Quest Journals
Journal of Research in Environmental and Earth Sciences
Volume 10 ~ Issue 4 (2024) pp: 28-36
ISSN(Online) :2348-2532
www.questjournals.org

Research Paper

Hydrogeological and Geophysical Investigation For Groundwater Exploration

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Abstract: *Hydrogeological and geophysical investigation was conducted in a proposed project area in Ozubulu for the purpose of groundwater exploration and development. The geophysical studies involved two Schlumberger vertical electrical soundings (VES) using the ABEM Terrameter. The hydrogeological evaluation comprise well boring, permeameter test, and pumping test. The geoelctric results for the VES sites unveils a variation in thickness and resistivity of the probed surbsurface layers. Analysis of the interpreted geoelectric sections show four layers composed of clayey sand, sandy clay, dry sand and wet/saturated sand layers. The resistivity of the wet/saturated sand layer was between 700 ohm-m-1000 ohm-m at depths of 59.5m and 120m for VES 1 and VES 2 locations respectively. Consequently, a depth of 150 to 200m was reccommended for the drilling of an exploration well. Lithological examination based on drill cuttings from the borehole reveal that the study site consist of a multi-aquiferous system. In the bid to evaluate the aquifer properties, six sand samples were obtained at depth ranges of 15.8-20.6m, 20.6-29.99m, 34.8-39.3m, 49.2-63.4m, 77.5-82.1m and 82.1-184.1m. The samples were analysed in the laboratory for permeability using the falling head permeameter test. The permeability of the aquifers ranged between 4.915x 10^{-2} - 6.75x 10^{-1} cm/Sec, while the transmissivity ranged between 25.44 - 511.12 m^2/day. Transmisivity evaluated from pumping test was 401.2 m^2/day and correlates with results from the permeameter test as both values falls within the same class of transmissivity magnitude (II) which is considered to be highly prolific.*

***R**eceived 05 Apr., 2024; **R**evised 14 Apr., 2024; **A**ccepted 16 Apr., 2024* *© The author(s) 2024.*
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I. INTRODUCTION

Water is a crucial driver of economic growth, but it is also a significant source of conflict globally (UNEP, 2010). Despite the images of our planet showing vast quantities of water, most of it is salty and unsuitable for human consumption (UN, 2015). Freshwater, which is fit for consumption, represents only 2.5% of the total water budget on Earth. Of this percentage, over three-quarters are locked up in ice caps and glaciers. Out of the remaining 25%, a significant proportion (23.5%) is groundwater (Fetter & Kreamer, 2021). Because it is often believed to be of greater quality, less prone to pollution, less treated, and accessible even in the absence of surface sources, groundwater is frequently chosen as a source of drinking water.

An essential part of developing and assessing groundwater resources is determining the hydraulic characteristics of aquifers. An aquifer's natural water flow and how it reacts to fluid extraction are largely dependent on its hydraulic characteristics (Batayneh, 2009). They are also useful parameters for predicting contaminant transport and groundwater protection (Shevnin et al, 2006). In groundwater hydrology, there are several techniques available for evaluating and estimating aquifer characteristics. The most commonly used technique is pumping tests, which involve analyzing and interpreting pumping test data from existing or newly drilled wells. Pumping tests have been very successful in estimating the transmissivity of aquifers. Mozac et al. (1985) used a single well pumping test to analyze transmissivity in an unconfined aquifer. Offodile (2002) recorded specific capacities in liters per hour per meter for some boreholes in the Niger Delta from pump tests.

An alternative way to estimate aquifer characteristics is the surface geoelectrical method, especially vertical electrical sounding (VES). The VES survey technique has been used effectively to study groundwater conditions and assess the subsurface geoelectric layers. This survey technique can also determine the thickness and depth of water-bearing formations (Oseji et al., 2006). Pre-drilling geophysical surveys are routinely conducted to determine the existence of subsurface aquiferous zones. The electrical properties of subsurface materials provide a reliable platform for determining sites for productive borehole construction and installation, which can assist in reducing costs (Oborie and Nwankwoala, 2012).

