

Assessment of Spatial Variation of Hydraulic Characteristics of Aquifers in Bori City Using Well Recovery Test

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ABSTRACT

Insufficient yielding of boreholes in certain parts of Bori city which could not be attributed to well interference necessitated the research to understand or identify areas with high yielding potentials. This was achieved by investigating the basic characteristics of aquifers within the study area using well recovery technique. The results showed that the transmissivity and permeability of the aquifers ranged from 1.89×10^{-3} to $1.056 \times 10^{-2} \text{ m}^2/\text{sec}$ and 1.09×10^{-4} to $3.59 \times 10^{-4} \text{ m/sec}$ respectively while the storativity lies from 5.78×10^{-5} to 1.156×10^{-4} with better yielding potentials towards the north-western region of the city. The results also informed that the aquifer materials ranged from medium sand to coarse sand hence necessary recommendations that will proffer economical supply of water to the residents of the city were made based on the findings.

Keywords: Boreholes, Permeability, Storativity, Transmissivity.

1. INTRODUCTION

Bori is a well-known city in Rivers State, Nigeria as the Ken Saro-Wiwa Polytechnic and the famous Birabi Memorial Grammar School (BMGS), both owned by the Rivers State Government are located there. Hence, the city is densely populated due to the presence of numerous students. Besides, the city is the commercial centre of Ogoni Kingdom thus, attracting traders and merchants which further increased the population. This notwithstanding, the city has no municipal water supply to meet domestic needs of the populated residents. This has necessitated drilling of boreholes by individuals for household water demand or for commercial purposes. However, residents are concerned about investing so much in drilling boreholes that may end up with low or no yield and/or poor water quality which may not be fit for intended use. Residents of the city have been in the practice of treating boreholes discharging poor water quality by means of chlorination (for bacterial treatment), use of granulated activated carbons or charcoals prepared locally (for adsorption of iron) and use of series of sand filters (for filtering out suspended impurities). In other words, the fear of not finding sufficient quantity of water in aquifers within the city is the main factor threatening prospective borehole owners. This can only be solved by scientific means since there has not been a report of water witching practice in the city and its environs.

An aquifer is a geologic formation or stratum that stores water and also is capable of transmitting or releasing significant quantity when extracted. Among the numerous characteristics or properties of aquifer, transmissivity (T), storativity (S) and permeability (k) are majorly used in describing the yield of an aquifer (Piscopo *et al.*, 2023; Urumovic *et al.*, 2023; Kirlas and Nagkoulis, 2023). Transmissivity is the discharge rate at which water flows through a unit width of an aquifer under unit hydraulic gradient. Storativity also known as storage coefficient is the volume of water released per unit surface area of an aquifer as the water table (for unconfined aquifer) or piezometric surface (for confined aquifer) drops by a unit depth. Permeability also known as hydraulic conductivity is a measure of the ease at which water flows through porous medium (soil mass). Pumping test and well recovery test are well-known scientific techniques used

in determining aquifer's characteristics however, the latter is more economical as it involves just a single well unlike the former that requires separate observation well(s) apart from the pumped well (Keach, 2022; Ahmadi *et al.*, 2020; Wong and Tong, 2020). Besides, well recovery test has been proven to be more reliable than pumping test since the data represent in-situ aquifers conditions (Tse and Amadi, 2008). Hence, this research focused on applying the technique of well recovery test to determine the main characteristics of aquifers within Bori city so that it could be properly documented for use in efficient management of the water resources since, to the best of the author's knowledge, nothing of such has been documented for the said area despite the water challenges experienced by residents.

2. METHODOLOGY

2.1 Study Area

The city of Bori is an Ogoni community that serves as the administrative headquarters of Khana Local Government Area (LGA) of Rivers State in Southern Nigeria. It is located in between Latitude $4^{\circ}39'8.084''\text{N}$ to $4^{\circ}41'1.156''\text{N}$ and Longitude $7^{\circ}21'22.734''\text{E}$ to $7^{\circ}23'26.513''\text{E}$, covering an approximated area of 13.25 km^2 . The northern and north-eastern parts of the city shared common boundaries with Kaani and Kor communities respectively while the eastern and south-eastern parts shared common boundaries with Wiiyaakara and Betem communities respectively, all in Khana LGA as could be seen in Figure 1. Bori city also shared common boundary with Yeghe community in Gokana LGA at the north-western part of the city. Just like other settlements in the Niger Delta region, the geology of the study area is of the sedimentary basement consisting of three stratigraphic subdivisions called Benin, Agbada and Akata formations in order of their increasing ages (Ogbozige and Toko, 2020). The aquifers are situated within the Benin formation and are majorly recharged by rainfall having average annual value of 2362 mm with the months of August and January being wettest and driest respectively while the temperature varies from 23.5 to 31.8°C (NIMET, 2023).

