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Groundwater Potentials Estimation of a Basement Terrain Using Pumping Test Data for Parts of Sanga Local Government Area, Kaduna State, Northwestern Nigeria

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Abstract

Aquifers derived from the crystalline basement rocks for parts of Sanga Local Government area of Kaduna State, Nigeria consist of clay, silt, sand, gravel and laterite materials which may be in various proportions. Using Cooper-Jacobs non-equilibrium graphical method, the hydraulic properties were estimated from pumping test data of 18 boreholes. Conductivity varies from 1.02×10^{-2} m/s to 4.07×10^{-2} m/s and transmissivity varies from 1.14×10^{-1} m^2/s to 4.40×10^{-1} m^2/s. The values of specific capacity range between 1.03×10^{-1} m^2/s/m and 9.00×10^{-2} m^2/s/m, and these values indicate that the aquifers in the area have low to moderate ground water potentials. The low yield range of between 0.45 l/s and 1.00 l/s recorded in the area shows the heterogeneous and anisotropy nature of the basement aquifer system in terms of groundwater discharge. On the average, the boreholes assessed have potentials to sustain local to regional supply provided the best drilling method and materials are used and well completion properly done.

Keywords

Pumping Test, Heterogeneous, Anisotropy, Conductivity, Discharge, Sanga

1. Introduction

Sanga local government is located at the extreme southern part of Kaduna state. It shears boundary with Nasarawa State Southward and covers a total land area of about

1402 Km^2 with a population of 149,333 [1]. Being a Rural Local Government with no pipe borne water, the populace depends, to a greater extent, on surface water sources made of streams with sources from nearby spring, perennial rivers that sustain flow throughout the year and streams and rivers whose flow cease at the peak of the dry season. The surface sources are prone to pollution and contamination. The groundwater sources are mainly Dug wells and Boreholes. Based on the statistic given by Kaduna State ministry of water resources [2], Sanga Local Government has a total of 128 boreholes; this serves a population of about 18,300 while projected population of 179,354 by the year 2015 is to be without enough portable water supplies, with majority of its population relying on surface water that is not protected from pollution or through the direct harvesting of rainwater during the wet season, a process that is not sustained for a longer period and unreliable. This water deficit can only be made up by the groundwater sources. [3] pointed out that the low yield of boreholes in the crystalline complex was attributed to thinness of the weathered regolith, interconnectivity of the fractures in fractured layers and the geology of the underlying rock materials. This research work is aimed at assessing the groundwater potentials of the area through the use of hydraulic properties determined from borehole pumping test data in the area of study.

The area investigated is located between Latitudes 9˚15'N to 9˚30'N and Longitude 8˚8'E to 8˚40'E at the southern part of Kaduna State, Nigeria. The area falls within the Guinea Savannah climatic belt of West Africa which is characterized by two distinct seasons, the wet and dry season. The wet period lasts for a period of 7 months commencing in March/April and terminates in October. The Eastern portion of the area receives more rainfalls due to its close proximity to the Jos Plateau region [4] (**Figure 1**).

The area consists of rocks that range in age from Pre-Cambrian to Lower Palaeozoic and Quaternary period. Four groups of rocks can be distinguished for the Basement Complex Terrain in the area [4]-[9]. The crystalline basement rocks which consist of gneisses and migmatites with different varieties of the gneisses like the banded gneiss, granite gneiss, biotite gneiss, hornblende gneiss and ortho genessis. The second group