Geological materials' resistivity may vary greatly based on a number of variables, including their porosity, water content, and salt concentration in groundwater. This variance may be used to measure groundwater quality and quantify water content. According to its ionic content and the number of dissolved particles, water's resistivity may vary from 0.2 to over 100 Ωm (Palacky, 1987), while natural water and sediments devoid of clay have resistivity ranging from 1 to 120 Ωm (Zohdy, 1989). It is feasible to connect hydraulic and electrical characteristics with pore space structure and heterogeneity. Effective estimation of aquifer characteristics and potentials may be achieved by combining geoelectrical parameters retrieved from surface resistivity measurements with aquifer parameters estimated from boreholes (Sikandar et al, 2010).

II. LOCATION, PHYSIOGRAPHY AND GEOLOGY OF THE STUDY AREA

The study area is situated at Ozubulu, which serves as the administrative center of the Ekwusigo Local Government Area in Anambra State, Nigeria. It lies between latitude 5^0 58′ 20.0" North and longitude 6^0 49′ 73.3" East. The research region has two distinct seasons: the rainy season (April–September) and the dry season (October–March), both of which are associated with the tropical wet climatic zone. According to Ekenta et al. (2015), the greatest monthly rainfall occurs during the peaks and ranges from 270 to 360 mm. The mean annual rainfall is around 2000 mm. The region's mean temperature ranges from 27 to 38 ºC, with a high value of 35 ºC often recorded between January and April Odumodu and Ekenta (2012).

Three drainage systems are identified in the area. They includemthe Niger, Orashi, and Njaba Rivers. Amorka, Okija, Ozubulu, Azia, and Ihiala towns are drained by the Orashi River. The Njaba River empties Uli. The Atlantic Ocean is the destination of all the rivers listed above. Shortly before it meets the Atlantic Ocean, Njaba River joins the Orashi River to the south of Oguta. The Niger River empties into the Atlantic Ocean straight southward.

Stratigraphically, the study area falls within the Bende-Ameki Formation. The lithology comprise fine to coarse sandstone with thin shaley limestone and calcerous shale intercalations at the base. This unit is overlain by loose cross-bedded white or yellow sandstone with bands of fine-grained sandstone and sandy clay. The Ogwashi-Asaba Formation lies on top of the Ameki Formation uncomformably. Thin layers of lignite are present to indicate the interface between these two strata. The Ogwashi-Asaba Formation is typified by a diverse range of lithologies, including lignites, clays, sands, sandstones, shale, and grits (Kogbe 1976). The sandstone units of the Ogwashi-Asaba Formation are typically yellowish, white, reddish to reddish brown in color, while the brownish to black lignite seams range in thickness from a few millimeters to a maximum of around 6 m

