Journal of Environmental & Analytical Toxicology
ISSN: 2161-0525

Akinwumiju and Orimoogunje, J Environ Anal Toxicol 2013, 3:2
DOI: 10.4172/2161-0525.1000168

Research Article Open Access

Predicting the Yields of Deep Wells of the Deltaic Formation, Niger Delta, Nigeria

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Abstract

The study examined the spatial characteristics of boreholes of ten selected locations with the opinion of appraising the sustainability of groundwater resource in the Deltaic formation, Niger Delta Nigeria. Data on Borehole Parameters (Depth of Hole, Screen Length, Yield of Well and Drawdown) were obtained from the Rivers State Ministry of Water Resources, Port Harcourt, and Rivers State. Both Descriptive and Inferential Statistical methods were employed in the analyses of the data while the relationship between the well yield and other borehole parameters was also modelled. The result showed that the aquifers of the study area are very thick, deeply located, and highly porous and saturated; emphasizing high yield potentials. It was also revealed that the basin contains adequate water to sustain her population as indicated by the high mean yield (30,056 lit/m) recorded for the study area. Finally, the result of the correlation statistics showed that the yield of well increases with depth of hole (r=0.82), rate of drawdown (r=0.62) and length of screen (r=0.63); and that the rate of drawdown increases as the length of screen increases (r=0.99). The study concluded by emphasizing the indispensability of adequate knowledge of hydrogeology in groundwater exploration and development particularly in regions of complex geological heterogeneity such as that of the Deltaic formation.

Keywords: Deep wells; Borehole yield; Deltaic formation; Niger Delta; Nigeria

Introduction

The significance of water as a resource is derived essentially from its two attributes. First, water is associated with human production, agriculture, mining and industrial activities. Secondly, the nature of hydrogen bonding in water enables it to support life of different forms [1]. Water is so basic to man's reproduction and survival on earth to the extent that all the known human societies (village, town, city, region, and nation) and research community lay much emphasis on in situ availability, quality and quantity of safe water [2]. In this case, any society that fails to develop and protect this vital resource may be jeopardizing the health and socio-economic well-being of her people [3-5]. No life can exist without water. It has been estimated that two-third of human body is constituted of water. Water is essential not only for survival of human beings, but also for animals, plants and other all other living beings [6-8]. Water is the most important factor that determines the capability of a given region to sustain population particularly in dry regions of the world [9]. In fact, during the Stone Age, water was the major determinant of the pattern of population distribution in Nigeria as well as in any other part of the world.

The Niger Delta is an oil-producing region with saline and brackish mangrove swamps drained by a very dense network of creeks, where thousands of inhabitants travel several kilometres on paddle canoes to get potable water. Water borne diseases and air borne particulate is rampart in places like Bonny, Okrika, Brass, Odioama and Nembe. Noxious particulate fallouts substances have rendered the rainwater deleterious to health. Indeed, acid rain is experienced in the region. The mixture of seawater and freshwater of the Niger River during high tides, render the water brackish and non-potable [10]. Despite the heavy annual rainfall of 3,000 mm in the delta and despite the numerous rivers that drain this region, provision of potable water has being a major problem. Hence, potable water availability and supply are major problems amongst the various communities. In response to these problems, much attention has been devoted to groundwater development and exploitation since mid-90s in this region.

The increasing demand for potable water as a result of recent population explosion in the Niger Delta has called for the assessment of the sustainability of the existing water resources particularly groundwater resource. In this case, the attempt to meet water demand majorly with groundwater has called for critical groundwater research especially sustainable yield assessment.

Groundwater is known to be an efficient perennial source of water and a much needed buffer during the times of drought [4,11]. A resource can be locally developed for in situ utilization [12]. Groundwater is believed to be the ultimate source of potable water for rural population because of its incremental development at affordable cost and its relative stability than its surface counterpart [4]. The mode of occurrence of groundwater depends largely upon the type of formation, and hence upon the geology of the area [8]. The possibility of *in situ* development and utilization of groundwater makes it suitable for developing countries particularly in the Sub-Sahara Africa where there is limited financial capability to invest in large-scale infrastructures. Despite these positive and potential attributes, especially in the Sub-Sahara Africa context, groundwater's advantage has not been fully taken [9,13].