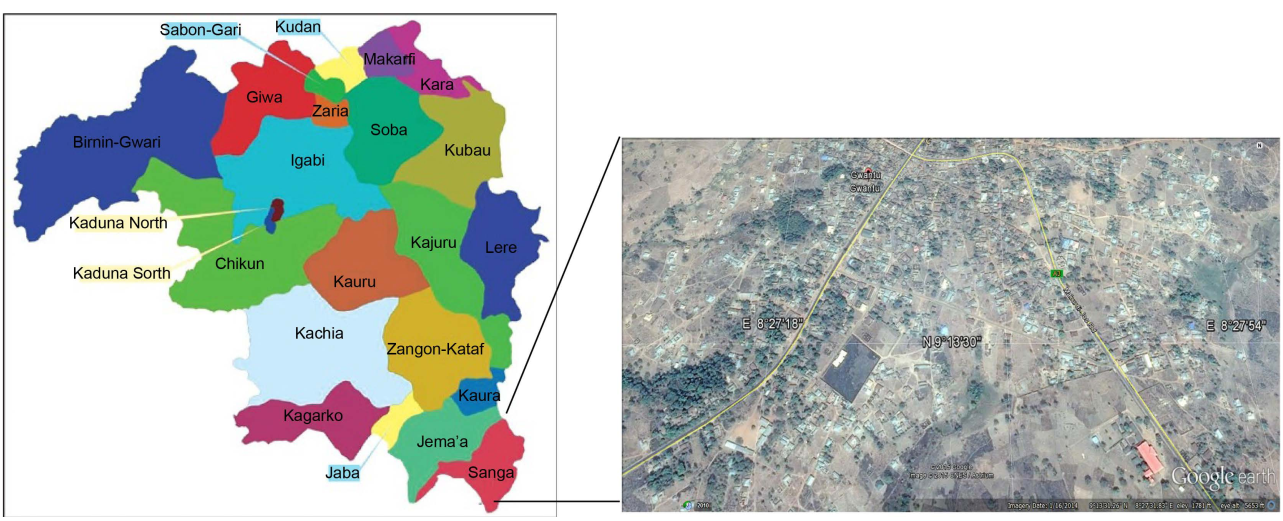

Figure 1. Map of Kaduna state showing the study area and satellite imagery showing part of Sanga local government area.

consists of the metasediments in the area and is represented by the quartzite. The third group is the intrusive rock consisting mainly of granites. The fourth group of rock is the basalt which is Quaternary in age. The ground water in the area contains in the soft overburden, fractured bedrock, and alluvium aquifers [10]. Parkman international and Parkman Nigerian limited (1997) reported the presence of three hydrogeological units in Kaduna state which includes: a modern alluvium of present day river channels and ancient alluvium of the Fadama under silts, and abnormally thick regoliths overlying Basement Complex, Granite and Metasedimentary rocks and fractures in the fresh granitic rocks, regoliths and ancient alluvium underlying basaltic flows (Figure 2).

