EVALUATION OF AQUIFER HYDRAULIC PARAMETERS IN SITE 3, DELTA STATE UNIVERSITY(DELSU), ABRAKA, WESTERN NIGER DELTA, NIGERIA, USING PUMPING TEST AND WELL LOGGING METHODS

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Abstract

Delta state university (DELSU), Abraka has witnessed increase in both human as well as infrastructural development recently, due to the return of all her students from Anwai campus, Asaba, which became a full-fledged Dennis Osadebey university, Asaba. This development has impacted on groundwater availability in the university. This study seeks to evaluate the hydraulic parameters of the aquifer in Site 3, Delta State University (DELSU), Abraka, Western Niger Delta, Nigeria. The method applied, was a combination of pumping test and well logging. Two boreholes, at 40 m distance apart, were drilled to evaluate the aquifer hydraulic parameters in the area. The well logs were analyzed while the pumping test data were evaluated using the Cooper – Jacob's analytic method. The result of the lithological study revealed a subsurface formation that comprised lateritic topsoil/sand, fine clayey sand, medium sand, medium to coarse sand, and coarse/very coarse sand. The results obtained from the computation of the aquifer hydraulic parameters revealed that that the aquifer's transmissivity, storage coefficient (storativity), specific capacity and hydraulic conductivity are 281 m^2/day, 0.00014, 1.07 m^2/min, 9.63 m/day and 2.41 m^2/day, 0.000012, 0.91m^2/min 8.25 m/day for wells 1 and 2 respectively. The analysis of the well logs shows that the aquifer would yield quality water for the community. These results indicate that the aquifer is confined and is capable of yielding a significant and adequate quantity of groundwater, as well as the best source of groundwater for the university community, for domestic and other purposes.

Keywords: Groundwater, Pumping test, Well logging, Storage coefficient, Aquifer, Transmissivity

Introduction

Insight into the aquifer hydraulic parameter evaluation of any region is crucial for groundwater assessment as well as management. Knowledge of aquifer hydraulic parameters (transmissivity hydraulic conductivity, specific capacity and storativity) will assist in the effective utilization of groundwater resources (Anomohanran 2015, Anomohanran et al., 2020; Valigi *et al*., 2021). Groundwater providers and researchers have used different geophysical techniques (electrical resistivity technique, geophysical well logging as well as pumping test) to determine aquifer parameters. However, these parameters are effectively evaluated using pumping test technique. Valigi *et al*. (2021) reported that "pumping test remains the most accurate tool for the evaluation of aquifer hydraulic parameters, even if the development of empirical equation is vital for areas with scarce data". However, evaluation of aquifer parameters, using pumping test procedure can be time consuming and costly (Richard *et al*., 2016) when compared with electrical resistivity method.

Several researchers and geoscientists (Akaolisa, 2006; Egbai and Iserhien – Emekeme, 2015; Chinyem, 2017a; Chinyem, 2017b; Khodapanah *et al*., 2019; Seli *et al*., 2021, etc.), have used electrical resistivity technique to determine aquifer parameters because of its cost effectiveness as well as the relatively simple field operations when compared with other techniques.

Recent works by geoscientists (Anomohanran *et al.,* 2020; Iserhien –Emekeme et al., 2020; Valiga *et al*, 2021; Ofomola et al., 2022) have shown that pumping test and well logging methods are most accurate tools in determining aquifer parameters in any given area. Anomohanran (2015) asserted that "geophysical logging technique is the most often used technique in aquifer hydraulic parameters as well as groundwater quality evaluation in a given area". The electrical resistivity log gives insight into the borehole lithology as well as the subsurface formation resistivity while the spontaneous potential (SP) log can ascertain the water quality. The field techniques have been found to be non-destructive and results obtained are usually reliable (Kambie *et al*., 2012; Anomohanran, 2015).