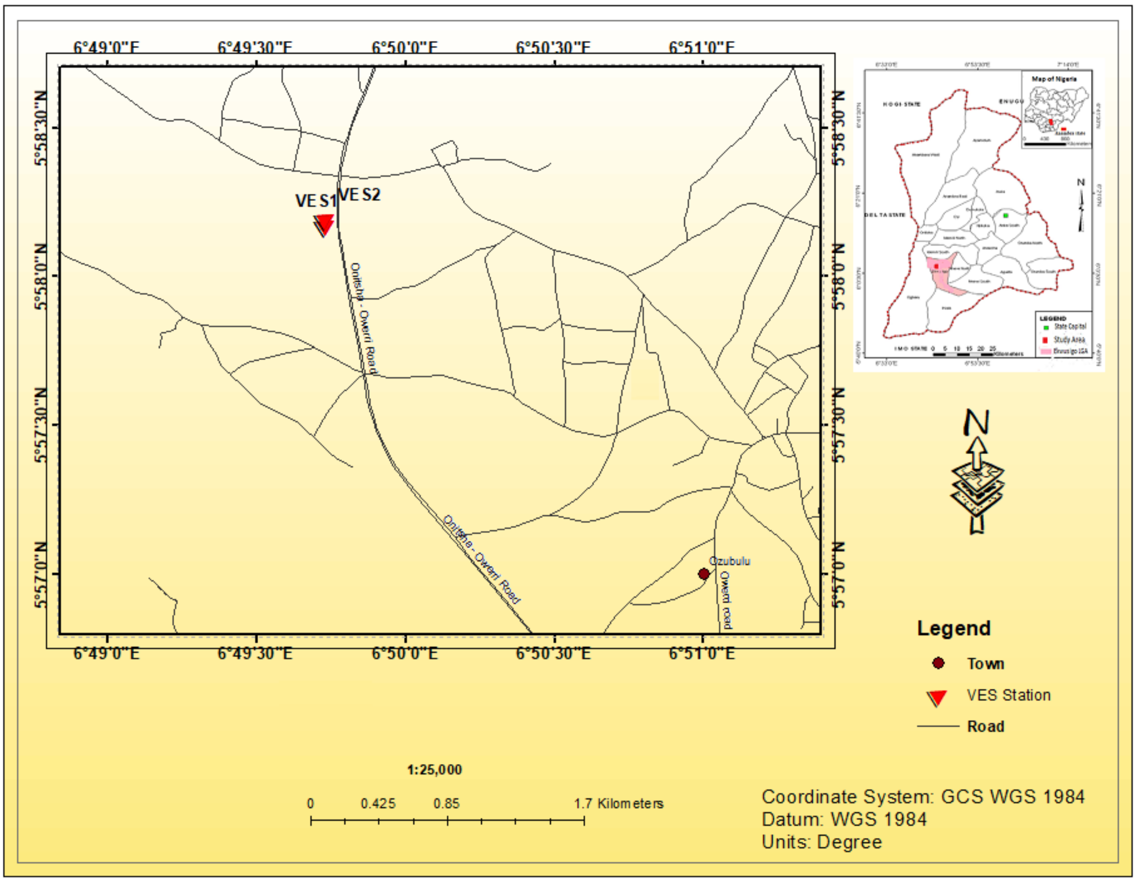

Figure 1: Location of study

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III. MATERIALS AND METHOD

3.I Geophysical Method

Here, electrical resistivity soundings are used to study variations in electrical conductivity. A maximum current electrode spacing of AB/2 of 400m was used for two Schlumberger vertical electrical soundings (VES). Direct current (DC) resistivity measurements were performed using a digital averaging instrument (ABEM SAS 1000 Terrameter). The device measures and displays the subsurface resistance of the area under investigation. It runs on a 12-volt direct current battery. Four stakes made of stainless steel served as electrodes.

In both soundings, the Schlumberger electrode arrangement was used. Each pair of current and potential electrodes in the Schlumberger arrangement are positioned symmetrically and collinearly with regard to the center (Kearey and Brooks, 2001). Less than 1/5 of the current electrode spacing is the potential electrode separation in this array. Only when the signal is too weak to detect is the distance between the potential electrodes raised.

The apparent resistivity is evaluated using:

$$\rho a = KR \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

here R is the measured resistance and K is the geometric factor. The geometric factor for the Schlumberger configuration is given by:

$$K = \pi \frac{\{½[AB]^2 - [½MN]^2\}}{MN} \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Therefore

$$\rho a = \pi \frac{\{½[AB]^2 - [½MN]^2\}}{MN} R \quad \ldots\ldots\ldots\ldots\ldots (3)$$

In this case, the half potential electrode separation is MN/2 and the half current electrode separation is AB/2. On a double logarithmic paper, the apparent resistivity was plotted vs half current electrode spacing. Later on, these early interpretations and the first approximation of the number of geoelectric layers served as a basis for quick computer-assisted interpretations.

Apparent resistivity is then plotted as a function of the log of some measure of electrode separation using the IP2WIN software computer programme which automatically calculates and displays the true resistivity and thicknesses of the delineated subsurface units.

3.2. Well Drilling

The direct circulation rotary drilling technique was applied in the drilling of this well. With this technique, drilling was done with a string of instruments that included drill bits, drill collars, and drill pipes of varying lengths. In soft strata, rotary bits are of the ordinary drag bit type, whereas in hard rock, they are of the roller cutter type. The bit rotates between 30 and 300 revolutions per minute.

During the drilling program a lot of hard and soft formation was penetrated which resulted to change of different bits. However, during the process of drilling a serious loss of circulation was encountered at the depth 98ft to 150ft which resulted to loss of drilling fluid. Serious techniques was employed to remedy this by thickening of drilling fluid with mud (bentonite), cement and saw dust so as to invade the formation and block the void. This loss of circulation can be attributed to highly permeable and porous formation within some areas of the site. Driller time log and lithological log was recorded in the course of the different drilling intervals. .