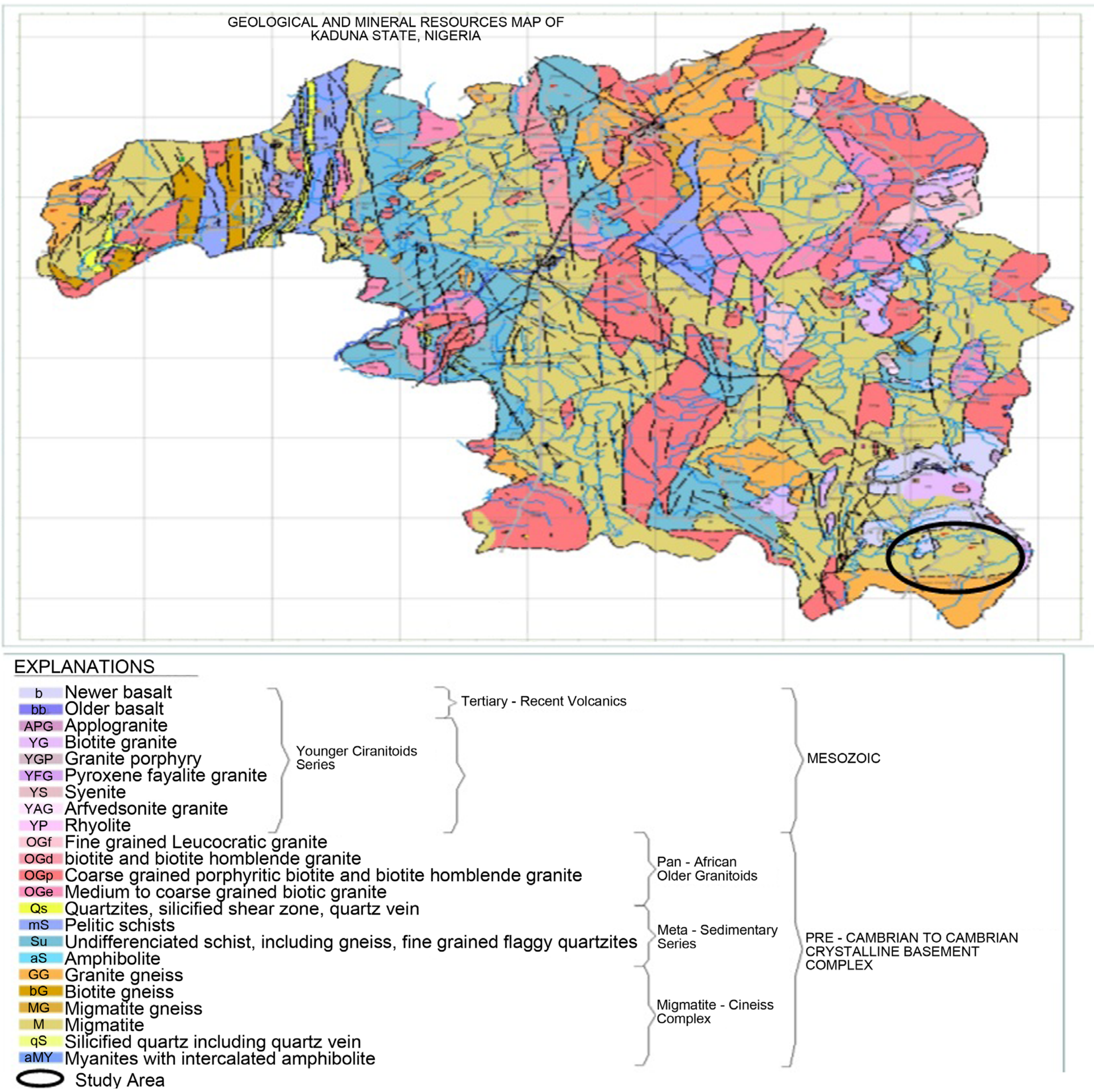

Figure 2. Geologic map of Kaduna state showing the study area (adopted from the geologic and minerals map of Kaduna state of the Nigerian geological survey agency 2006).

2. Data and Methods

2.1. Data

Pumping test data for the 18 boreholes tested were obtained from the rural water supply unit of Kaduna state ministry of water resources. The boreholes were drilled under the MDGs (millennium development gold) program for the year 2009 by Carling Earth Resources Nigerian Limited Kaduna Nigeria were used for this study [11]. The pumping phase data were used from the study. Table 1 contains information on the boreholes used for the hydraulic properties assessment.

2.2. Methods

Pumping test data from 18 boreholes were used. The aquifer was tested for periods of between 60 and 180 minutes depending on the time equilibrium was reached in the individual well. The is' non-equilibrium graphical method is given bellow

$$s = \frac{Q}{4\pi T}\int_{U}^{\infty}\frac{e^{-u}\,du}{u} \tag{1}$$

where s = drawdown,

Q = constant well discharge,

Table 1. Pumping test data of borehole used in the study area.

S/NO	Community	Borehole depth (m)	SWL (m)	Screen length (m)	Final drawdown (m)
1	Agamati Market	30	7.00	9.00	16.20
2	Fadan Karshi	43	7.00	12.00	9.94
3	Kufai Aboro	43	13.48	12.00	6.89
4	Ankara	40	11.74	9.00	13.42
5	Maitozo Distric House	29	6.20	9.00	20.70
6	Kwagiri Village	32	6.20	9.00	16.70
7	LGEA Landa	27	5.1	9.00	10.70
8	Dorowa	30	14.43	9.00	3.80
9	Kwassu Ung. Dutse	33	13.74	12.00	7.03
10	FadanAyu	28	4.00	9.00	12.50
11	Dangam	22	6.50	12.00	9.90
12	LGEA Ancha	24	4.20	9.00	6.80
13	LGEA Aboro	27	7.50	12.00	15.30
14	PHC Kutal	25	5.60	9.00	8.20
15	LGEA Amantu	23	4.00	9.00	12.50
16	Aboro Village	31	7.30	9.00	11.00
17	LGEA SabonGida	30	6.90	9.00	5.10
18	Wasa Village	31	9.20	9.00	13.30

u = well function,

T = Transmissivity,

r = radius of well.