The survey site is at Site 3, DELSU, Abraka, which is located in Western Niger Delta Basin (Figures 1 and 2). The university town hosts many staff and students (undergraduates and postgraduates) as well as large number of commercial business owners and farmers, who depend on surface water and groundwater from shallow wells for their daily water needs. The population of people in the university community is growing rapidly, following the return of all her students from one of its campuses at Asaba, as a result of the creation of Dennis Osadebey University, Asaba, which now stands on its own as a full-fledged university campus. Consequently, this development has impacted on groundwater availability as water demand has increased tremendously more than it used to be fifteen years ago. Unfortunately, there had not been any provision of functional public water supply by the State Water Board in the area, as the only attempt to supply the people water was unsuccessful as the project was uncompleted as a result of lack of political will. Consequently, the people have resulted to drilling personal boreholes while others depend on surface water (from nearby river), which is usually contaminated. Although Anomohanran (2015) had investigated the aquifer properties of Abraka town using integrated approaches (geoelectric method, well logging and pumping test), but published work on the aquifer hydraulic parameters of site 3, of the university community is lacking. Currently, the university is in collaboration with the Nigerian Erosion Watershed Management Project (NEWMAP) and Nigerian Hydrogeological Services Agency (NHSA) for the installation of an underground water borehole monitoring station at site 3, DELSU Abraka. With such a goal in mind, the need to assess the aquifer's hydraulic parameters becomes crucial. This present contribution therefore will help provide information on the aquifer's hydraulic parameters in the area, using pumping test and well logging techniques, with a view to providing the people sufficient quantity of water for domestic and other purposes.

Materials and Methods

Location and Geology of the Study Area

The study was carried out in site 3, DELSU, Abraka, located in the Western part of Niger Delta, Nigeria. It is located between longitude $6^0$10.1' and 6^0 12.3'E and Latitude 5^0 77.8' and 5^0 79.9'N (figures 1 and 2). Various authors (Short and Stauble, 1967; Burke, 1972; Avbovbo, 1978; Doust and Omatosola, 1990), have discussed the geology of the Niger Delta. Short and Stauble(1967) reported that "the geology of the Niger Delta consists of three Formations namely the Akata, Agbada and Benin Formations respectively, that are distinguished on the basis of sand/shale composition". The Benin Formation (Miocene to Recent), consists of alluvium/clay/shale and sand deposits up to 2000 m thick (Short and Stauble, 1967). The Agbada Formation (Oligocene to Recent) underlies the Benin Formation. This Formation consists of alternation of sand/shales, with an estimated thickness of 3700 m. The next lithostratigraphic unit is the Akata Formation (Paleocene to Recent). This Formation underlies the Agbada Formation and comprises principally, thick shale sequences, interbedded with minor sand and clay sequences. Doust and Omatsola (1990) asserted that "the Akata Formation is the source rock for the prolific Niger Delta area".

The project site is underlain by the Benin Formation (water bearing Formation in the Niger Delta) and it is exploited for groundwater resources anywhere it outcrops.

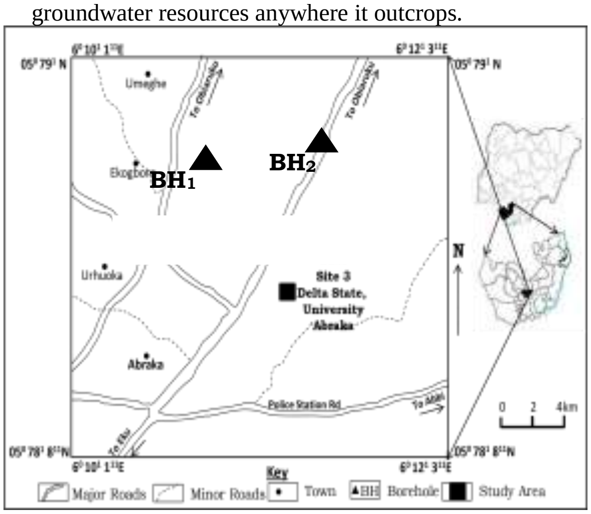

Figure 1: Accessibility map of the study area

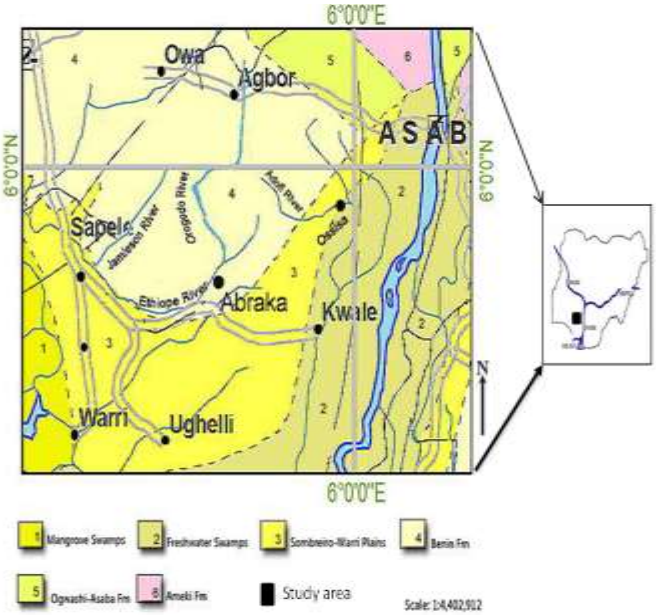

Figure 2: Geological map of part of Western Niger Delta, showing the study area (after Akpoborie and Efobo, 2014)

