Research Journal of Environmental and Earth Sciences 3(1): 1-7, 2011
ISSN: 2041-0492

Received: September 03, 2010 Accepted: October 14, 2010 Published: January 05, 2011

Groundwater Resources Potential in the Coastal Plain Sands Aquifers, Lagos, Nigeria

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Abstract: The hydraulic properties of the aquifers located in the coastal plain sands, Lagos, Nigeria had been investigated. A review of both the theoretical and practical applications of pumping tests in groundwater resource evaluation for coastal plain sands aquifer was carried out. The main activities involved collation of information related to well logs, step-drawdown and constant rate pumping tests from existing database on borehole drilling in seven wells to an average depth of 100 m. Graphical methods based on Rorabaugh's Hantush-Bierschenk's analyses were used to determine the components of drawdown due to well and aquifer losses from the step-drawdown pumping tests. Conventional analytical methods based on non-equilibrium equation were used to assess the local hydraulic regime of the groundwater system using constant rate pumping tests data. Data from 11 controlled pumping tests in Shomolu area of Lagos metropolis were analyzed. The transmissivity values of the multi-layered aquifer system range between 345.6 and 2,332 m^2/day while the storage coefficient values range between $2.8x10^{-4}$ and $4.5x10^{-4}$. Both results indicate confined aquifers of artesian conditions. The step-drawdown pumping tests results indicate that well losses constituted a significant component of drawdown in the pumped wells, a phenomenon due to poor well design, well development; and non-Darcian flow in the multi-layered aquifer. The pumping test results allowed for theoretical and practical prediction of aquifer and well yields in the study area.

Key words: Aquifer loss, coastal plain sands, drawdown, groundwater potential, well loss, well yield

INTRODUCTION

Water as a finite resource is becoming very scarce in most nations of the world. The competition for the available supplies among users such as the industries, agriculture, and hydroelectricity will continue to put great stress on water supply especially in arid and semi-arid nations of the world where water shortage could constitute an important constraining economic factor. Aside, high rate of urbanization is also known to have contributed to increased water demand globally (Oteri and Atolagbe, 2003; Vaknin, 2005; WHO/UNICEF, 2005; UNESCO, 2006). In the last three decades Lagos State had witnessed a phenomenal increase in population and urbanization. Today, the state is the most urbanized and densely populated state in Nigeria, with an estimated population of close to 13 million from only 3.6 million in the early 80s. Lagos metropolis where over 70% of the entire state's population resides could no longer cope with adequate water supply in terms of both quality and quantity. In response to the shortage in demand, a series of water supply projects based on groundwater resource exploration and exploitation of the Coastal Plain Sand's aquifers had been embarked upon by both public and private sectors (Longe *et al.*, 1987; Coode Blizard Ltd., 1997). The shortfall in public water supply by the State Water Corporation to meet with the increasing water supply situation has led to unplanned and uncontrolled groundwater exploitation within the metropolis in recent past. Boreholes are sited by both skilled and unskilled technicians with varying degree of success. The uncontrolled sitting of boreholes in the metropolis portends great danger on the volume and quality of groundwater that could be abstracted. A large groundwater withdrawal with little or no recharge is known to have caused large drawdown and deterioration in groundwater quality (Oteri and Atolagbe, 2003; Misut *et al.*, 2003; Benhachmi *et al.*, 2003). The current study aimed at investigating the groundwater potentials of the coastal plain sands aquifer with particular reference to the importance of step-pumping tests in groundwater resource evaluation and development.

MATERIALS AND METHODS

Study area: The study area is located in Shomolu, Lagos metropolis, Nigeria (Fig. 1). The entire area is low-lying and is characterized by two major climatic seasons, a dry season spanning from November through March and April, and a wet or rainy season from April to October with a short break in mid-August. Annual precipitation of over 2000 mm is a major source of groundwater recharge in the area.