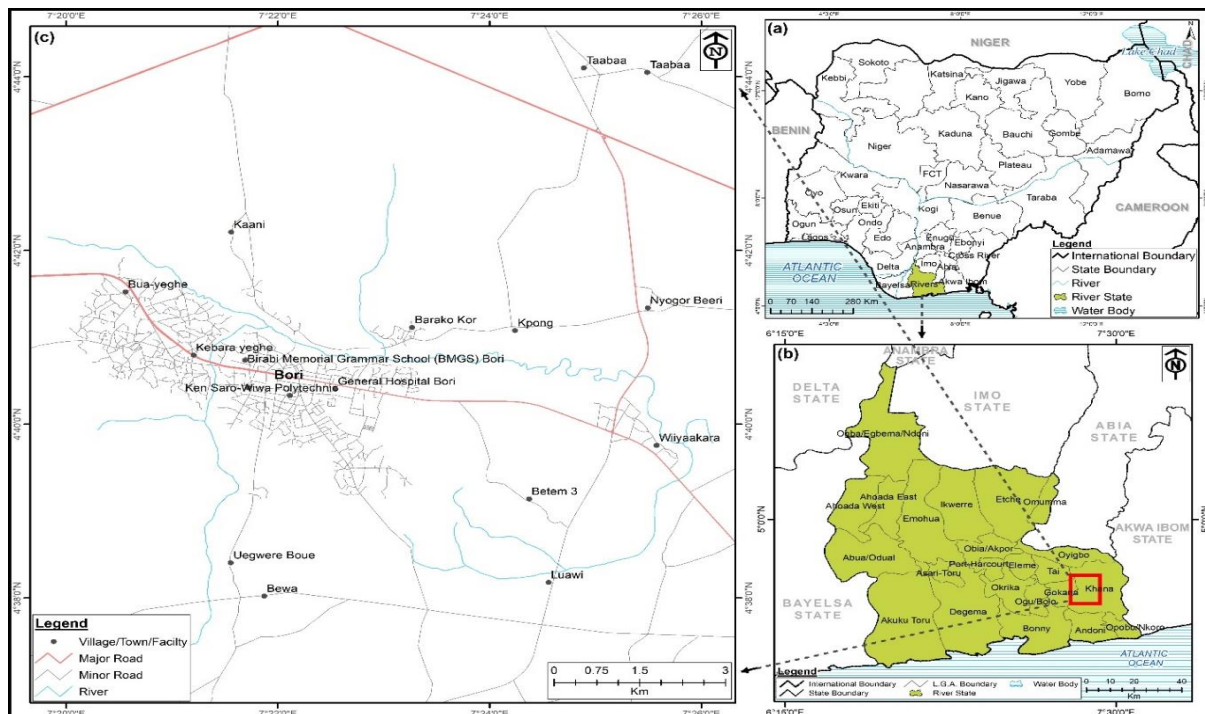


Figure 1: Map of the Study Area

2.2 Well Recovery Test

Five wells (boreholes) with available lithologic-logs information were selected, comprising points in the northern, southern, eastern, western and central parts of the city, and their geographic coordinates were recorded. Thereafter, the static water level above ground surface in each of the wells were measured by means of a dipmeter gradually lowered into the wells and recording the mark on the tape when it beeps a sound (which indicates that the sensor is in contact with water). This was followed by pumping out water at steady rate from the wells through a pumping machine attached with a flowmeter for a certain period (360 minutes) then stopped, and recording the drawdown (s) immediately. Afterward, the wells were allowed to recover while residual drawdowns (s') were recorded through a dipmeter at several durations since when the pumping was stopped (t'). However, prior to the measurement of residual drawdowns during the recovery phase, the drawdowns in the wells at 360 minutes were recorded. Also, during the pumping period, it was ensured that the pumped water was discharged at far distances (≥ 50 meters) from the wells to avoid returning into the wells.

