded on the internet from http://www.swstechnology.com.

The solution method adopted with the software is the Cooper-Jacob Solution (Time-Drawdown) for Confined Aquifers which is suitable for the analysis of single well test since all the wells being considered in this evaluation are single wells.

The general applications of the software include:

a. Estimating the hydraulic properties of aquifer, that is, Hydraulic conductivity K, Storativity S, and Transmissivity T.
b. Predicting drawdown effects resulting from groundwater pumping.
c. Optimizing pumping test design considering well diameter, pumping rate, screened interval, etc.
d. Optimizing the placement of new pumping wells due to proximity to existing wells
e. Mapping and contouring drawdown from groundwater pumping.

Interpretation of Test Results
After calculating for transmissivity values in m^2/day, the question is, what does that value mean? Is a value of $10m^2$/day good or bad? The answer mainly depends on what the intended yield of the borehole is. MacDonald *et al* [12] carried out modelling using typical assumptions and parameters applicable to emerging countries, and came to the conclusion that for a borehole supplying 5,000 litres per day (20 litres per person for 250 people), the Transmissivity value of the aquifer should be at least 1 m^2/day. An aquifer with a Transmissivity value of $10m^2$/day would be capable of yielding around 40,000 litres per day. By comparison, a public water-supply borehole in a typical sandstone aquifer in England capable of yielding about two million litres per day would have a Transmissivity value of 300-400 m^2/day when tested. Highly productive aquifers, capable of supporting major abstractions, can have Transmissivity values of 1,000- 2,000 m^2/day. In fact, a calculated Transmissivity value is most useful for comparison with other boreholes in similar hydrogeological environments or geographical areas. This is why it is important to keep good records of pumping tests. An overall picture of groundwater development potential in a certain region can be built up from the results of many tests.

RESULTS AND DISCUSSION
Results
A total of seventeen (17) pumping test data representing seventeen (17) locations across the State from the three (3) geo-political zones were used in the evaluation.

Table 1: Pumping Test Result for Ologba

PUMPING TEST RESULTS								
STATE: KOGI			LGA: DEKINA			VILLAGE: OLOGBA		
BOREHOLE DEPTH: 180M			SCREEN SETTING:					
PUMP TYPE: 5.5HP GRUNDFOS			PUMP SETTING: 102M			PUMP RATE: 138L/MIN		
pH:7			STATIC W/L: 75.5M			CONDUCTIVITY:840msec/cm		
TESTED BY:						DATE: 23/11/2008		
PUMPING PHASE				RECOVERY PHASE				
ELAPSED TIME (MIN)	PUMPING W/L (M)	DRAW DOWN (M)	PUMPING RATE (L/S)	TIME (MIN) SINCE RECOVERY STARTED	TIME (MIN) SINCE PUMPING STARTED	RATIO T/T'	WATER LEVEL (M)	RESIDUAL DRAW (M)
0	75.5	0	2.3		0		93.98	18.48
1	76.8	1.3			1		90.15	14.65
2	79.25	3.75			2		88.26	12.76
3	83.3	7.8			3		86.17	10.67
4	86.15	10.65			4		84.75	9.25
6	88.21	12.71			6		82.5	7
8	88.5	13			8		81.72	6.22
10	90.17	14.67			10		81.01	5.51
15	91.45	15.95			15		79.05	3.55
20	93.45	17.95			20		78.55	3.05
25	93.46	17.96			25		77.91	2.41
30	93.47	17.97			30		77.8	2.3
45	93.48	17.98			45		77.73	2.23
60	93.5	18			60		77.55	2.05
75	93.56	18.06			75		77.3	1.8
90	93.8	18.3			90		77.25	1.75
100	93.85	18.35			100		77.24	1.74
120	93.98	18.48			120		77.22	1.72
150	93.98	18.48			150		77.22	1.72
180	93.98	18.48			180		77.22	1.72

The pumping test results were analysed using the Aquifer Test Pro 4 software. Chart for results for three selected boreholes, one in each district, are shown Figures 3to 5. The summary of the results of analysis for all the wells is shown in Table 2. Figures 6, 7, 8 and 9 show the contours of Transmissivity, hydraulic conductivity, borehole depth and pumping rate respectively obtained across the State.