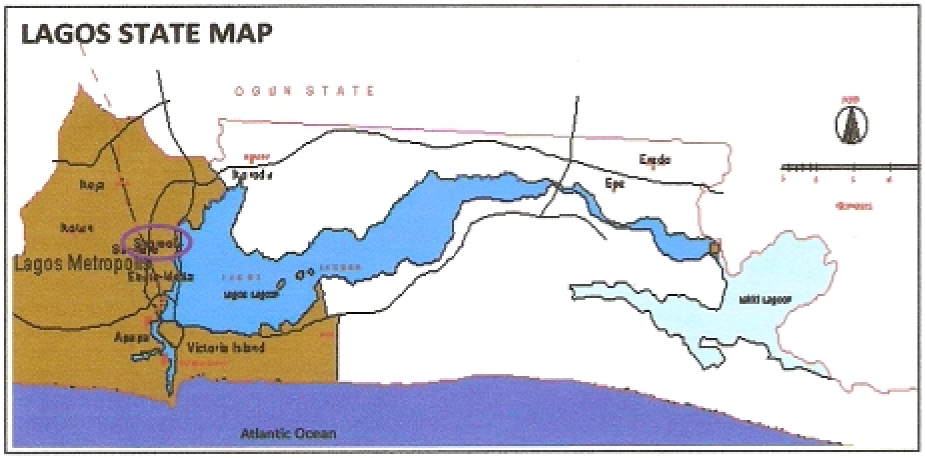

Fig. 1: Map of Lagos state showing area of study

The geology of Shomolu is consistent with the regional geology of Lagos metropolis which is made up of Coastal Plain Sands (CPS) and the recent sediments. The Recent sediments are underlain by the CPS while the CPS overlay a thick clay layer, the Ilaro Formation. The CPS consists of thick bodies of yellowish and white sands and gravels. The formation is poorly sorted and has local shale interbeds, lenses of clays and sandy clay with lignite of Miocene to Recent age. The layers are somewhat lenticular, lenses of clays and sandy clay with lignite of Miocene to Recent age. Though the layers are somewhat lenticular, some are of rather limited lateral extension. The CPS is equally referred to as the Benin Formation (Short and Stauble, 1969). The Recent deposits consist of unconsolidated beach type sands, whitish in colour, with varying proportions of clay and mud. The Recent sediments form a water table aquifer which is exploited by hand-dug wells and shallow boreholes while the Coastal Plains Sands aquifer is a multi-aquifer system consisting of three aquifer horizons separated by silty or clayey layers (Longe *et al.*, 1987). The latter is the main aquifer in Lagos metropolis and it is exploited through boreholes for domestic, municipal and industrial water supply.

Data acquisition: The present study is based on collation and analysis of data obtained from existing groundwater database on the study area, Shomolu, Lagos, Nigeria from the Lagos State Water Corporation. This was followed by site assessments in 2008 of the study area. Hydrogeological data relating to well logs, step-drawdown and constant rate pumping tests in six wells were collected and analyzed. All the wells were drilled by rotary method using direct mud circulation. They were completed with API 5a steel-casing with threaded couplings while the screens used were heavy duty stainless steel wedge wire type with continuous slot. Prior to usage, each well was developed by air lifting and high velocity jetting. Pumping test data on step-drawdown, constant discharge and recovery tests were collected and analyzed (Table 1).

Table 1: Data collection and pattern

	Type of pumping test performed data		
Borehole	Step-drawdown	Constant	Observation
Well 1	√		√
Well 2	√	√	√
Well 3	√		√
Well 4	√		
Well 5	√		
Well 6	√		

√ = Collected data

The step-drawdown pumping tests were conducted at varied discharge rates that ranged between 12 and 24 m^3/h until the drawdown within each well was stabilized. Maximum discharge rates ranging from 62 to 100 m^3/h were applied through a successive series of intermediary steps. From data, an average test time of 28 min of fixed duration for each step within each well was achieved based on field conditions. Equally, data relating to constant discharge test in Well 2, drawdown and recovery tests in Wells 1 and 3 (observation wells) were obtained for evaluation. Inference on hydraulic condition of aquifer based on results of analyzed data in the study area was then deduced.