This was used for the estimation of transmissivity (T) and Storage (S) but assuming a small radius for the well, and a fairly long pumping time, Equation (1) above was simplified [12] to

$$T = \frac{2.30Q}{4\pi\Delta s} \quad \text{Measured in } (\text{m}^2/\text{s}) \tag{2}$$

where Δs = drawdown over one long cycle.

In determining the slope Δs early times were excluded because for early time approximation is not valid due to casing/wellbore storage, true aquifer response to pumping is masked until storage is exhausted. Only the medium and late times were considered, these represent a transition period during which matrix blocks feed their water to an increasing rate to fractures resulting in partly stabilizing drawdown and pumped water coming from storage in the fractures and matrix block respectively [13]. The pumping phase data were plotted on a semi-log graph sheet against the corresponding time; a straight line was then drawn through the field data points. The values of the drawdown per log cycle of time were determined from the slope of the graph as Δs. The above Cooper-Jacob equation of (1946) was used for the estimation of the transmissivity of the aquifers in the area, single well model was utilized for the studies since no observations wells was available [14]. Meaning the pumping well also serves as the piezometer, the straight line obtained for the semi-log plot of drawdown against time indicates the radial flow of water into the pumped well (**Figure 3**).

The Hydraulic Conductivity K is computed from the relation:

$$K = T/B \quad \text{measured in } (\text{m/s}) \tag{3}$$

where B = aquifer thickness or length of screen used,

T = Transmissivity.

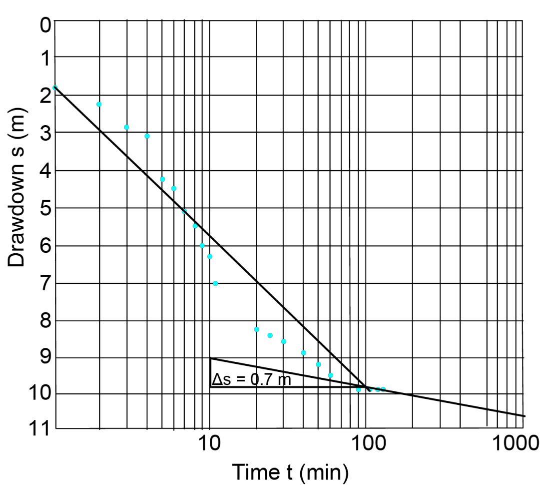

Figure 3. A semilog time-drawdown curve plot of pumped-tested borehole at Dangam.

While Specific capacity was computed from the equation

$$Q/s \quad \text{Measured in m}^3\text{/s} \tag{4}$$

where Q = borehole yield or discharge,

s = total drawdown recorded in pumped well.

3. Results and Discussion

Transmissivity recorded in the area ranges between 1.14×10^{-1} and 4.40×10^{-1} with an average of 2.18×10^{-1} while the hydraulic conductivity ranges between 1.02×10^{-2} and 4.07×10^{-2} with an average of 2.18×10^{-2}. Hydraulic conductivity obtained falls within the range given in Table 2 and Table 3, this shows that the composition of materials of the aquifer is heterogeneous in nature comprising of finer clay, silt, gravel and fractured basement rocks with average to low yield.

Reduction as well as break in discharge experience during pumping, is an indication of the heterogenic and anisotropic nature of the basement aquifer in the study area. The low to average Transmissivity value of 2.18×10^{-2} m²/s of the aquifer is attributed to the decrease in aquifer thickness and saturation. High average Drawdown recorded values

Table 2. Aquifer characteristic in the study area.

