Water and Environment Journal. Print ISSN 1747-6585

Shallow aquifer resources in the federal capital territory of Nigeria

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Keywords
Nigeria; permeability; shallow aquifer; well yield.

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doi:10.1111/j.1747-6593.2008.00107.x

Abstract

Public water supply to the Federal Capital Territory (FCT) of Nigeria is inadequate and an alternative source of water includes streams, hand-dug wells and boreholes. A survey showed that 41% of the territory uses hand-dug wells, while 23% depends on boreholes and 16% depends on streams. Measurements were taken from 84 wells in 2002 and 2003 to assess the contribution of hand-dug wells. The parameters considered include ground surface elevation, water level, permeability and well yield. The well diameter ranged between 0.7 and 1.2 m, while the depth ranged between 4.5 and 16 m. The permeability ranged between 0.000518 and 0.002541 cm/s. The source of recharge to the aquifer is rain, and well productivity ranged between 211 and 1806 L/day. Wells located in seven out of nine groups considered cannot meet the water demand of an average household (20 people) in the territory.

Introduction

The Federal Capital Territory (FCT) of Nigeria consists of Abuja City, Area Councils, Satellite Towns and Villages (Fig. 1). It became the capital city of Nigeria in 1991 after 15 years of planning and development. Development of the territory was divided into four phases, and as of now, only the first phase and part of the second phase have been developed.

The population of the territory was estimated to be 1 300 000 in 1998 (Water and Dam Services Company [WADSCO] 2005), which is higher than the projected population for the city when all phases are developed. Public water supply is from a 100 Mm^3 capacity reservoir (Usuma Reservoir), which was constructed in 1986. Initially, the system had a treatment plant of 5000 m^3/h capacity, and it was proposed that the plant capacity would increase to 10 000 m^3/h in 1992, 15 000 m^3/h in 1997, and 30 000 m^3/h in 2002 (Abuja Master Plan 1979). However, the capacity of the plant was 10 000 m^3/h in 2002. This means that only a third of the plant capacity required for providing potable water to the city was provided. The implication is that if raw water is available in the reservoir, the existing plant cannot provide adequate potable water to the territory. The situation has also worsened by the increase in population beyond the planned level. Consequently, people depend on water from streams, hand-dug wells and boreholes to meet their daily needs. Although water from shallow aquifers can easily be contaminated, the use of hand-dug wells for groundwater exploitation is common in the territory. The main objective of this study is to assess the contribution of hand-dug wells to water supply in the territory.

The study area

The territory occupies an area of 7700 km^2 in central Nigeria with its mid-point at latitude 8°55′N and longitude 7°11′E (Fig. 1). The south-western corner of the territory is about 68 km north of the confluence of Rivers Niger and Benue. The western edge of the territory extends northward for 90 km immediately west of River Gurara, a south-flowing tributary to River Niger. The principal physiographic elements of the territory are hills, plains and River Gurara along its western boundary. Hills in the north are the highest in the territory, reaching 1200 m in altitude. The height decreases towards the south and the west. The altitude at the central and western part of the territory is 200 m. Hat-topped hills rising 300–400 m are distinctive topographic features in the south. Most of the streams drain into River Gurara, except in the extreme east where some streams flow into River Koto, a tributary to the River Benue.

The daily temperature ranges from 23.5 °C to 33 °C with an average of 27.5 °C. The annual rainfall ranges from 1000 to 1670 mm with an average of about

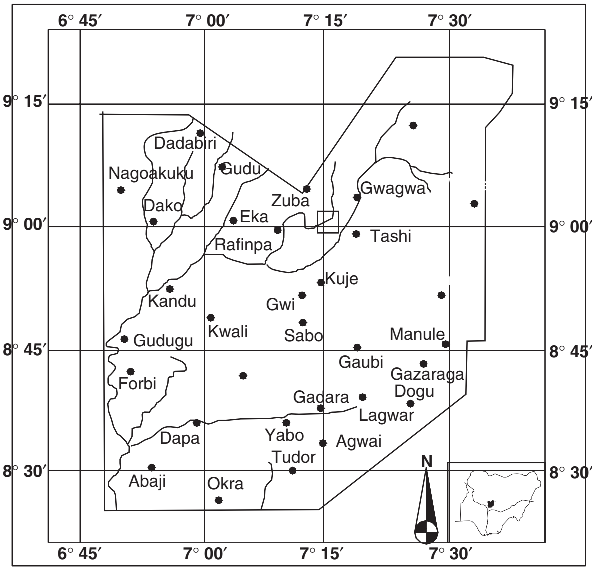

Fig. 1. Location of the Federal Capital Territory of Nigeria.

1200 mm. Rainy season is between April and October with the peak in August or September. The relative humidity is a little <50% during the dry season and above 60% during the wet season. Generally, the value of sunshine duration is about 7–9 and 10 h/day during the rainy and dry seasons, respectively.