2.3 Determination of Aquifer's Characteristics

The time since the beginning of pumping corresponding to the recorded residual drawdowns were calculated by adding the duration of pumping (360 minutes) to the respective durations since the pumping stopped (t') and were denoted as t . The ratios t/t' were then computed in each well and a semi-log graph was used in plotting the residual drawdowns (s') on linear scale against the ratios t/t' on logarithmic scale. The concerned hydraulic properties being transmissivity (T), storativity (S) and permeability (k) were thereafter determined through Equations (1), (2) and (3) respectively as reported in Raghunath (2006). It is important to note that in Equation (2), radius of the well (r_w) was used because the pumped well is the same as the observation well since the research considered well recovery test, unlike pumping test where the observation well is different from the pumping well with a radial distance denoted as (r).

$$T = \frac{2.30Q}{4\pi\Delta s'} \quad (1)$$

$$s = \frac{2.30Q}{4\pi T} \log_{10} \left[\frac{2.25Tt}{r_w^2 S} \right] \quad (2)$$

$$k = \frac{T}{b} \quad (3)$$

Where:

T is the transmissivity in m^2/sec ,

Q is the flowrate of water in m^3/s recorded from flowmeter connected to pumping machine,

$\Delta s'$ change in residual drawdown for one log-cycle in *metres* (obtained from semi-log graph),

s is the recorded drawdown in *metres* immediately the pumping was stopped,

t is the duration of pumping in *seconds*,

r_w is the radius of well in *metres*,

S is the storativity (*dimensionless*),

k is the permeability in m/sec ,

b is the aquifer's thickness (total length of screens) in *metres*.

2.4 Mapping of Aquifer's Characteristics

The hydraulic characteristics of aquifers in other locations within the city apart from the selected boreholes were identified by interpolating between the values recorded in the considered boreholes using inverse Ogbozige, Francis James: Assessment of Spatial Variation of Hydraulic Characteristics of Aquifers in

distance weighted (IDW) interpolation technique through ArcGIS 10.8 software. This is because the technique has been proven to be successful in mapping water related researches by numerous authors including Bhat and Singh (2023), Ohlert *et al.* (2022), Ogbozige and Toko (2022), Khouni *et al.* (2021), Kamaruddin *et al.* (2021), Sapna *et al.* (2018) and Ogbozige *et al.* (2018). Mathematically, it is expressed as shown in Equation (4).

$$Z_p = \frac{\sum_{i=1}^n \left\{ \frac{Z_i}{[d_{(p,i)}]^2} \right\}}{\sum_{i=1}^n \left\{ \frac{1}{[d_{(p,i)}]^2} \right\}} \quad (4)$$

Where:

Z_p is the predicted aquifer's characteristics at unknown point p ,

Z_i is the aquifer's characteristics at known point i ,

$d_{(p,i)}$ is the linear distance between the unknown or new point p and the known point i ,

n is the number of known points (i.e. number of selected wells).

3. RESULTS AND DISCUSSION

The basic information about the selected wells, obtained through field measurement and from the lithologic logs provided by the well owners are shown in Table 1. However, the explanation for the determination of the hydraulic properties were only done for the first well (W_1) since the procedure is the same for the remaining wells hence, the first two columns of Table 2 gives the raw data obtained during the well recovery test for W_1 which were used for explanations. The plot of the residual drawdown (s') on a linear scale against t/t' on a logarithmic scale is shown in Figure 2 and it clearly revealed that the change in residual drawdown ($\Delta s'$) for a log-cycle is 0.26 m. The discharge (Q) recorded from the flowmeter attached to the pumping machine was 0.9 m³/min (0.015 m³/sec) hence, Equation (1) was employed in determining the transmissivity.

$$T = \frac{2.30Q}{4\pi\Delta s'} = \frac{2.30(0.015\text{m}^3/\text{sec})}{4(3.142)(0.26\text{m})} = 1.056 \times 10^{-2} \text{ m}^2/\text{sec}$$