Theoretical background: The choice of methods of analyses was guided by the objective of the study; which is to determine both the aquifer and well characteristics with focus on the proportion of drawdown due to well losses. The applications of the predictive formulas using Transmissivity and Storavity values from pumping test data were employed. The above methods are found to be critical in designing and developing well for maximum productivity.

The step drawdown: The theoretical background for step-drawdown analysis is based on the premise that total drawdown in a well is a sum of two components, comprising the logarithmic drawdown curve at the well surface, and a well loss which itself is caused by flow through the well screen, and the flow inside of the well to the pump intake (Bonnet *et al.*, 1967). The step-drawdown data were analyzed by modified Rorabaugh's method by Hantush-Bierschenk well loss analysis (Bierschenk, 1964; Hantush, 1964). The total drawdown (S_w) at the well for a steady state confined aquifer is given thus:

$$S_w = Q/\pi T \ln (r_o/r_w) + CQ^n \qquad (1)$$

where,

Q = Well discharge rate or the pumping rate
T = Transmissivity
C = Well loss coefficient, governed by the radius, construction and condition of the well.
r_o = radius of influence
r_w = well radius
n = a constant greater than one,

The total drawdown (S_w) consists of the formation loss BQ and well loss CQ^n respectively. B is the formation loss constant and it is proportional to the pumping rate Q, and it increases with time as the cone of depression expands. It arises from the resistance of the formation to fluid flow. The formation constant B, is determined by the relationship:

$$B = \ln [r_o / r_w] / 2\pi T \qquad (2)$$

The general equation for calculating the total drawdown inside a pumped well including the well losses is given by substituting for the right hand side of Eq. (2) in (1) thus:

$$S_w = BQ + CQ^n \qquad (3)$$

The well loss is associated with turbulent flow and it is proportional to an n^{th} power of the discharge as CQ^n, n typically varies between 1.5 and 3.5 depending on the value of Q. A value of 2 is reasonably assumed for n (Todd, 1980).

Hence, the total drawdown (S_w) at any time (t) becomes:

$$S_w = BQ + CQ^2 \qquad (4)$$

where,

BQ = formation loss
CQ^2 = the well loss

The formation loss (BQ) is an aquifer complex, a linear drawdown that is provoked by laminar flow in the aquifer around the well in response to Darcy's law. The well loss (CQ^2) in contrary defines the quadratic drawdown, non-linear, provoked by turbulent flow in the screen and in the casing. Well loss has been found to be a substantial fraction of total drawdown in a well especially when pumping rates are large (Todd, 1980; Karanth, 2006). The relationship between drawdown and discharge is used to choose, empirically, an optimum yield for a pumped well, or to obtain information on the condition or efficiency of the well. The step-drawdown test is therefore, a useful tool in well design (Korom *et al.*, 2000). The simple technique of determining B and C is to re-arrange Eq. (4) thus:

$$S_w/Q = B+CQ \qquad (5)$$

The above expression is a straight line equation, where Sw/Q is the specific drawdown.

From the plots of specific drawdown (S_w/Q) against the pumping rate (Q), fitting a straight line through the points, both the well loss coefficient C and formation loss coefficient B are estimated. C is given by the slope of the fitted straight line while B is obtained by the intercept Q = 0. The well loss is a function of rate of discharge, pump capacity, well and screen diameter. The determination of significant decreases in head losses in groundwater system is a very useful tool to improving well designs, pumping plans as well as well rehabilitation (Korom *et al.*, 2000).