3.3 Methods for Aquifer Evaluation

3.3.1 Falling Head Permeameter

The sample is put in the apparatus and, using a falling head permeameter, water is added to the standpipe until it reaches a certain height, h1, and then the valve is released to allow the water to seep into the sample, causing the water level in the standpipe to drop to h2. The test's start time, test length, and test finish time are all noted. The coefficient of permeability (K), is then obtained by substituting the previously indicated parameters, together with the cross sectional area (A) and sample length (L), in the following formula, which is derived from Darcy's law.

$$K = 2.3\ \mathrm{QL}\log_{10}\frac{h_1 - h_2}{A(t_2 - t_1)} \quad \text{..................(4)}$$

Furthermore, the transmistivity of the aquifer formation can be computed by multiplication of the thickness (H) of the various aquifers penetrated and the coefficient of permeability as stated as KH. Where K is the coefficient of permeability obtain from laboratory analysis and H as aquifer thickness. However, permeability can be also referred as hydraulic conductivity of the aquifers measured in Cm/sec.

3.3.2 Pumping Test

In a pumping test, water is extracted from the well at a predetermined pace, and the water level in the aquifer around the well is then monitored for drop. To ascertain the aquifer's hydraulic properties, the data were examined. The pumping tests of the borehole consist of step down test and recovery test.

For this study, the pumping test was conducted in accordance with the “code of practice for test pumping of water wells” (BS ISO14686:2003). Both pumping and observation was carried out in the same well. The pumping test was carried out to assess the hydraulic behavior of the well and to determine the aquifer hydraulic properties of the well.

These tests where carried with the aid of the following equipment:-

1. Certified dip meter (consist of measuring tape, a probe and red light indicator)
2. Stop clock
3. Certified graduated 25litres plastic bucket.
4. 7.5HP submersible pump

Step down test involves pumping the well in a series of steps, each at different discharge rate. The method employed was the constant rate test using the water level indicator. The dynamic water level was measured in stages in relation to time till final equilibrium level was achieved. The yield at each stage was noted by measuring the time it takes to fill a known volume (25 liters). After these stages of test, the recovery rate was then measured immediately and the same readings were achieved. All measurements were done in the pumping borehole since there was no observation well available.

IV. RESULTS AND DISCUSSION

4.1 Geoelectric Data and Analysis

The data obtained from the fieldwork are shown Tables 1 and 2, while the locations for the vertical electrical soundings are shown in figure 1.

Table 1: Geoelectric Layer Parameters at VES 1 Study Site

Layer	Apparent Resistivity Ωm	Thickness (m)	Depth (m)	Inferred Lithology
1	4500	1.5	1.5	Top sand
2	1700	8.0	9.5	Clayey Sand
3	8000	50.0	59.5	Dry sand
4	700	-	-	Wet sand

Table 2: Geoelectric Layer Parameters at VES 2 Study Site

Layer	Apparent Resistivity Ωm	Thickness (m)	Depth (m)	Inferred Lithology
1	200	1.2	1.2	Top clayey sand
2	150	7.0	8.2	Sandy Clay
3	6500	120.0	128.2	Dry sand
4	1000	-	-	Wet/ Saturated Sand

The computer interpreted geoelectric layers show four layers as picked up by the field instrument. In VES 1, the first layer had apparent resistivity of 4,500 Ωm and a thickness of 1.5 metres while the second layer had apparent resistivity 1700 Ωm and a thickness of 8.0 metres. The third layer had an apparent resistivity of 8000 Ωm and a thickness of 50.0 metres, while the fourth layer had an apparent resistivity of 700 Ωm and an indeterminate thickness. This layer is the water bearing layer.

VES 2 had a maximum of four layers. The first layer had apparent resistivity of 200 Ωm and a thickness of 1.2 metres while the second layer had apparent resistivity 150 Ωm and a thickness of 7.0 metres. The third layer had an apparent resistivity of 6500 Ωm and a thickness of 120.0 metres, while the fourth layer had an apparent resistivity of 1000 Ωm and an indeterminate thickness. This layer is the water bearing layer. Analysis of the VES results was used to determine the reccommended borehole depth of 150 to 200 metres in the study.