The recorded drawdown (s) in the well at 360 minutes (21600 seconds) of pumping (i.e. immediately after stoppage of the pump or prior to the well recovery recording) was 2.35 m while the radius of the well (r_w) based on the information in Table 1 was recorded as 2.5 inches (0.0635 m). Hence, the storativity (S) was calculated through Equation (2).

$$s = \frac{2.30Q}{4\pi T} \log_{10} \left[\frac{2.25Tt}{r_w^2 S} \right]$$

$$\Rightarrow 2.35\text{m} = \frac{2.30(0.015\text{m}^3/\text{sec})}{4(3.142)(1.056 \times 10^{-2}\text{m}^2/\text{sec})} \log_{10} \left[\frac{2.25(1.056 \times 10^{-2}\text{m}^2/\text{sec})(21600\text{sec})}{0.0635^2\text{m}^2(S)} \right]$$

$$2.35\text{m} = 0.2599\text{m} \log_{10} \left[\frac{127277.8}{S} \right]$$

$$\Rightarrow \frac{2.35\text{m}}{0.2599\text{m}} = \log_{10}(127277.8) - \log_{10}(S)$$

$$\therefore \log_{10}(S) = \log_{10}(127277.8) - \frac{2.35\text{m}}{0.2599\text{m}} = -3.937$$

$$\therefore S = 10^{-3.937} = 1.156 \times 10^{-4}$$

The total thickness of the aquifers in well W_1 as revealed in Table 1 is 32.24 m (gotten from the summation of the screen lengths) hence, permeability (k) which has been expressed in Equation (3) was then calculated as; $k = \frac{T}{b} = \frac{1.056 \times 10^{-2} m^2/sec}{32.24m} = 3.275 \times 10^{-4} m/sec = 1.179 m/hr = 28.30 m/day$

Table 1: Basic Information about Selected Wells

| Well ID | Geographic Coordinates | Diameter (inches) | Depth (m) | Total thickness of Aquifer (m) | Type of Aquifer |
|---------|--------------------------------|----------------------|--------------|-----------------------------------|--------------------|
| W1 | 4°40'51.368"N 7°21'34.957"E | 5 | 58.51 | 32.24 | Confined |
| W2 | 4°40'32.532"N 7°23'0.156"E | 5 | 43.88 | 18.05 | Confined |
| W3 | 4°39'27.723"N 7°22'40.723"E | 4 | 65.83 | 21.30 | Confined |
| W4 | 4°40'10.444"N 7°21'37.699"E | 5 | 47.54 | 15.66 | Confined |
| W5 | 4°40'22.409"N 7°22'14.375"E | 6 | 73.14 | 17.25 | Confined |

Note: Values in columns 4, 5 and 6 were obtained from the well logs provided by the well owners

Table 2: Well recovery test results for W_1

| Time since stopping of pumping, t' (min.) | Residual drawdown, s' (m) | Time since beginning of pumping, $t = 360 + t'$ (min.) | t/t' |
|--|--------------------------------|---|--------|
| 1 | 2.33 | 361 | 361.0 |
| 2 | 2.24 | 362 | 181.0 |
| 3 | 2.20 | 363 | 121.0 |
| 4 | 2.18 | 364 | 91.0 |
| 5 | 2.14 | 365 | 73.0 |
| 10 | 2.06 | 370 | 37.0 |
| 20 | 1.99 | 380 | 19.0 |
| 30 | 1.95 | 390 | 13.0 |
| 40 | 1.91 | 400 | 10.0 |
| 60 | 1.88 | 420 | 7.0 |
| 80 | 1.85 | 440 | 5.5 |
| 100 | 1.83 | 460 | 4.6 |
| 125 | 1.81 | 485 | 3.9 |
| 150 | 1.79 | 510 | 3.4 |
| 180 | 1.78 | 540 | 3.0 |

Note: In the third column, 360 was used in the addition because the pumping was done for 360 minutes.