There exist some notable studies aimed at assessing groundwater resources in Nigeria and most of them have been by University researchers. A notable study attempted the prediction of borehole

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Received November 22, 2012; **Accepted** February 01, 2013; **Published** February 04, 2013

Citation: Akinwumiju AS, Orimoogunje OOI (2013) Predicting the Yields of Deep Wells of the Deltaic Formation, Niger Delta, Nigeria. J Environ Anal Toxicol 3: 168. doi:10.4172/2161-0525.1000168

Citation: Akinwumiju AS, Orimoogunje OOI (2013) Predicting the Yields of Deep Wells of the Deltaic Formation, Niger Delta, Nigeria. J Environ Anal Toxicol 3: 168. doi:10.4172/2161-0525.1000168

yield in the Precambrian Basement Complex and Sedimentary Rock in Central Western Nigeria [14]. The study showed that the boreholes of the sedimentary rock have greater yield potentials than their counterparts in the Precambrian Basement Complex rock. The study revealed that depth of hole, drawdown and screen length determine borehole yield in the sedimentary rock while this is not the situation in the Basement Complex rock. The study concluded that the aquifers of the sedimentary rocks have higher yield potentials than those of the Precambrian Basement Complex. Another study adopted statistical techniques to assess the aquifer characteristics of 91 producing boreholes in the Crystalline Basement Complex Area of Northern Nigeria [15]. The study uncovered three distinctive aquifers that are exploitable for rural water supply within the study area. These aquifers include the River Alluvium aquifer, the Newer Basalts Aquifer and the Weathered Zone of Basement Complex aquifer. The weathered zone aquifer is said to be the most extensive and oftentimes poorly aquiferous. The study showed that the aquifer generally has low yield with an average yield of 45.77 lit/min or 65.91 m^3/day. However, it was discovered that higher yield occur in fractured zones. From the statistical evaluation, the study inferred that yield and specific capacity of aquifers are not related to regolith thickness and saturated thickness at the borehole points. The study recorded poor negative correlation coefficients and weak negative linear relationships for pairs of the parameters. The study concluded that regolith and saturated thicknesses do not play significant role as much as hydraulic characteristics of weathered zone in aquifer productivity within the study area. Also, there was an attempt to appraise the groundwater resource potential of the Basement Complex Rock aquifers in Zamfara State, Nigeria [16]. The study concluded that groundwater in the Basement Complex rocks of the state can mainly be sourced from fractures and joints commonly and in the intergrannular pores of fine to coarse (white or light grey) sand or gravel in the sedimentary areas. The study, however, concluded that the borehole yield is generally low within the study area. A study adopted vertical electrical resistivity in order to determine the aquifer systems of Ndokwa Land in Delta state, Nigeria [17]. The study identified 2-4 layers of aquifer with the third and fourth geoelectric layers of the earth. These layers consist of medium to coarse-grained sand formations, which have resistivity values ranging from 300 Ohms to 1,500 Ohms and an average thickness of 35 m. The study concluded that aquifers within the study area are mostly unconfined and are very prone to overhead contamination. However, the study revealed that sustainable water supply could be tapped between the depths of 30 m and 45 m below the ground surface within the study area. Vertical Electrical Sounding using Schlumberger configuration was adopted to delineate shallow aquifers in the coastal plain sands of Okitipupa area in South-western Nigeria [18]. The study delineated two distinct aquifers within the study area. The first aquifer is the shallow (which in most cases is unconfined) that occur between the depths of 5.8 m and 61.5 m below the ground surface. The second aquifer unit is the intermediate (which is mostly confined) that occur between the depths of 32.1 m and 127.5 m below the ground surface. The study showed that the aquifers are made up of medium-grained saturated sand with an average resistivity of 296.8 Ohms. The study concluded that the occurrence of aquitards above the aquifers of ajagba, Aiyesan, Agbetu, Ilutitun, Igbotako and Erinji make the aquifers less vulnerable to near surface contaminants than in agbabu, Igbisin, Ugbo and Aboto where aquifers are overlain by less resistive materials.