Specific capacity: The specific capacity, a measure of productivity of well, was calculated from the approximate non-equilibrium equation and well loss:

$$s_w = 2.30Q/2\pi T \log (2.25\ Tt / r_w^2 S) + CQ^n \qquad (6)$$

Re-arranging (6),

$$Q/s_w = 1 / (2.30\ Q / 4\pi T) \log (2.25\ Tt/ r_w^2 S) + CQ^n \qquad (7)$$

where,

Q/s_w = Specific capacity, the larger it is the better the well
S = Storage coefficient
t = time

Other parameters of the equation are as previously defined.

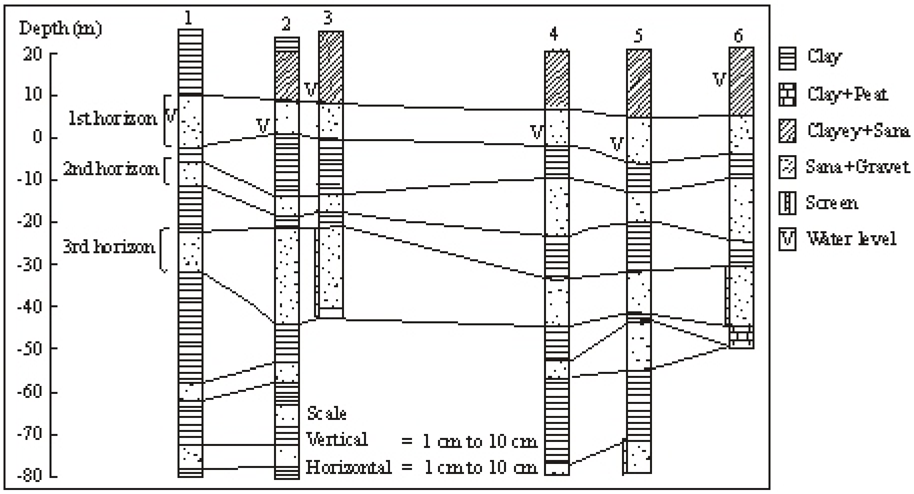

Fig. 2: Lithologic correlation of sampled wells

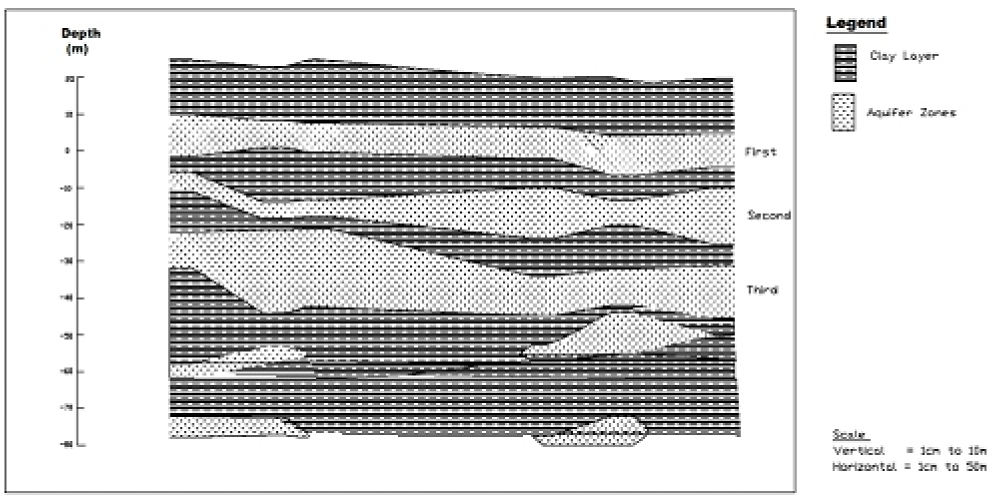

Fig. 3: Delineated aquifer horizons in the study area

Well efficiency (E_w): Well Efficiency E_w, was estimated by the relationship:

$$E_w = 100\ (Q/s_w)\ /\ (Q/BQ) = 100\ (BQ\ /\ s_w) \qquad (8)$$

Constant discharge pumping and recovery tests: Conventional methods for constant rate pumping and recovery test data analyses based on non-equilibrium equation of unsteady flow in confined aquifers, established by Theis (1935), Cooper and Jacob (1946) and Walton (1962) methods (Todd, 1980) were used in Kruseman and De Ridder, (1983, 1990). Jacob's method was used to evaluate transmissivity values in all wells. Theis' method was applied to observation well while Walton's method was used only in cases of suspected effects of drainage on the constant drawdown time curves.