S/N	Community	Discharge Q (l/s)	Transmissivity T (m²/s)	Hydraulic conductivity K (m/s)	Specific capacity m²/s/m	Drawdown per log cycle Δs (m)
1	Agamati Market	0.50	1.31×10^{-1}	1.10×10^{-2}	3.10×10^{-2}	0.70
2	Fadan Karshi	0.86	1.43×10	1.20×10^{-1}	9.00×10^{-2}	0.11
3	Kufai Aboro	0.84	4.40×10^{-1}	3.66×10^{-2}	4.00×10^{-2}	0.20
4	Ankara	0.68	2.07×10^{-2}	2.30×10^{-2}	5.10×10^{-2}	0.60
5	Maitozo District Head House	0.60	3.04×10^{-1}	3.05×10^{-2}	3.00×10^{-2}	0.40
6	Kwagiri Village	1.00	2.30×10^{-1}	2.54×10^{-2}	6.00×10^{-2}	0.80
7	LGEA Landa	0.75	2.30×10^{-1}	2.54×10^{-2}	7.01×10^{-2}	0.60
8	Dorowa	0.70	3.00×10^{-1}	3.20×10^{-2}	1.84×10^{-1}	0.45
9	Kwassu Ung. Dutse	0.50	2.61×10^{-1}	2.20×10^{-2}	7.11×10^{-2}	0.35
10	Fadan Ayu	0.64	1.60×10^{-1}	1.74×10^{-2}	5.12×10^{-2}	0.70
11	Dangam	0.70	1.83×10^{-1}	1.53×10^{-2}	7.07×10^{-2}	0.70
12	LGEA Ancha	0.70	3.22×10^{-1}	3.60×10^{-2}	1.03×10^{-1}	0.40
13	LGEA Aboro	0.60	1.22×10^{-1}	1.02×10^{-2}	4.00×10^{-2}	0.70
14	PHC Kutal	0.45	2.10×10^{-1}	2.30×10^{-2}	5.50×10^{-2}	0.40
15	LGEA Amantu	0.50	1.14×10^{-1}	1.30×10^{-2}	4.00×10^{-2}	0.80
16	Aboro Village	0.70	2.60×10^{-1}	2.85×10^{-2}	4.02×10^{-1}	0.50
17	LGEA SabonGida	0.80	4.00×10^{-1}	4.07×10^{-2}	2.00×10^{-1}	0.40
18	Wasa Village	0.50	1.14×10^{-1}	1.30×10^{-2}	4.00×10^{-2}	0.80

Table 3. Summary of aquifer properties for the 18 boreholes in the area of study.

Aquifer property	Transmissivity T (m^2/s)	Hydraulic conductivity k (/m/s)
Minimum	1.14×10^{-1}	**1.02×10^{-2}**
Maximum	4.40×10^{-1}	**4.07×10^{-2}**
Mean	**2.18×10^{-1}**	**2.18×10^{-2}**

obtained shows the aquifer to be poor in terms of both recharge and discharge of groundwater; this is also an indication of the inefficiency of the aquifer as a transmitting medium. It is evidently clear also that the low yields range of between 0.45 to 1.00 l/s recorded, high level of drawdown recorded and poor aquifer properties obtained for the area, indicated that the aquifers in this area are predominantly made of fine clayey or Silty materials which are derived from the *in situ* chemical decomposition of the basement rock which are generally characterised with low permeability and poor water yield. The value range of conductivity obtained in this study fall within the range of 10^{-3} to 10^{-1} as given by [12] for clay, sand and gravel mixtures (till). Similarly poor performance of the fractured aquifer in the area can be attributed to low fracture density with poor conduit connectivity which characterise most basement aquifers. Although they yields obtained can sustain water abstraction by hand pump for small population, it will not be sufficient for a higher populated community with greater water demand.

4. Conclusion

The area is characterised by low to moderate groundwater resources, since this is the readily available portable source of water available, there is a need for this resource to be properly harness by carrying out an in-depth investigation on the groundwater resources reserve in the area. Similarly it is strongly recommended that a longer duration of pumping test period of about 24 hours should be adopted in the future so that a better assessment of the aquifer productivity and water potentials can be fully properly determined. The use of modern technology and scientific methods such as groundwater modelling will assist in giving the clear picture of the subsurface and understanding of the groundwater resources of the area. It will also give the chance to water managers to properly plan for the present and future water demand for the fast growing population in the area before the provision of pipe borne water is realised in the area.

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