4.2. Well Drilling Data

Below is a graph of drill time in hours against rate of penetration in feet per hour (figure 2) and the lithologic log of the soil profile (figure 3)

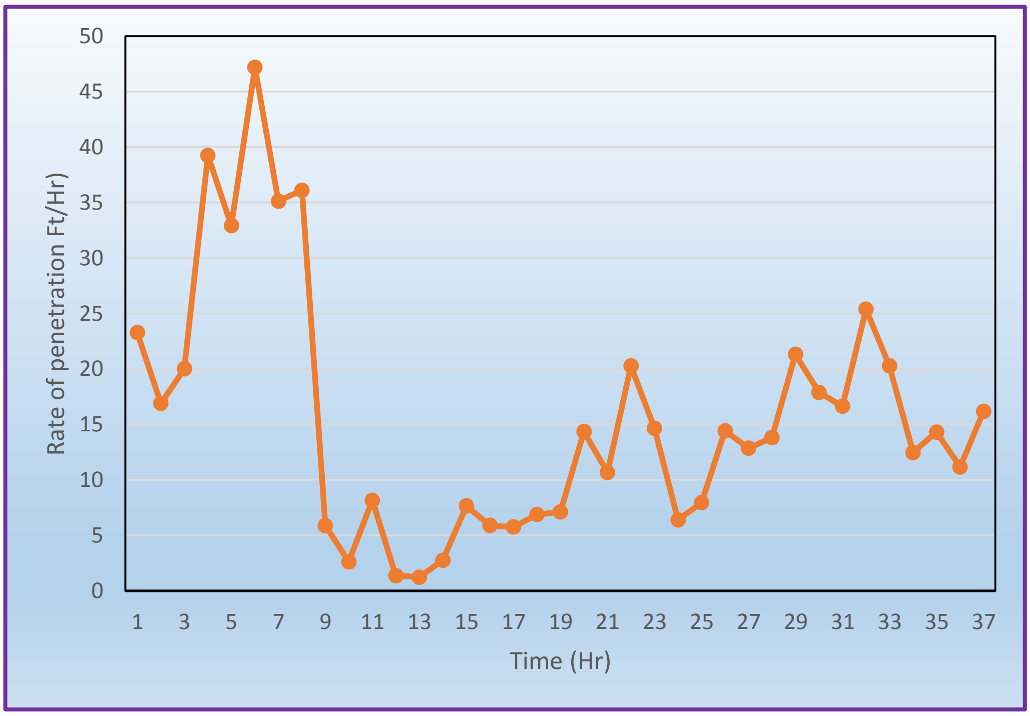

Figure 2: Drill time against rate of penetration in feet per hour

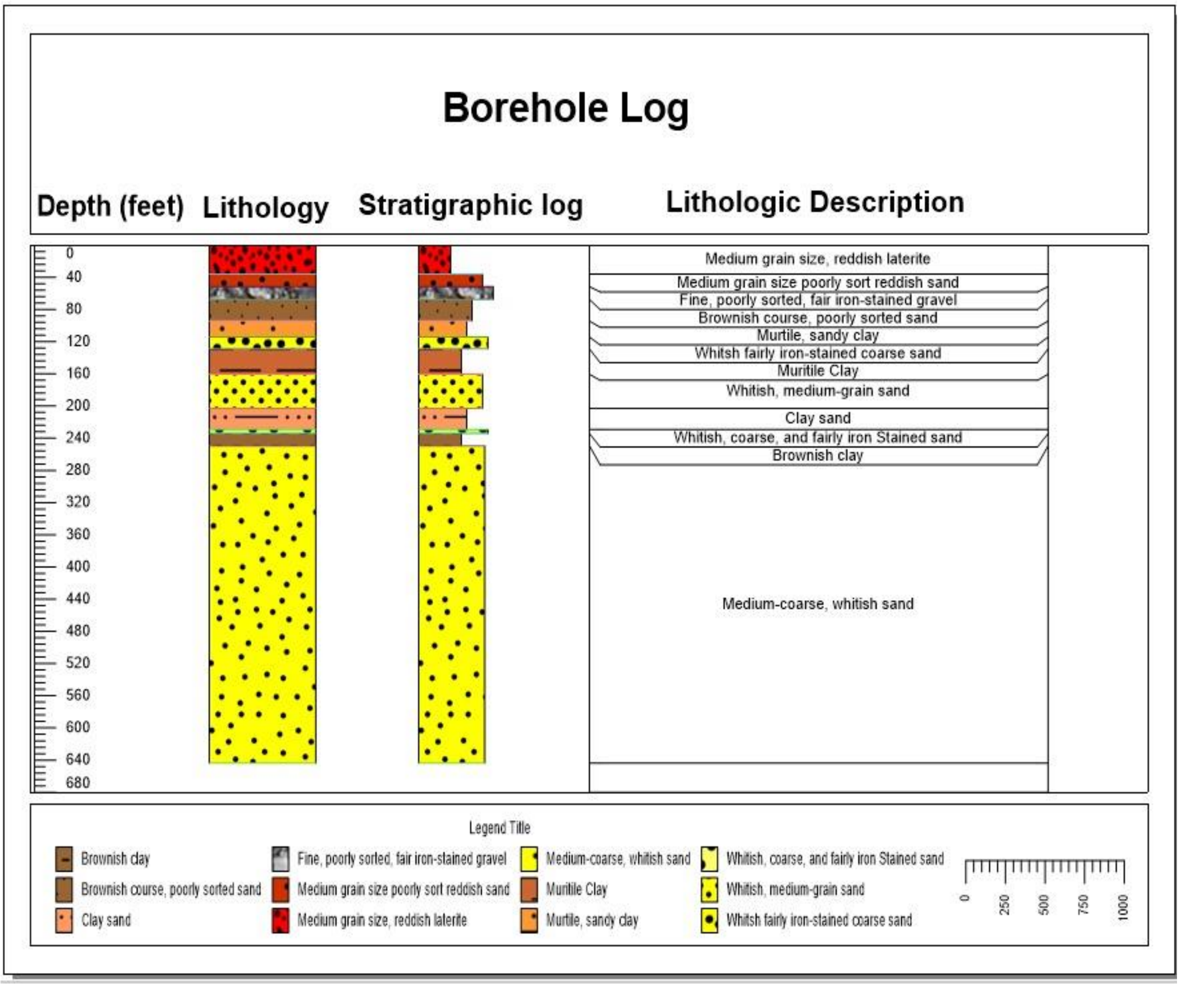

Figure 3: Litho and stratog of the exploration welll

From the lithologic well record of the borehole drilled, the depth of 0-36.2ft (0-11.0m) consist of medium grain-size reddish lateritic sand 36.2-51.8ft (11.0-15.8)m consist of fine poorly sorted reddish sand, 51.8-67.5ft (15.8-20.6m) consist of fairly iron-stained gravel, 67.5-98.4ft (20.6-29.99m) consist of Brownish coarse poorly sorted sand, 98.4-114.2ft (29.99-32.8m) consist of murtile sandy clay, 114.2-129.0ft (34.8-39.3m) consist of whitish fairly iron-stained coarse sand, 129.0-161.5ft (39.3-49.2m)consist of murtile clay 161.5-208.0ft (49.2-63.4m) consist whitish medium grain sand, 208.0-239.0ft (63.4 -72.9m) consist of clay sand, 239.0-254.2ft (72.9-77.5m) consist of whitish coarse fairly iron stained sand, 254.2-269.5ft (77.5 - 82.1m) consist of Brownish clay and the depth range of 269.5-603.9ft (82.1-184.1m) consist of medium coarse sand (depth of termination of the borehole). The borehole at the site consists of multi-aquiferous system of different textural, physical, and hydraulic conductivity characteristics. A prolific confined aquifer of extensive thickness 334.7ft, ranging from 269.5-603.9ft depth, of which 29% was screen for maximum ground water production.

4.3. Aquifer Permeability Evaluation

4.3.1 Falling Head Permmeameter analysis

The borehole drilled at the study site consist of multi-aquiferous system as indicated in the lithology. Six sand samples were obtained at different depth ranges of 51.8-67.5ft (15.8-20.6m), 67.5-98.4ft (20.6-29.99m), 114.2-129.0ft (34.8-39.3m), 161.5-208.0ft (49.2-63.4m), 239.0-254.2ft (77.5 - 82.1m) and 269.5-603.9ft (82.1-184.1m) and analysed in the laboratory for permeability using the falling head permeameter. The computation of the permeability of the aquifers is presented in Table 2 below.