Field Procedure

Two boreholes, at 40 m distance apart, were drilled to evaluate the aquifer hydraulic parameters in the area. One of the wells, referred to as test well, while the other designated as observation well. Pumping was done from the test well while measurement of water levels at intervals was done from the observation well. Both boreholes consist of well casing pipe, bottom sump, well screen surrounded by batholith gravel pack, and at the bottom a borehole seal to protect the submersible pump in the test well from damage by sand particles. A 0.75 kw capacity submersible pump, powered by a 2.5 kw generator was installed in the well. Pumping using an open-end discharge pipe was carried out. A flow meter, inserted into the test well, was used to measure the flow rate (discharge) of the pumped water. Pumping was done at a uniform discharge rate of 0.064 m^3/m in the test well. The water level in the observation well was measured at specified time intervals using an electronic probe meter (water level indicator). This was used to evaluate the drawdown (difference between the water level before pumping commenced and the level after pumping has commenced). The draw down data was then plotted against the time of pumping on a semi-logarithm graph paper. The graph paper was subsequently employed to determine the draw down per log cycle of time (Δs) on the vertical axis and the time intercept on the horizontal axis of the graph sheet. The Cooper-Jacobs formula, was later applied to evaluate the aquifer parameters, as follows:

Transmissivity, $T = \frac{2.3Q}{4\pi\Delta s}$ - (1)

Storage Coefficient (Storativity), $S = \frac{2.3T_{to}}{r^2}$ (2)

Specific Capacity, $Sc = \frac{Q}{\Delta s}$ (3)

Hydraulic Conductivity, $K = \frac{T}{b}$ (4)

Where

Q is the discharge (m^3/s), Δs is the drawdown per log cycle of time (slope), r is the radial distance from the test well, t_o is the time since pumping began, b is the aquifer thickness.

Results and Discussion

Evaluation of lithology

The rock samples/cutting obtained from the drilled borehole were collected and analysed at about 3 m intervals. The lithologic log obtained from the borehole drilling as well as the downhole geophysical logs are presented in figure 3. The figure shows that the first layer consists of brownish, unconsolidated, lateritic layer (topsoil) of about 3 m thick. The first layer is underlain by a reddish lateritic sand layer (2.7-6.4 m). The resistivity log as well as the Spontaneous Potential (SP) log from the lower portion of the formation give values of approximately 0 Ωm and -0.4 mV respectively. The third layer is composed of reddish brown, fine clayey sand of about 2.7m thick (6.4-9.1 m). There was no significant difference in the values of both resistivity log and the SP log. The fourth layer is composed of brownish fine to medium sand. A slight increase was noted in the resistivity as well as the SP log within this formation. The fifth layer is about 4.1 m thick, stretching from a depth of 12.2 m-16.3 m. The lithology consists of yellowish, medium to coarse sand. The resistivity value of the fifth layer increases slightly more than the preceding layer while the SP log value becomes more positive. Underlying this formation is the sixth layer, composed of whitish, medium to coarse sand of about 3.3 m thick (16.3-19.6m). The resistivity log continues to show an increase in value while the SP log shows a slight increase. The depth range between 19.6 and 48.8 m represent the aquiferons region (layer) of about 29.2 m thick. The lithologic log shows that this layer is composed of whitish coarse/very coarse sand. The resistivity log shows an increase of 400 Ωm while the SP log value shows a more stable value, indicating that the fluid contained in this formation is of better quality than the preceding layers. The borehole logging stopped at 48.8 m depth. So, considering the trend in the downhole geophysical logs (resistivity and SP), it can be inferred that this formation would yield a significant quantity of groundwater as well as the best source of groundwater for domestic purpose and other purposes.