RESULTS AND DISCUSSION

Aquifer system: The aquifer system in the area is consistent with the general pattern of the regional aquifer system for the metropolitan Lagos as described by Longe *et al*. (1987). Three major aquifer units exist, the first, a water table aquifer, made of dirty, white to grayish colored unconsolidated sands with an average thickness of 10 m (Fig. 2). This water table aquifer is found within the recent alluvial deposits. Yield is limited and with high risk of contamination. The second, a confined aquifer is separated from the first by successive deposits of increasing impermeabilities of sandy clay to silty clay to clay. The entire impermeable layer attains a maximum thickness of about 10 m. The saturated zone varies in thickness from few centimetres to about 15 m and occurs at a depth of between 5 and 20 m below sea level (bsl).

Table 2: Results of step-drawdown pumping tests in the study area

Well No.	Yield (m^3/h)	Specific Capacity (m^3/h/m)	T (m^2/d)	B (h/m^2)	C (h^5/m^5)	BQ (m)	CQ^2 (m)	Well loss (%)
1	100.4	9.9	414.74	0.0918	0.00000	99.1970	0.9073	8.98
2	63.3	6.3	224.64	0.1482	0.00020	9.37930	0.8011	7.86
3	62.1	32.3	2073.6	0.1373	0.00150	9.20320	0.7713	7.73
4	100	5.49	2332.8	0.1528	0.00040	15.2812	4.0001	20.75
5	78.3	6.93	2332.8	0.0689	0.00110	5.39490	6.7440	55.56
6	95.4	17.8	1555.2	0.0550	0.00001	5.24700	0.0910	1.70

T = Transmissivity, B = Formation loss coefficient, C = Well loss coefficient, Q = Discharge rate

Table 3: Evaluated hydraulic properties of coastal plain sands aquifer

			Transmissivity, T (m^2/day)			Storage Coefficient (S x 10^{-4})	
Well No	Aquifer Horizon	Well no.	Jacob's Method	Theis'Method	Walton's Method	Theis' Method	Walton's Method
1Cd	3	1Cd	345	-	-	-	-
2Cd (Obs)	2	2Cd (Obs)	NA	449.2	146.9	3.1	2.9
2R (Obs)	2	2R (Obs)	NA	362.9	380	2.8	2.8
6Cd (Obs)	3	6Cd (Obs)	NA	1831.7	1926.7	4.9	4.8
6R(Obs)	3	6R(Obs)	NA	1883.2	1987.2	4.8	4.1

Cd = Constant Discharge test, R = Recovery test, Obs = Observation, NA = Not applicable

The third major aquifer zone exists between 20 to 70 metres (bsl). This zone is located within a semi permeable sequence of sandy clay and clay deposits (Fig. 3).

According to Longe *et al.* (1987), in their study of the hydrogeology of Lagos, the aquifer horizons 2 and 3 are one zone but a multi-layered system which is defined by three distinct sub-zones. Their third major aquifer zone exists between 118 and 166 m (bsl), which is locally not captured in the current study.

Pumping test results: The results from the step-drawdown pumping tests and from the constant discharge pumping tests are presented (Table 2 and 3). Graphical representations of the step-drawdown method are presented on Fig. 4 to 9. Table 3 presents the aquifer and well loss constants, (B and C) determined from the graphical method. The aquifer and well loss components of drawdown computed for the maximum test discharge, BQ and CQ are also presented. The results indicate that well losses comprise significant portion of the total drawdown in wells 4 and 5 with well losses of 20.7 and 55.5%, respectively. The well losses range between 7.73 and 8.98% in wells 1, 2 and 3.