Table 3: Computation of aquifer permeability and transmissitivity

Depth (Ft)	Depth (m)	Thickness (Ft)	Thickness (m)	Thickness (cm)	Permeability (K) cm/sec	Transmisstivity (KH) m^2/day
51.8-67.5	15.8-20.6	15.7	4.8	480	1.47×10^{-2}	60.96
67.5-98.4	20.6-29.99	30.9	9.4	940	4.915×10^{-3}	39.80
114.2-129.0	34.8-39.3	14.8	4.5	450	1.8×10^{-2}	69.98
161.5-208.0	49.2-63.4	46.5	14.2	1420	6.75×10^{-2}	82.8
239.0-254.2	72.9-77.5	15.2	4.6	460	6.348×10^{-3}	25.44
269.5-603.9	82.1-184.1	334.4	102	102,000	5.808×10^{-3}	511.12

4.3.2. Pumping Test Analysis

A minimum of 3 steps was performed with the final step test flow rate allowing an estimate of the well maximum yield. Below shows the record of the step down test data

Volume = 25Litres

Table 4: Time and discharge rates

Time (s)	Discharge rate L/S
6.17	Q_1 =4.05
6.12	Q_2 = 4.08
6.05	Q_3 = 4.13

Recovery Test

A recovery test involves the analysis of the rise in ground water level that results when the pump is switched off.

Result:

The dynamic water level measured against time is represented and recorded below

Static water level: 38.7m

Type of pump submersible: (7.5HP)

Depth of pump:110m

Table 5: Elapsed time and dynamic drawdown values

Time since pumping started (mins)	Water- level (m)	Time since pumping started (mins)	Water- level (m)
1	38.7	50	39.60
2	38.75	55	39.60
3	38.80	60	39.60
4	39.85	65	39.60
5	38.90	70	39.60
6	38.95	75	39.60
7	39.00	80	39.60
8	39.05	85	39.60
9	39.10	90	39.60
10	39.15	95	39.60
12	39.20	100	39.60
14	39.25	110	39.60
16	39.30	120	39.60
18	39.35	130	39.60
20	39.40	140	39.60
25	39.45	150	39.60
30	39.50	160	39.60
35	39.55	170	39.60
40	39.60	180	39.60
45	39.60		

The dynamic water level is plotted against time on a semi-log graph of which the difference in draw-down over one log cycle is obtained and used in computing some of the aquifer parameters such as transmissivity and specific capacity. The plot is represented below.

Table 6: Summary of aquifer parameters of borehole in the study area

Swl (m)	Critical Flow rate (L/S)	Aquifer Efficiency (%)	Equilibrium Dynamic (m)	Step-down at Critical Flow (m)	Specific Capacity (m^2/h)	Average pumping rate (m^3/Day)	Transmissivity (m^2/day)
38.7	4.1	97.72	39.6	0.9	16.4	354.24	401.2

The computed transmissivity value is 401.2 m^2/day and is designated “high” based on Krasny (1990) classification of transmissivity magnitude. Generally, the higher the transmissivity value of an aquifer, the better its productivity prospect.

Table 7: Classification of transmissivity magnitude (Krasny, 1990)

Ttransmissivity m^2/day	Class of transmissivity magnitude	Designation of transmissivity magnitude	Groundwater supply potential	Approximate discharge in L/s at 5m drawdown
Above 1000	I	Very high	Withdrawals of great regional importance	Above 50
100 - 1000	II	High	Withdrawals of lesser regional importance	5 - 50
10 - 100	III	Intermediate	Withdrawals for local water supply e.g small communities	0.5 - 5
1 - 10	IV	Low	Smaller withdrawals for local water supply e.g private consumption	0.05 – 0.5
0.1 - 1	V	Very low	Withdrawals for local water supply with limited consumption	0.005 – 0.05
Less than 0.1	VI	Imperceptible	Inadequate for local water supply	Less than 0.0005

V. CONCLUSION

From the result of the geophysical investigation, lithology record and evaluated aquifer transmisstivity, a minimum drill depth of 600ft and casing diameter of 8 inches is recommended. Insertion of casing and screen should be carried out immediately after the drilling to avoid caving in or collapse of sandy formations. A screen slot width (screen opening or hole) size should be of 40% retention from the grain size analysis of the aquifer of interest. Considering the yield and draw down of the boreholes, the borehole is considered to be high yielding and has a considerable gradual decrease in draw down. The exploration borehole drilled for the study can conveniently sustain 15HP submersible pump. The transmissivity of the aquifer penetrated is prolific and yield a minimum average pumping rate of 354.24 m^3/day

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