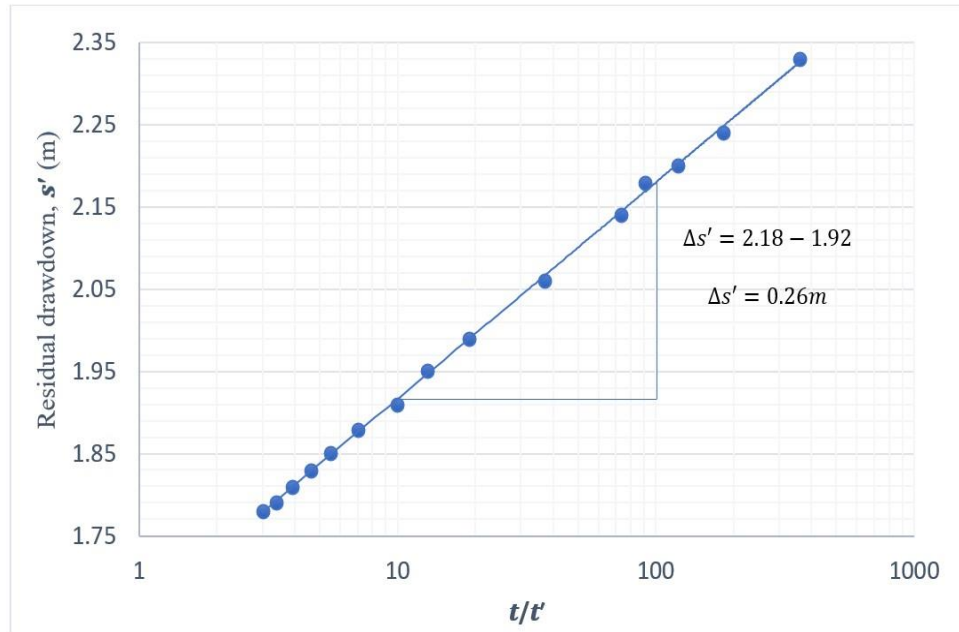


Figure 2: Residual Drawdown Curve for Well Recovery Test of W_1

As earlier stated, the transmissivity, storativity and permeability of the remaining wells (i.e. W_2 , W_3 , W_4 and W_5) were determined in the same way and their values are given in Table 3. However, the mapping of the entire city with respect to the investigated hydraulic properties being transmissivity, storativity and permeability are shown in Figures 3, 4 and 5 respectively. The maps clearly revealed that the values of transmissivity, storativity and permeability of aquifers in Bori city are highest at the north-western part but lowest at the central part of the city. The transmissivity of the aquifers (1.89×10^{-3} to 10.56×10^{-3} m²/sec) which is equivalent to 1.89 to 10.56 litre per second per 1 metre width of the aquifer under a hydraulic gradient of 1 metre per 1 metre, suggest that the aquifers transmissivity is moderately good. The range values for storativity informed that the aquifers are confined (Suprapti and Pongmanda, 2020) which is in line with the information obtained from the lithologic-logs of the wells. The permeability which lies within 1.09×10^{-4} to 3.59×10^{-4} m/sec (i.e. 9.42 to 31.02 m/day) suggest that the aquifers within Bori city ranged from medium sand to coarse sand, based on the permeability classifications reported by Singh (2008) and Bell (2007).

Table 3: Values of Investigated Hydraulic Properties of Wells

| Well ID | Transmissivity, T (m ² /sec) | Storativity, S (dimensionless) | Permeability, k (m/sec) |
|---------|---|----------------------------------|---------------------------|
| W1 | 1.056×10^{-2} | 1.156×10^{-4} | 3.275×10^{-4} |
| W2 | 6.478×10^{-3} | 6.444×10^{-5} | 3.589×10^{-4} |
| W3 | 3.329×10^{-3} | 7.029×10^{-5} | 1.563×10^{-4} |
| W4 | 3.267×10^{-3} | 5.779×10^{-5} | 2.086×10^{-4} |
| W5 | 1.894×10^{-3} | 6.107×10^{-5} | 1.098×10^{-4} |