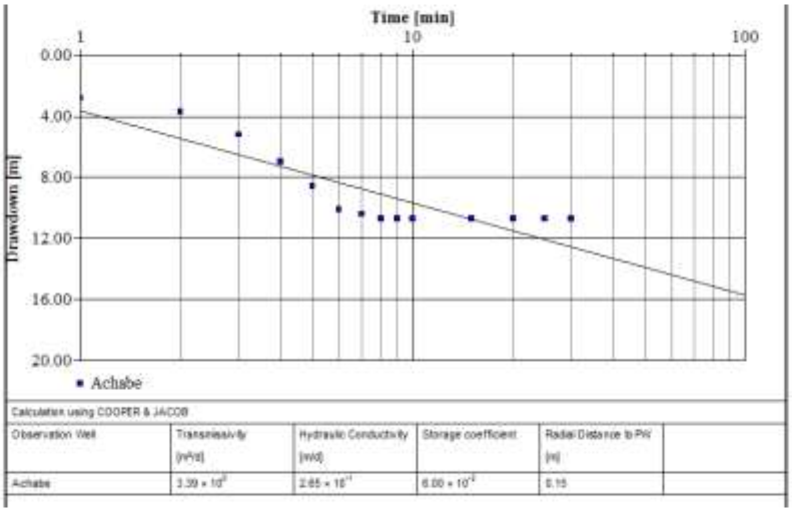

Fig-3: Time-Drawdown graph for Achabe

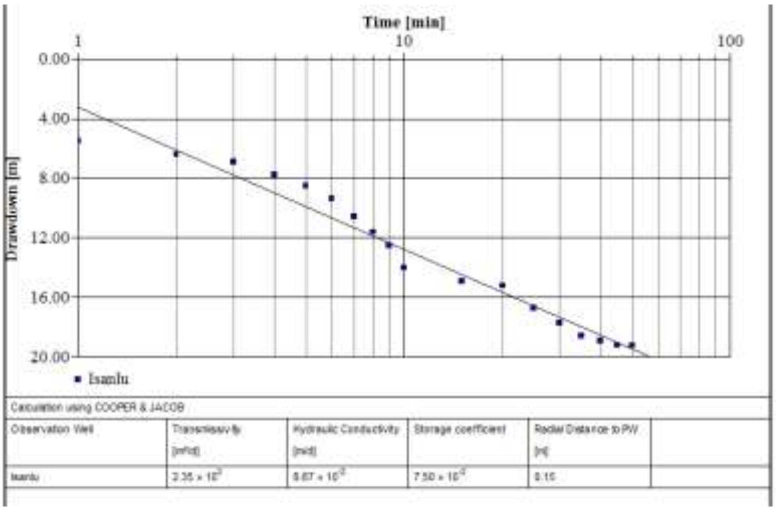

Fig-4: Time-Drawdown graph for Isanlu

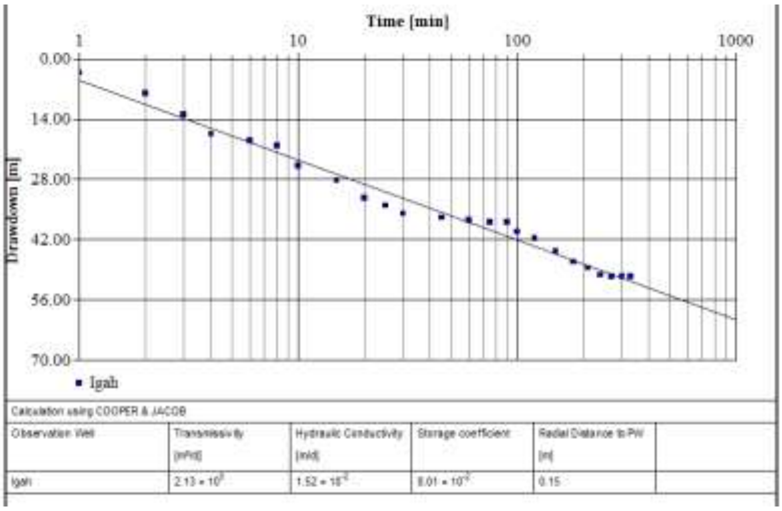

Fig-5: Time-Drawdown graph for Igah

Table 2: Summary of Results and Analyses

S/No	Location	LGA	Senatorial District	Borehole Depth (m)	Pump Rate (L/s)	Hydraulic Conductivity (m/day)	Transmissivity (m^2/day)
1	Ologba	Dekina	Eastern	180	2.3	0.0152	2.13
2	Ogbatolo	Dekina	Eastern	184	2.3	0.0237	2.91
3	Igah	Olamaboro	Eastern	202	2.5	0.0152	2.13
4	Idah	Idah	Eastern	201	8	0.141	2.38
5	Adogo	Ajaokuta	Central	31.1	1.13	0.17	4.3
6	Gegu	Kogi	Western	18.6	1.23	0.764	1
7	Achabe	Kogi	Western	20.4	1.3	0.265	3.39
8	Aseni	Kogi	Western	26.8	1.4	0.596	4.89
9	Isanlu	Yagba-East	Western	32.3	1.42	0.0867	2.35
10	Igbajogun	Mopa	Western	29.9	1.42	0.405	1.15
11	Iluke	Kabba-Bunu	Western	13.1	1.33	1.33	7.31
12	Ejiba	Yagba West	Western	23.2	1.33	0.198	4.36
13	Iyamoye	Ijumu	Western	11.3	1.33	1.33	8.92
14	Omode	Kabba-Bunu	Western	33.2	1.02	0.0239	0.751
15	Ishi	Kabba-Bunu	Western	43.9	1.42	0.0731	2.96
16	Emiworo	Ajaokuta	Central	45	1.33	0.04	1.7
17	Lokoja	Lokoja	Western	36.6	1.33	0.208	6.57