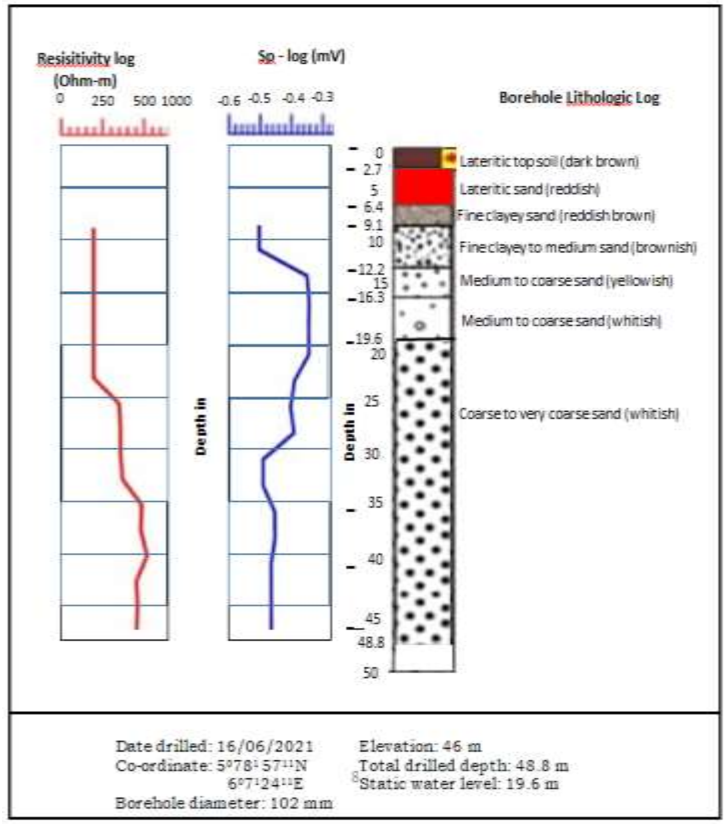

Figure 3: Cross section of the lithologic log from the borehole plotted against a downhole geophysical logs in the area.

Pumping Test Analysis

The borehole pumping test result of the drilled wells is presented in figure 4. The plot gives a graphical representation of the borehole data (Table 1) and this shows the relationship between the water level and the time of pumping. Figures 5a-b give the plot of drawdown computed against the time since the pumping began. The values obtained from these computations were imputed into the Cooper-Jacob's equation and the transmissivity (T), storativity (S), Specific Capacity (Sc) and hydraulic conductivity (K) were obtained as follows:

For well 1,

Transmissivity (T) = $\frac{2.3Q}{4\pi \, x \, \Delta s} = \frac{2.3 \, x \, 0.064}{4 \, x \, 3.14 \, x \, 0.06}$

= 0.195329 m^2/min = 281 m^2/day.

Storage Coefficient (Storativity) (S) = $\frac{2.3 \, x \, T \, to}{r^2} = \frac{2.3 \, x \, 0.195329 \, x \, 0.5}{(40)^2}$

= 0.00014

Specific Capacity, Sc = $\frac{Q}{\Delta s} = \frac{0.064}{0.06} = 1.07$ m^2/min

Hydraulic Capacity, K,

K = $\frac{T}{b} = \frac{0.195329}{29.2} = 0.006689$ =9.63 m/day

For well 2,

Transmissivity (T) = $\frac{2.3Q}{4\pi\ x\ \Delta s} = \frac{2.3\ x\ 0.064}{4\ x\ 3.14\ x\ 0.07}$ = 0.167318 m^2/min

= 241 m^2/day.

Storage Coefficient (Storativity) (S) = $\frac{2.3\ x\ T\ to}{r^2}$

$= \frac{2.3\ x\ 0.167318\ x\ 0.5}{(40)^2}$ = 0.00012

Specific Capacity, Sc = $\frac{Q}{\Delta s} = \frac{0.064}{0.07}$ = 0.91 m^2/min

Hydraulic Capacity, K,

K = $\frac{T}{b} = \frac{0.167318}{29.2} = 0.00573\ m/\min = 8.25\ m/day$

Table 1: Pumping test data obtained from the borehole drilled at Site 3, DELSU, Abraka.