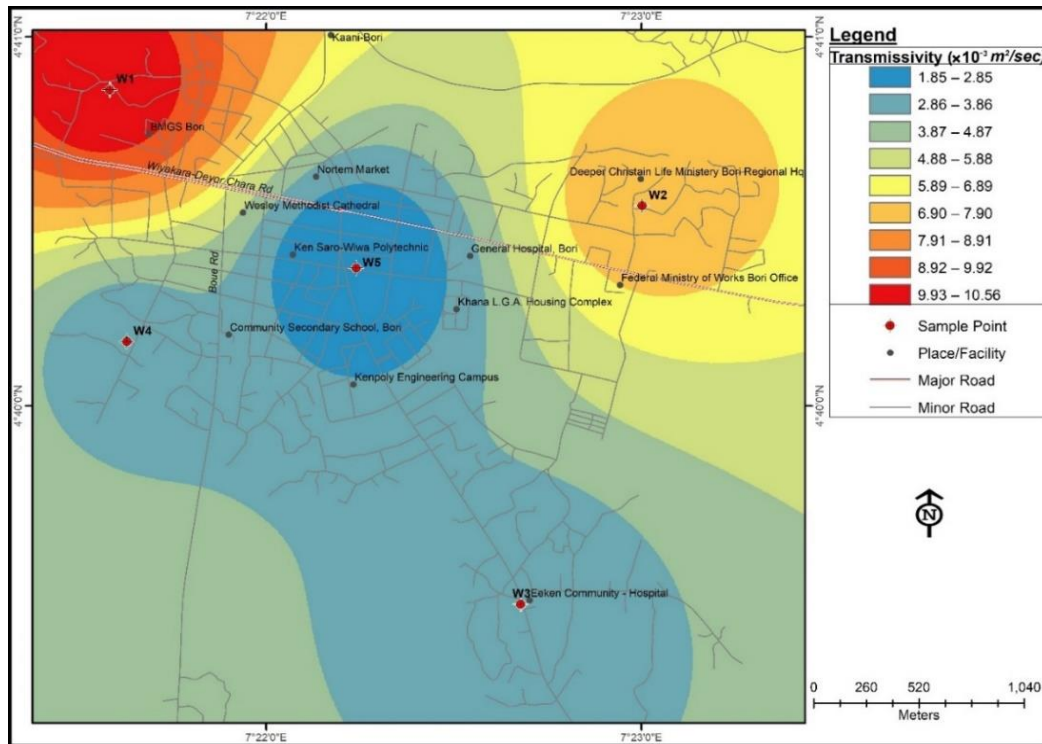


Figure 3: Variation of Transmissivity within Bori City

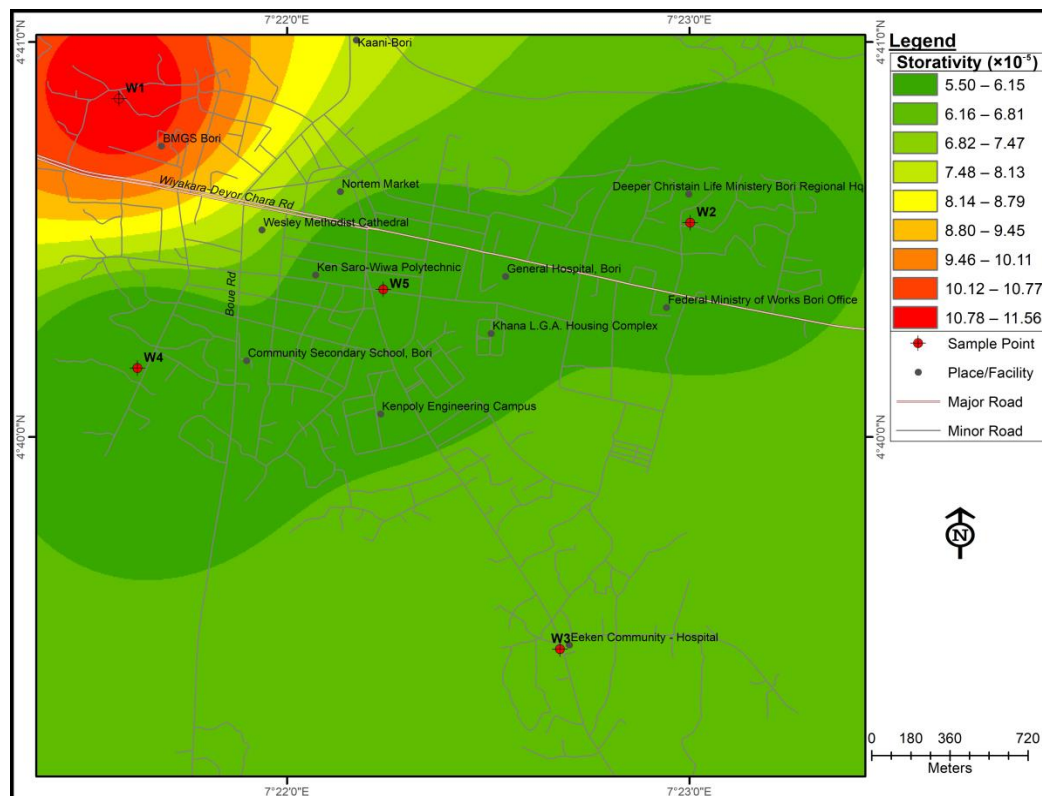


Figure 4: Variation of Storativity within Bori City

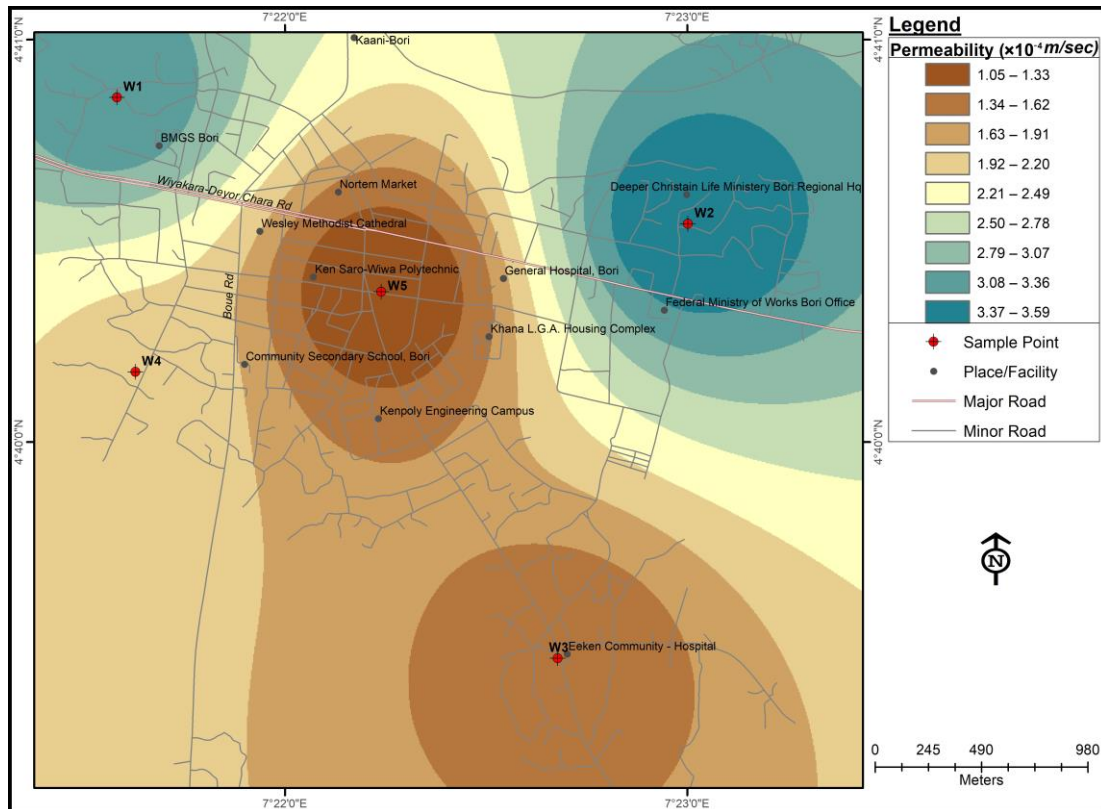


Figure 5: Variation of Permeability within Bori City

4. CONCLUSION

The research has shown the variation of the basic properties of aquifers within the City of Bori, Rivers State, Nigeria. This has consequently revealed areas in the city with high water yielding potentials especially the north-western region. The calculations involved were simplified as much as possible to ease prospective researchers of similar studies. Hence, it is recommended that a municipal water supply facility be provided with water source being a borehole at the north-western region of the city where the aquifer's characteristics were identified to be better than the rest. This is because such borehole or well will easily recover water from the surrounding aquifer after pumping into reservoirs or treatment plant.

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