The geology of the region falls into basement and sedimentary formations. Sixty-five per cent (65%) of the area is basement complex rocks. Forty per cent (40%) of Kuje and Kwali areas fall under sedimentary formation. This formation is underlain essentially by Nupe sandstone. It shows some lateral facies changes and is reportedly equivalent to the Patti formation and Lokoja sandstones, which in succession overlie the basement. The Patti formation has a maximum thickness of 100 m of fine to medium grain sandstone, clay and carbonaceous silt. The older Lokoja sandstone on the other hand overlies the basement directly and consists of pebble clay, grits and sandstones. The formation underlies the Patti formation to the north of Lokoja in the Abaji area. The thickness of the alluvial deposits along the course of River Gurara ranges from 10 to 70 m. Groundwater in the alluvium is recharged directly by rainfall or adjoining flood water from river systems (Adeleye 1976).

The regolith in the groundwater basin varies from 30–120 to 25–48.5 m. Shallow groundwater development, which mainly sustains water supply to the rural community through shallow wells, is found in the localized alluvial deposit in low depressions. The main confined zones are normally at an average depth of about 48.76 m based on the piezometric surface (Offodile 1992).

Method of investigation

Eighty-four wells were selected for the study. The wells (Fig. 2) are located in the six area councils of the territory, namely Bwari, Abaji, Kwali, Kuje, Gwagwalada and Abuja Municipal area councils. The wells are representative of the geological formation of the territory as well as the spread of the existing wells in the territory. The investigation involved collating data from literature, interview, field measurement and laboratory analysis. Data collected from relevant literature include topographic and borehole data from the Federal Ministry of Water Resources and Agricultural Development Agency.

The physical parameters measured include the location, depth and diameter of each well. Other parameters are elevation of ground level at each well, well lining, well covering, soil description and static water level during the dry and wet seasons. The level of water in the well was taken weekly during the wet and dry seasons of 2002 and 2003. The depth of each well was measured. The positions of the wells were determined using the global positioning system (GPS).

The research team obtained permission from the owner of each well so as to take readings for determining well yield. Although the team was not allowed to pump water from each well, the research team was able to take the water depth reading in the evening (between 6:30 and 8:30 hours) and in the morning (between 6:00 and 8:00 hours) the next day. Water was not lifted from the wells when these readings were taken. The yield (y_m) for each

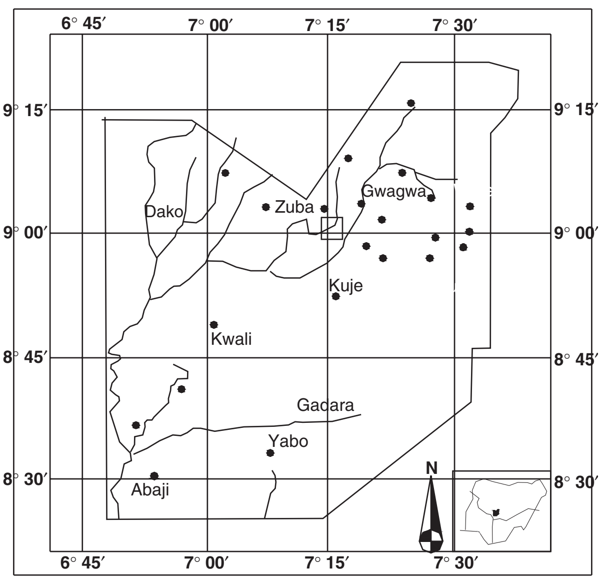

Fig. 2. Location of selected wells in the Federal Capital Territory of Nigeria.

well was calculated using the following equation (Driscoll 1987 and Rushton 2003):

$$y_m = S_y V, \quad (1)$$

$$V = \frac{\pi D^2 \Delta h}{4 \Delta t}, \quad (2)$$

where S_y is the specific yield of the well, D is the well diameter, Δh is the change in water level and Δt is the difference between times when readings were taken. Soil properties were determined using standard laboratory test procedures.

Result

A survey carried out revealed that the territory depends on hand-dug wells, boreholes, streams and a public water system for their domestic needs. The result (Table 1) showed that only 20% depends on municipal supply. This is due to the sudden increase in population beyond the planned level. More area depends on hand-dug wells than boreholes. The cost of digging a well, with cover and concrete casing, is about \$450, but the cost of sinking a borehole in the basement complex is over \$4000. Economic factors made people prefer hand-dug wells as against boreholes. This survey confirms earlier studies (Abuja Water News 1999 and WADSCO 2005) on the inadequacy of the public water supply system in the territory.