Based on the previous studies reviewed above, one can conclude that the geology and the occurrence of groundwater (hydrogeology) in various parts of Nigeria vary heterogeneously as a result of the differential geological and geomorphological histories of various landforms and the underlying rocks. In this regards, variability does exist in the nature of groundwater occurrence in terms of its quantity and characteristics. In response therefore, this study is carefully designed to assess the sustainability and yield potential of boreholes within the study area. The specific objectives are to examine the relationships among the identified borehole parameters; establish a relationship between the yield of borehole and some target borehole parameters for the study area; examine the implication of the above objectives on groundwater development and management in the Deltaic formation, Niger Delta Nigeria.

Study Area

The Niger Delta has been growing from Paleocene time (65 million years ago), that is, from the time of the separation of South America from the African continent. The Niger Delta is a fan shaped piece of land which lies between Longitudes 5.30°E and 8.30°E and Latitudes 4.15°N and 5.00°N [19] (Figure 1). Niger Delta can be divided into two based on its surface geology and physiography. The Benin formation (which is the older deposition) covers the upland and the northern part of the delta. The Deltaic formation (which is the recent deposition) covers the swampy part of the delta with a dense network of creeks. This is the zone of major oil exploitation activities, characterized by complex environmental condition. This is as a result of its direct contact with Atlantic Ocean, which is a major influencing factor of the basin's environmental condition. The deltaic formation is the focus of this study and all analyses and investigations shall be limited to this sub-region.

Materials and Methods

Borehole parameters (depth, yield, screen length, drawdown) for ten locations within the Eastern part of Deltaic formation were obtained from the Rivers State Ministry of Water Resources in Port Harcourt, Rivers State. These data cover the depths from ground surface to 520 meters below sea level. The selected locations are presented in figure 2.

The Multiple Correlation and Regression Methods were employed to show the relationship among the borehole parameters and predict borehole yield (dependent variable) based on its relationship with depth of hole, screen length and drawdown (predictor variables X_1, X_2, X_3.......X_n). This is defined in equation 1:

$$Y=a + b_1X_1 + b_2X_2 + b_iX_i \pm e$$

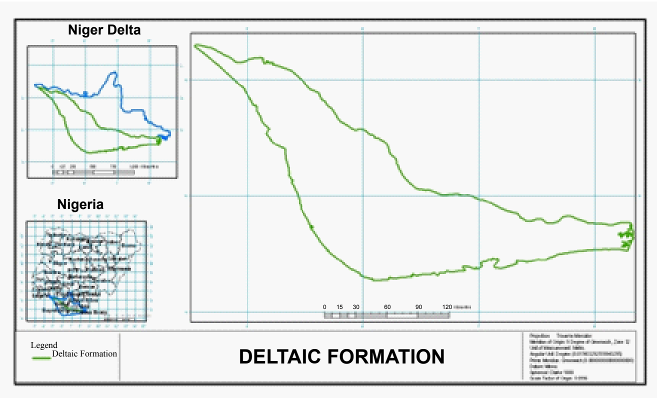

Figure 1: The Map of the Study Area.

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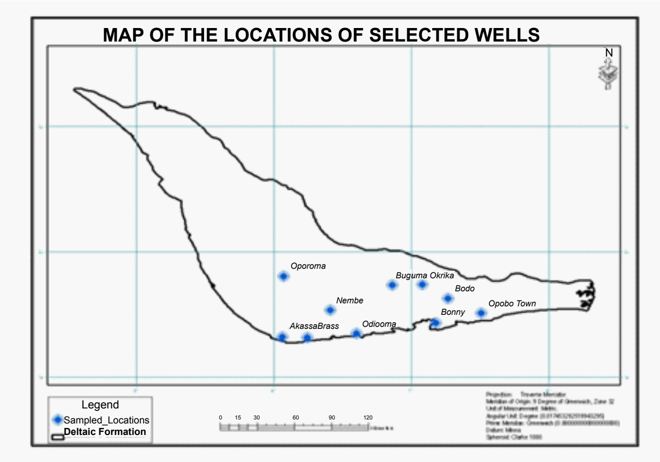

Figure 2: Map of the Locations of Selected Wells.