There is no noticeable direct correlation between obtained transmissivity values and the inferred proportion of drawdown due to well losses. Even though, the percentage well loss is significant in wells 4 and 5, on the contrary, their transmissivity values however depict very good transmitting aquifer system. Furthermore, there are no deductions of any direct influence of the percentage well loss pattern as well as the computed CQ^2 values for maximum discharge on the transmissivity of the aquifer. Even though well loss coefficient is a critical parameter in estimating sustained yield of a well, a number of other intervening factors could have influenced this observation. Such intervening parameters include the pump capacity, pumping rate, aquifer transmissivity, and

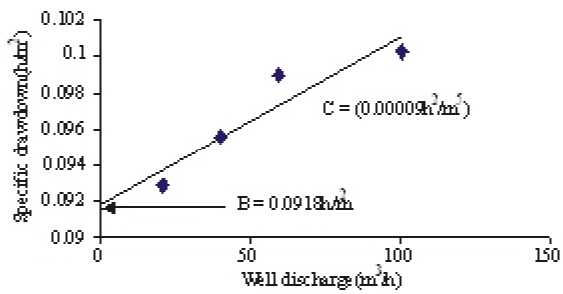

Fig. 4: Plot of specific drawdown against discharge in well 1

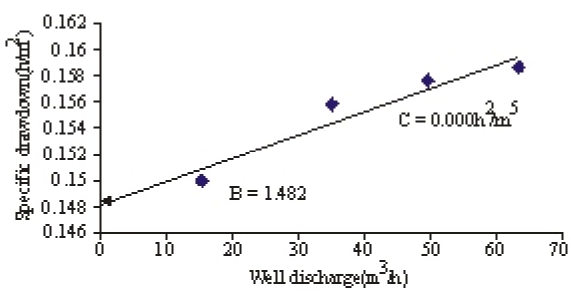

Fig. 5: Plot of specific drawdown against discharge in well 2

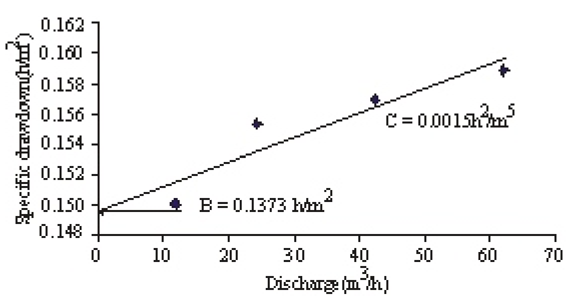

Fig. 6: Plot of specific drawdown against discharge in well 3

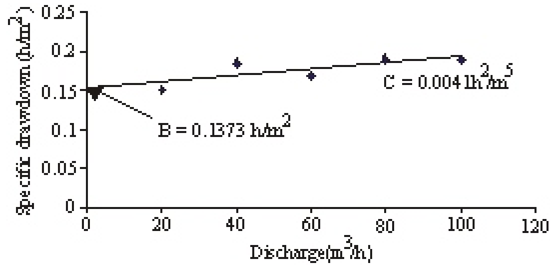

Fig. 7: Plot of specific drawdown against discharge in well 4

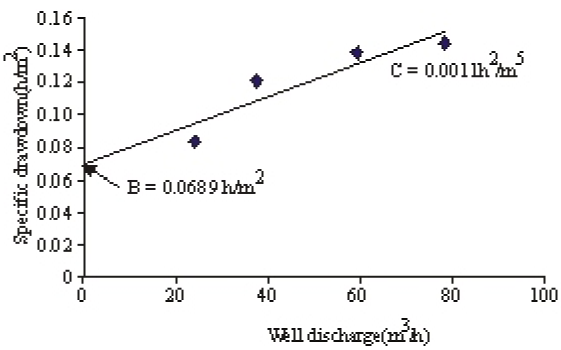

Fig. 8: Plot of specific drawdown against discharge in well 5

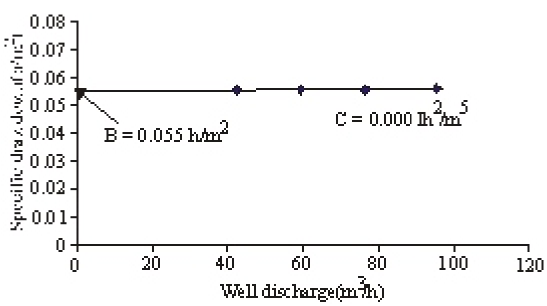

Fig. 9: Plot of specific drawdown against discharge in well 6

the rate at which drawdown changes with time and recharge characteristic. Hence, the high values of percentage well loss obtained for wells 4 and 5 are rather due to poor well development and completion than low transmissivity and poor yield of the aquifer.

From Table 3, the average transmissivity value of 1120 m^2/day obtained indicates aquifer medium of good ability to transmit water. The transmissivity values are comparable with the results obtained from the step-drawdown recovery tests (Table 2). An average value of 3.77×10^{-4} was obtained for the Storage Coefficient.

It could be further observed that there are no significant variations in the hydraulic properties of the aquifer under constant discharge and recovery regimes. However, the contrasted transmissivity values from the step-drawdown recovery tests (Table 3) and the constant rate discharge method (Table 3) is expected. The transmissivity values from the step-drawdown recovery tests, more or less define individual well performance, while transmissivity values from constant rate method give regional evaluation of aquifer hydraulic properties. Furthermore, transmissivity values obtained in a step-drawdown test is generally less reliable in terms of a regional evaluation of aquifer properties compared with values from a long term discharge pumping test. The values from the step-drawdown are more influenced by geologic configuration. There are no significant variations between the transmissivity values calculated from the Thesis and Walton's methods (Table 3). The storage coefficient values for both methods compare favourably.