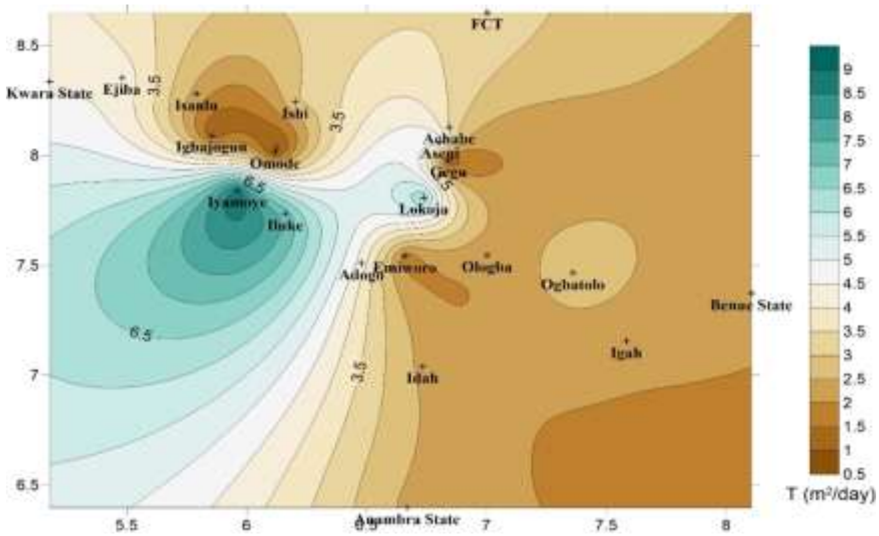

Fig-6: Contour Map for Transmissivity

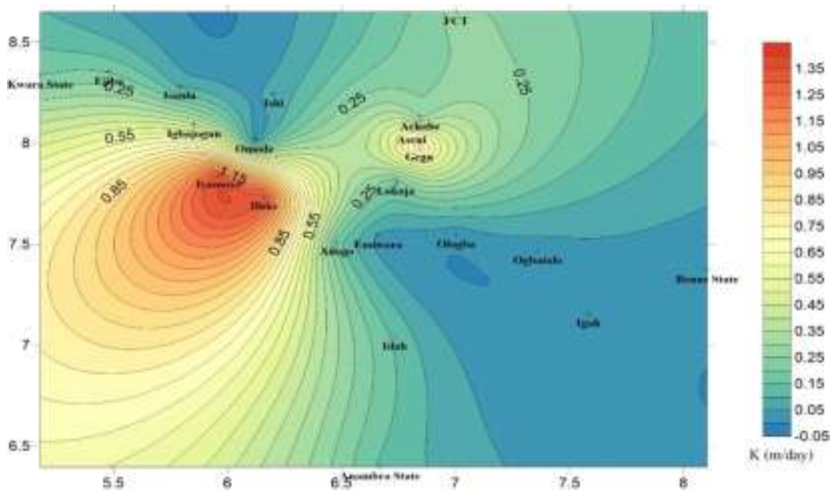

Fig-7: Contour Map for Hydraulic Conductivity

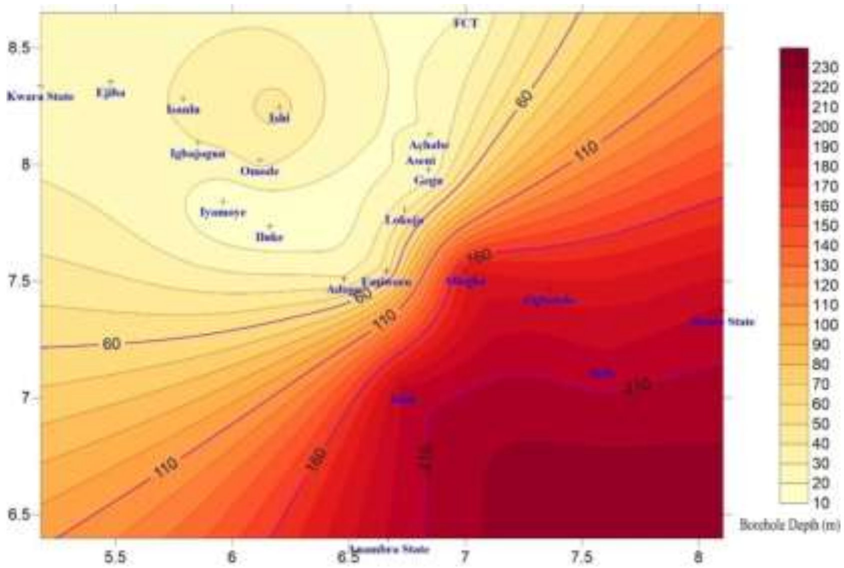

Fig-8: Contour Map for Borehole Depth

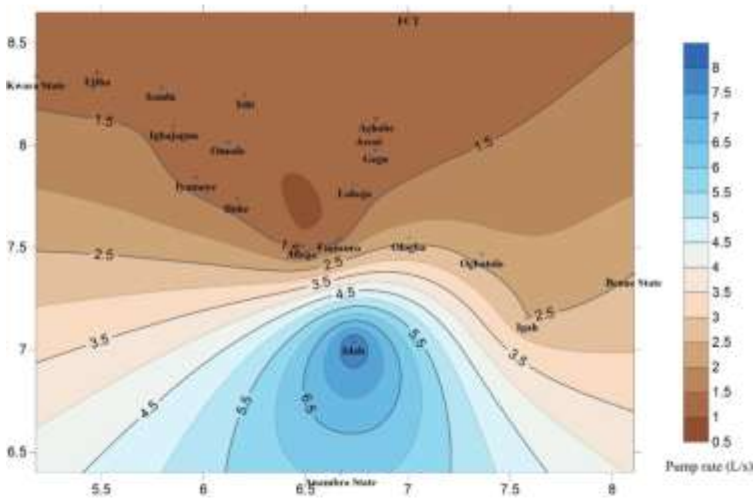

Fig-9: Contour Map for Pumping Rate

DISCUSSION

For the wells located in the eastern district, computed values of transmissivity ranged from 2.13 - 2.38 m^2/day, or an average Transmissivity of 2.39 m^2/day. Values for the hydraulic conductivity ranged from 0.0237 -0.141 m/day with an average of 0.049 m/day. Pumping rates ranged from 2.3 – 8 l/s, or an average of 3.73 l/s. Borehole depths ranged from 180 – 202 m or an average borehole depth of 192 m.

Likewise, for wells in the western district, computed values of transmissivity ranged from 0.751 – 8.92 m^2/day, or an average transmissivity of 3.97 m^2/day. Values for the hydraulic conductivity ranged from 0.0867–1.33 m/day with an average of 0.48 m/day. Pumping rates ranged from 1.02 – 1.42 l/s or an average pumping rate of 1.2 l/s. Borehole depths ranged from 11.3 - 43.9 m or an average borehole depth of 27.1 m.

Wells located in the central district have computed transmissivity values that ranged from 1.7 – 4.3 m^2/day or an average transmissivity of 3 m^2/day. Values for the hydraulic conductivity ranged from 0.04 -0.17 m/day with an average of 0.105 m/day. Pumping rates ranged from 1.13 - 1.33 l/s or an average well yield of 1.23 l/s. Borehole depths ranged from 31.1 – 45 m or an average depth of 38.05 m.