Where, a=Intercept; b_1.......b_i=Partial Regression Coefficients; e=Error Term.

The Linear Regression Analysis uses the observed value of the Dependent and Independent Variables Y and X1….X_n to estimate the Regression Constant (a) and the Regression Coefficient (b) such that given any value of X_1….X_n, the corresponding value of Y can be computed and vice vasa. The strength of the relationship between X1….X_n and Y (the correlation) can also be determined by calculating the difference between the computed value of the Dependent Variable and the actual observed value called the Standard Error (SE). The Regression Models were computed with the aid of electronic computing using SPSS statistical package.

Results

The spatial characteristics of boreholes are presented in table 1. Analyses show that the mean depth of hole is 218.5 metres, which indicates that most of the reliable freshwater-bearing aquifers are located at great depth within the study area. In response, boreholes in the Deltaic formation are very deep and variable both relatively and absolutely especially as indicated by the results of the standard of deviation and coefficient of variation (SD=166.01 m; CV=53.09 %). This can be explained by the high percentage of unconsolidated materials that make up the basin.

The mean length of screen is very high (13.29 m). This partly explained why more water is yielded into the wells of the sedimentary basin than those of basement complex rock formation. However, the standard deviation recorded is very low (17.48 m), indicating low absolute deviation while the coefficient of variation (131.52%) indicates that the screen length is highly heterogeneous within the basin.

The mean drawdown recorded (5.45 m) is very low and may be attributed to the capacity of pumping machines and or the high thickness of the aquifers because of the nature of geological sequence of the basin. As a result of this, moderate energy is required to pump water from well in the study area. The standard deviation (7.20 m) and the coefficient of variation (132.11%) indicate that drawdown is generally heterogeneous and this can simply be explained in the context of the variability existing in the detail geology of the aquifers of the formation.

The mean yield calculated is very high (30,056 lit/m). The high value is expected in the view of high water table, high permeability and high hydraulic conductivity of the basin owing to high proportion of unconsolidated materials that predominate the soil layers to a great depth. The standard deviation (44,577.15 lit/m) and the coefficient of variation (148.31 %) show that the yield of well within the basin is highly largely heterogeneous both absolutely and relatively. Hence, there is assurance of yield of abundance of water by well but the question comes in the area of quality and safety of the water.

The correlation matrix of the borehole parameters is presented in table 2. The results of the analyses show that yield is the only parameter that has positive association with all other parameters. In this case, depth of hole, drawdown and length of screen have positive and strong relationship with yield, with correlation values of 0.82, 0.62 and 0.63 respectively. The interpretation of this is that yield of well increases as the parameters increase. This is expected in view of the fact that, the greater the depth, the greater the storage ability of the regoliths since there are more pore spaces to store water.

In addition, the lower the drawdown (which is simply the rate of fall in head of water), the more the depth of well coincides with the aquifer length, the higher the ability of water to get to the well and the higher the yield of well. Also, the length of screen and drawdown has high correlation value (0.99), which is strong. This is expected since the aquifer, which coincides with the length of screen, is the portion that directly controls the drawdown. The facts presented above imply that yield of well is controlled by all the examined borehole parameters. The relationship between borehole parameters and the yield of well is explained by the equation below: Y=0.09326 (Depth) +0.77129 (Drawdown) +2.3997 (Screen Length) + 2.86229.......... (equation 1)

(R^2=90.67%; SE=16,672)

This relationship explains 90.67% of the regression plain, which is quite significant. Hence, it can be emphasized that the depth of hole, drawdown and length of screen are strong variables that can give meaningful explanation of borehole yield in the Deltaic formation. Therefore, the explanation of borehole yield in the study area can best be done by examining the hydrogeological variables.