Hand-dug wells in the region are usually 0.8–1.2 m in diameter and rarely more than 10 m deep. They are dug with pick (digger) and shovel by one or two men working at the bottom of the shaft. Excavated soil is lifted out with a bucket and rope. The casing or lining of hand-dug wells is concrete, steel or brick. The casing is installed in two ways. First, the shaft is sunk and the casing is built in sections. As the well depth increases, more sections of casing are added. This process continues until the water table is reached; then the second method called caissoning is used to sink the well into the aquifer.

The intake of each hand-dug well is designed to fit the nature of the aquifer. Usually the lower section of the casing, that is, the region within the aquifer, is made of porous concrete to allow groundwater to seep through. However, if the aquifer has fine sand, which could clog the porous concrete, the lower section is made of standard concrete and the bottom of the shaft is lined with layers of carefully selected gravel. The well head is a concrete apron, which is meant to drain surface runoff from the well.

Table 2 shows the summary of the particle size distribution of samples taken from each soil group. The uniformity coefficient of each sample is >2; thus the samples are well graded (Bear 1972). The proportion of silt or clay in each group is zero. The grouping was based on the characteristics of the soil samples taken from the wells.

Table 3 shows the summary of water levels during wet and dry seasons. During the wet season, the depth of water level from the ground surface was smaller than that of the dry season. The lowest depth of water level from the ground surface was obtained during the peak of the wet season (in September), while the highest depth of water level from ground surface was recorded during the peak of the dry season (February or March). This confirms that the source of recharge to the aquifer is rainfall between April and October. During the dry season, water is either abstracted from the aquifer through wells, lost through evaporation, or both. These processes lower the water table in the unconfined aquifer.

The table also shows the change in water level from the peak of the wet season to the peak of the dry season, which we referred to as the seasonal difference in water level. The highest seasonal difference in water level was

Table 1 Sources of water for domestic use in the Federal Capital Territory (FCT)

Sources	% Dependence
Municipal supply	20
Borehole	23
Hand-dug well	41
Streams or rivers	16

Table 2 Particle size distribution

Group	Region	No. of wells	% gravel	% sand	Cu = D_{60}/D_{10}	Remarks
1	Kado, Karmo, Gwagwa	23	10.24	89.76	8.63	Well-graded gravely sand
2	Kuje	3	14.38	85.62	11.07	Well-graded gravely sand
3	Gwagwalada, Kwali	7	19.69	80.31	11.30	Well-graded gravely sand
4	Bwari	7	14.73	85.22	9.44	Well-graded gravely sand
5	Garki, Lugbe, Pyakassa	12	8.14	91.86	8.24	Well-graded gravely sand
6	Abaji, Gada, Biu, Kwaita	4	14.04	85.96	9.40	Well-graded gravely sand
7	Yaba	3	21.98	78.98	12.70	Well-graded gravely sand
8	Karu, Nyanya, Orozo	12	16.04	83.96	3.30	Well-graded gravely sand
9	Kubwa, Gwarinpa, Zuba	13	24.35	75.65	7.14	Well-graded gravely sand

Table 3 Summary of water levels in the wells

Group	Elevation of ground level (m)	Elevation of water surface		Seasonal difference in water level
		Rainy season	Dry season	
1	374.0–454.0	371.7–446.4	371.0–445.0	0.2–2.95
2	299.8–300.7	293.7–299.8	291.6–296.3	2.2–3.5
3	176.0–199.0	173.4–197.5	171.0–193.0	1.0–4.8
4	527.0–575	525.7–569.1	522.0–567.0	2.1–4.5
5	360.0–532.0	356.0–532.2	354.0–528.0	1.0–4.4
6	102.0–130.0	96.8–124.6	94.6–119.0	1.5–5.5
7	68.4–91.8	65.0–84.8	62.6–83.8	1.0–2.9
8	335.0–462.0	331.3–456.2	328.0–454.0	0.1–5.1
9	390.0–494.0	327.1–488.0	324.0–487.0	0.2–4.7

Table 4 Aquifer properties

Group	Permeability (cm/s)	Porosity (%)	Void ratio e	Specific gravity
1	0.000518	30	0.42	2.62
2	0.000977	39	0.64	2.67
3	0.000941	38	0.62	2.63
4	0.001017	40	0.67	2.62
5	0.001955	44	0.78	2.62
6	0.002310	45	0.82	2.68
7	0.002541	48	0.91	2.66
8	0.002030	45	0.82	2.68
9	0.002420	46	0.84	2.63