From the charts in Figures 3 to 5, it is observed that the curves follow a general pattern which is a gradual decrease in drawdown. According to MacDonald *et al* [12], this kind of behaviour occurs because the aquifer is gaining water from other source or sources either because the aquifer is leaky, or because the expanding cone of depression has intercepted a source of recharge, such as surface water. This is an encouraging sign for the boreholes as a sustainable water source. Also according to MacDonald *et al* [12], an aquifer with transmissivity values ranging from 1 m^2/day–10 m^2/day would be capable of yielding around 5,000-40,000 litres per day which is sufficient forr domestic uses in small communities. Since the pumping test data collected were from wells used for domestic water supply in small communities of Kogi state, and based on the transmissivity of the aquifers, it can be inferred that the wells are satisfactory for their intended use.

CONCLUSION

The hydraulic parameters of aquifers in selected wells in Kogi State have been determined by the analysis of available pumping test data. Groundwater maps for transmissivity, hydraulic conductivity, borehole depths and pumping rates have also been developed. Transmissivity and hydraulic conductivity were found to be highest in the western district of the state. The rate of pumping however was highest in the Eastern district. It can be deduced that wells located in the eastern district are deeper than those in the western and central districts. This implies that the depth to groundwater is more and therefore it would be more difficult and expensive to drill boreholes in the eastern district. The aquifers within the study area have also been shown (based on transmissivity values) to be capable of serving as sustainable water sources for domestic uses.

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