Discussion

The results of the analyses carried out in this study agree with previous studies that were undertaken on groundwater resources in the Deltaic formation. The study shows that the aquifers of the basin contain adequate volume of water that is sustainable enough to cater for its population as earlier stated by previous studies [20,21]. This is obvious as a very low mean drawdown was recorded for the basin. It was revealed by this study that resistivity values of the aquifers tapped by all the sampled boreholes were 40 ohms and above. The calculated

	Mean	Standard Deviation	Coefficient of Variation
Depth	218.5	116.01	53.09
Screen Length	13.29	17.48	131.52
Drawdown	5.45	7.20	132.11
Yield	30056	44577.15	148.31

Table 1: Spatial Characteristics of boreholes.

	Yield	Depth	Drawdown	Screen Length
Yield	1.000			
Depth	0.820	1.000		
Drawdown	0.637	0.232	1.000	
Screen Length	0.639	0.212	0.998	1.000

Table 2: Correlation Matrix of Borehole Parameters.

high mean length of screen indicates that the freshwater-bearing aquifers within the basin are very thick. This assertion has earlier been emphasized by a previous study [20]. On the other hand, this study recorded high mean yield (30,056 lit/m) for wells (boreholes) of the sedimentary basin of the Deltaic formation in contrast to the results obtained by earlier studies in the Crystalline Basement Complex Area of Northern Nigeria where average borehole yield is said to be as low as 45.77 lit/m [15,16]. The results of this study affirmed that depth of hole; screen length and drawdown are strong variables that can give meaningful explanation of borehole yield in the Deltaic formation as opposed to the situation in Basement Complex Area. Where it was earlier discovered that yield and specific capacity of aquifers are not related to screen length and saturated thickness at the borehole points [14,15]. This study revealed that producing and reliable aquifers are deeply located within the study area. This submission differs from the findings in the Benin formation of Niger Delta (Ndokwa Land in Delta State) where aquifers are mostly shallow unconfined (30 m-45 m) and in the coastal area of South-western Nigeria (Okitipupa Area in Ondo State) where aquifers are mostly shallow unconfined (5.8 m-61.5 m) and intermediate confined (32.1 m-127.5 m) [18,22].

The quantitative approach and methodology employed in this study have increased the understanding of the challenges of groundwater resources development and management in the study area. For instance, this study reveals that depth of hole, drawdown and screen length are strong variables that can give meaningful explanation of borehole yield within the study area. Finally, this study established a relationship (model) between the yield of well and the predictor variables that could be used to predict the yield of well in any part of the study area and any region that has similar hydrogeology.

Implication of the Study

The nature of weak correlation between depth of hole and resistivity is an indication that the aquifer resistivity does not substantially increase with depth of hole. This shows that the level of salinity decreases with depth of well and this actually tallies with major hydrogeological laws. All the wells in the study area of great depths, suggesting that they may be expensive in terms of cost of construction and this is because of the problem of salt water intrusion, which prompted that deep aquifers should be located.

A comparative analysis of the pattern of relationship between borehole yields and other parameters shows that some differences exist in the nature of the influence of these variables from one location to the other in the Deltaic formation. The value of the coefficient of determination is very high. In this case, explanation of the yield of borehole in the study area can best be done by examining the hydrogeological variables.

Finally, borehole yield was observed to increase with increasing depth, level of drawdown and length of screen while drawdown also increases as length of screen increases. Although, in the case of yield and depth of hole, this position will only hold for certain depth, after a while, the position seizes to operate. However, all the other positions are acceptable.

Conclusion

This study adopted quantitative approach and methodology to examine the influence of hydrogeological characteristics on the yield of boreholes in the Deltaic formation, Niger Delta Nigeria. The study shows that the basin contains adequate water to sustain its population. It has also been revealed that producing aquifers within the basin are very deep, thick and highly porous. Finally, the study has also confirmed that depth of hole, drawdown and screen length influence the yield of boreholes and thus, they are strong enough to explain and determine the yield of boreholes within the study area.

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