CONCLUSION

Wells sited in the Coastal Plain Sands are found to be of very high yields in Lagos and generally along the coast of Nigeria (Longe *et al.*, 1987; Oteri and Atolagbe, 2003). Observed contrasts in transmissivity values of the multi-layered aquifer system in the study area, confirms heterogeneity of the water bearing zones in the Coastal Plain Sands. The existence of clay lenses and pockets of water bodies affect lateral continuity of the aquifer system, which equally affects the yield. Well losses constitute significant portion of the total drawdown despite high well yields recorded. The nature of well loss is attributable to poor well completion and development and to non-Darcian flow in the vicinity of the poorly developed wells. This suggests that wells sited in this multi-layered aquifer system may be difficult to complete and develop without adequate well logging prior to casing and screening. Well logging should therefore be incorporated in borehole development process in the coastal plain sands aquifer for safe and sustainable yields.

Pumping test is a standard step in groundwater resource evaluation providing in-situ parameters, with values averaged over a large and representative aquifer volume, it is not without disadvantages. For instance, the general assumption that aquifer is bounded above and below by impermeable strata is contradicted by most-known instances in nature. From this study therefore, the occurrence of alternating sequences of clay and sand deposits call for proper and careful well sitting, drilling and development by use of adequate borehole technology despite great potential for groundwater resource in coastal aquifers in general and in coastal plain sands aquifer specifically (Ferreira and Naim, 2007). Occurrence of localized bodies of water when tapped gives limited and poor yields. Regular post-construction well monitoring through logging is a recommended useful tool in enhancing well yield and well performance. Such logging will be helpful in respect of well design and completion process that guarantees long term yield and performance as well as optimized locations for groundwater.

ACKNOWLEDGMENT

The author wishes to express thanks to Lagos State Water Corporation for access granted to their groundwater database, hence acquisition of the information used in this research. Also appreciated is the financial support received from Leimich Associates towards the project.

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