Table 5 Estimated average well yield

Group	Well depth (m)	Well diameter (m)	Specific yield (%)	Yield (L/day)		
				Minimum	Maximum	Mean
1	6.0–10.0	0.7–1.0	21	72	347	211
2	5.0–8.0	0.7–1.0	31	82	414	249
3	6.0–8.0	0.7–1.0	31	365	682	525
4	6.0–8.0	0.7–1.0	37	259	930	502
5	4.5–8.0	0.7–1.0	43	159	1149	582
6	5.0–16.0	0.7–1.0	45	226	1527	897
7	7.0–9.0	0.7–1.0	44	1095	2219	1806
8	6.0–13.0	0.7–1.0	53	448	2824	1012
9	5.0–10.0	1.0–1.2	40	1	1578	767

5.5 m in the Abaji area. The lowest seasonal difference of water level was 0.1 m in Jikoyi, while the seasonal difference in water level at Yaba varied from 1.0 to 2.9 m. Jikoyi area lies on basement formation overlain by lateritic soil while Yaba area falls on alluvial deposit underlain by Nupe sandstone formation.

Table 4 shows the permeability, porosity, void ratio and specific gravity of soil. The porosity varied between 30 and 48%. Group 1 had the lowest value (30%) while Groups 6 and 8 had 45% each. The porosity of soil from wells in Group 9 was 46% and Group 7 had the highest value (48%). The permeability ranged between 0.518×10^{-3} and 2.541×10^{-3} cm/s. The permeability of wells in Group 8 had the highest value while Group 1 had the lowest. Wells in Groups 6–9 are therefore expected to perform better than those in Groups 1–3.

The estimated yield for each well is shown in Table 5. It was found that the diameter of the wells did not exceed 1.2 m, indicating a small-diameter well. There are concrete pipes suitable for casing such well sizes. The study showed that well yield is not considered in selecting well diameter. Rushton (2003) discussed the advantage of large-diameter wells whenever geological formation favours such construction. This factor should be considered in areas where the productivity of wells is low. The well depth varied with region. The well depth ranged between 4.5 and 16 m, indicating the thickness of covering over the basement formation. Wells in Abaji had the highest depth.

The specific yield of wells in Group 1, 2 or 3 was <35%, indicating that the material of the aquifer is gravely sand (Dawson & Istok 1991). The specific yield of wells in Group 4 was 37% while that of Group 9 was 40%, indicating sand material. The specific yield of wells in Groups 5–8 exceeded 40%, indicating that the aquifer contains alluvial deposit (Dawson & Istok 1991). The volume of water [*V*, in Eq. (2)] abstracted from wells in Groups 5–8 during the study were higher than those of wells in Group 1, 2 or 3. The mean yield ranged between 211 and 1806 L/day. Wells located in Group 7 (Yaba area) had the highest yield while those in Groups 1 and 2 (Kardo, Karmo, Gwagwa and Kuje) had the least yield value. The wells located in Yaba area had the highest yield because Yaba lies on alluvial deposit underlain by Nupe sandstone formation while those wells that have the lowest yield are located on basement formation overlain by lateritic soil. Assuming an average consumption of 70 L/c/day (WADSCO 2005), a hand-dug well in FCT satisfies the water demand of 3–26 people. Considering an average household size of 20 people, wells located in Groups 1, 2, 3, 4, 5, 6 and 9 cannot meet half of the water demand of an average household in FCT. Increasing the number of hand-dug wells per land area might increase the well productivity at the initial stage but could result in overexploitation of the shallow aquifer. This is because recharge from rainfall in the semi-arid region is $<30\%$ due to the seasonal rainfall and the soil moisture deficit before the commencement of the rainy season (Rushton *et al*. 2006). This shows that recharge is limited. Wells located in Groups 7 and 8 are capable of meeting the water demand of an average household in the territory.

Conclusion

(1) The study showed that a small diameter well is used in FCT to abstract water from the shallow aquifer, and the source of recharge is rain which occurs between April and October.
(2) The direction of flow within the shallow aquifer is from northeast to southwest towards River Gurara. The permeability of the aquifer ranged between 0.518×10^{-3} and 2.541×10^{-3} cm/s. The well yield ranged from 211 to 1806 L/day, which is sufficient to meet the water demand of 3–26 people based on a water per capita consumption of 70 L/day.
(3) The study showed that the productivity of a hand-dug well depends on region. Considering an average household of 20 people, the study showed that wells located in seven out of nine areas considered cannot meet half of the water demand of a household.
(4) The low yield could be attributed to geological formation and length of dry season in the region. Because rainfall, which is the source of recharge of a shallow aquifer, is limited in quantity and time, the number of wells per household cannot be increased for the purpose of meeting the water need of the territory.
(5) There is a continuous exploitation of groundwater resources in the territory because of inadequate supply from the public water supply system. Although water from the shallow aquifer can easily be contaminated, the proportion of the territory that depends on hand-dug wells is greater than the proportion that depends on boreholes because it is easier and cheaper to construct.
(6) It is, therefore, recommended that the use of hand-dug wells should be made with caution in view of its limitation in quantity.

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