Time (minutes)	Water Level (m)	Draw Down (m)
0.5	19.60	0.00
0.9	19.62	0.02
1.5	19.67	0.04
1.8	19.72	0.05
2.4	19.77	0.06
4	19.82	0.08
5	19.87	0.09
7	19.89	0.10
9	19.90	0.11
10	19.91	0.12
10	19.92	0.13
12	19.92	0.13
15	19.92	0.13
20	19.92	0.13
25	19.92	0.13
30	19.92	0.13
40	19.92	0.13
60	19.92	0.13
120	19.92	0.13
150	19.92	0.13
180	19.92	0.13

Table 2: Aquifer hydraulic parameters obtained from the drilled well.

Wells	Transmissivity (m^2/day)	Storage coefficient (Storativity)	Specific capacity(m^2/min)	Hydraulic conductivity (m/day)
Well 1	281	0.00014	1.07	9.63
Well 2	241	0.00012	0.91	8.25

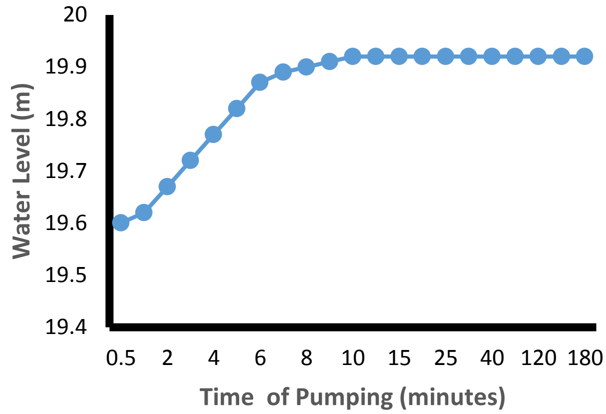

Figure 4: Graph of water level against time of pumping

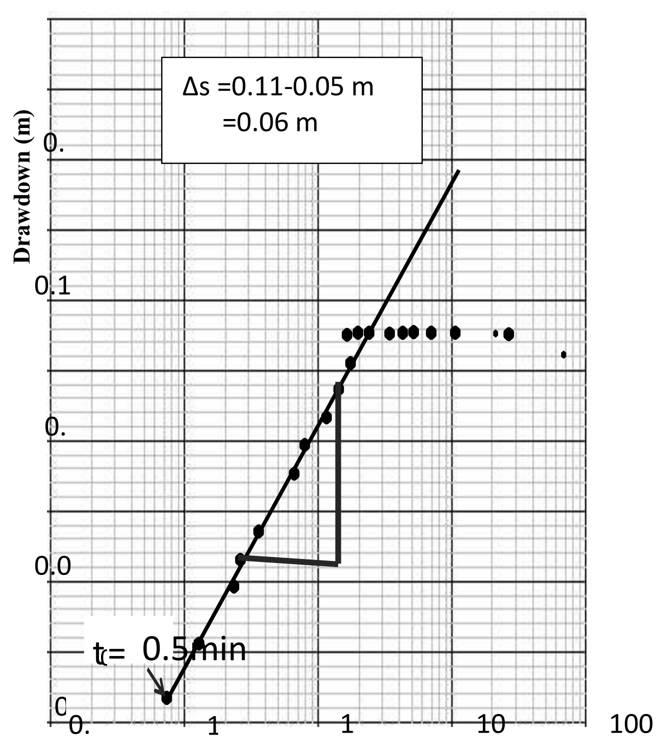

Figure 5a: Plot of drawdown against time of pumping for well 1

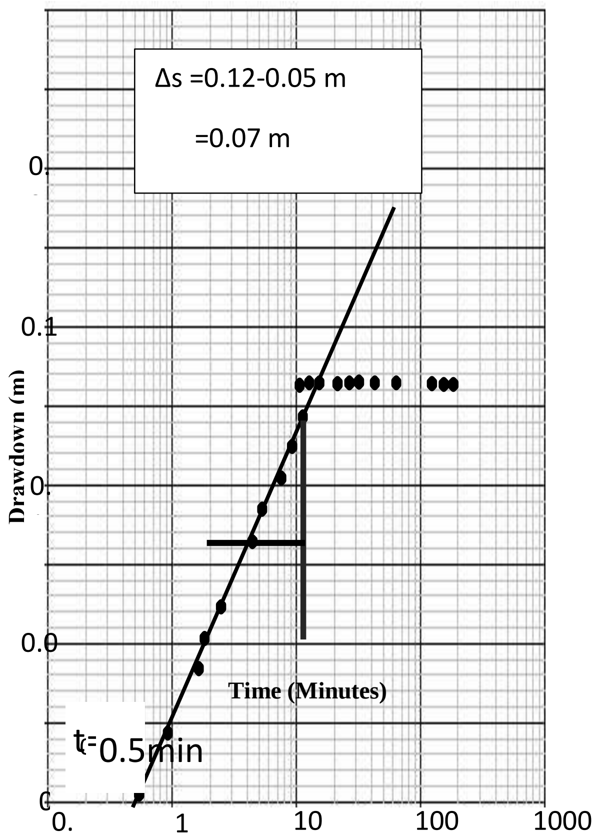

Figure 5b: Plot of drawdown against time of pumping for well 2

The results obtained from the computation, give the transmissivity, storage coefficient (storativity), specific capacity and hydraulic conductivity as 281 m^2/ day, 0.00014, 1.07 m^2/min, 9.63 m/day and 241 m^2/day 0.00012, 0.91 m^2/min, 8.25 m/day for well 1 and well 2 respectively. The transmissivity value obtained shows an aquifer with a high flow rate which is capable of supplying sufficient quantity of water to the university community, for both domestic and research needs. According to Agbasi and Etuk (2016), transmissivity range of 100- 1000 m^2/ day is high and represent groundwater supply potential of regional importance. Hence, the transmissivity value obtained in this study is in agreement with the study carried out by Anomohanran (2014b) and Anomoharan (2015) respectively, within the Delta central district, where he obtained transmissivity values that ranged between 0.068 – 0.070 m^2/ min (97,92 – 100.8 m/ day) and 0.0713 m^2/ min (102.7 m/ day). The storativity (storage coefficient) of an aquifer refers to the volume of water an aquifer discharges or takes into its storage, per unit surface area per unit change in the hydraulic head (Todd, 2004; Anomoharan, 2015). The storativity is simply the amount of water that is given up per unit horizontal area of an aquifer and per unit change fall in the water table. Fetter (2007) asserted that "the storativity for a confined aquifer ranges from 0.00005 and 0.005". The result from this study gives the value of 0.00014 and 0.00012 for the two wells respectively, which confirms that the aquifer is confined, thus making it more reliable source for domestic water need. This claim is strongly supported by the findings by Rajasekhar et al (2014) that obtained a transmissivity of a confined aquifer as 0.065 m/ min (93.6 m/day). The values of hydraulic conductivity of 9.63 m/ day and 8.25 for the wells show that the geologic material (aquifer) is predominantly sand. This agrees with the work of Bouwers (1978), who reported a standard for a geologic material having a hydraulic conductivity range of 1-100 m/ day as sand (fine to course).

The specific capacity of the drilled well, which is a measure of how productive a well is, was determined and the values of 1.07 m^2/ min and 0.91 m/min for the two wells respectively. It is the rate at which water is pumped out of the well divided by the fall in water level. The value of the specific capacity obtained implies that the well is capable of providing sufficient water for staff and students residing within and around the university community. The significance of the value of specific capacity is that it helps in monitoring the efficiency of the well over time as well as other wells within the area.

The values of the parameters (transmissivity, storativity, specific capacity and hydraulic conductivity) obtained from the pumping test imply that the aquifer can withstand heavy pumping as well as provide good yield. Although, hydraulic parameters of the aquifer within site 3, DELSU, Abraka have been evaluated, it is recommended that a geochemical investigation be carried out with a view to ascertaining the groundwater quality as well as electrical resistivity sounding (vertical electrical sounding) so as to determine some aquifer electrical properties such as resistivity within the study area.

Conclusions

This study has helped to evaluate the aquifer hydraulic parameters within site 3, DELSU, Abraka, through pumping test technique using Cooper- Jacob evaluation principle. The results obtained from the computation of aquifer pumping test revealed that the transmissivity, storage coefficient, specific capacity and hydraulic conductivity are 281 m^2/ day, 0.00014, 1.07, 9.63 m^2/min and 241m^2/day, 0.00012, 0.91m^2/min, 8.25m/day for wells 1 and 2 respectively. The results of this investigation show that the aquifer is confined, prolific and will be able to supply significant quantity of water to the university community. The finding of this study will act as basis for groundwater monitoring as well as performance evaluation for other wells within the study area.

Declaration of competing interest.

The authors declare that they have no conflict of interest and that the study did not receive any funding from external source.

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