

Hydrogeology and Geohydraulic Parameters Estimation Using Pumping Test and Geological Data: A Case Study of Western Niger Delta Basin, Nigeria

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ABSTRACT

Occasioned by the paucity of pumping test data, population explosion, and unplanned drilling of boreholes within the Western Niger Delta Nigeria, this study was, therefore undertaken to provide a lucid representation of the hydrogeological framework and estimate aquifer parameters of the study area from geological (lithological logs, borehole depth (static water level (SWL), hydraulic head, etc.) and pumping test data respectively. The methods used include diagrammatic representations of the geological data while the Cooper-Jacob straight-line graph was utilized to analyse the time-drawdown. The range of borehole depth (38.5 m–189 m), SWL (0.40 m – 116 m), and hydraulic head (0.60 m – 120 m) denotes the existence of shallow and deep aquifers. The hydrostratigraphic layers revealed that the water-bearing layers comprised the recent deltaic sands, alluvium, coastal plains etc., which are unassigned equivalents of the Benin Formation, and Ogwashi-Asaba Formation. The geohydraulic parameters computed using data obtained from the pumping test indicated a range of 0.1 m²/day – 5145.47 m²/day, 0.01 m/day – 677.04 m/day, and 0.000053 m/hr/m to 222.1 m/hr/m for Transmissivity, Hydraulic conductivity and Specific capacity respectively. The results showed that except few boreholes within the study area, the majority of the boreholes possess geohydraulic parameters.

Keywords: Aquifer parameters; Transmissivity; Water-bearing layers; Hydrogeological framework; Pumping test; Western Niger Delta.

INTRODUCTION

Groundwater as a natural resource has received unprecedented attention because it provides most of the water supply needed for the survival of all living things; for

agricultural processes; for industrial processes, and it also drives the food chain (Ahmed II et al., 2022; Akudo et al., 2010; Nyaberi, 2022; Singh & Tripura, 2022). Despite being identified as a renewable resource; it is already proven to be limited in

geographical distribution due to inhomogeneity in geological Formations (Abdullahi, 2013; Nagaraj et al., 2021) globally. Groundwater quantity which stands at a paltry 33% of the total volume of water consumed worldwide (Hassan et al., 2019), is further limited in quantity by the near-collapse or collapse of public water infrastructure in developing countries in Africa. The diminishing groundwater quantity available worldwide is due partly to unprecedented population explosion and escalated industrialization (Chinyem, 2013; Nwankwo et al., 2023). The over-dependence on groundwater is further heightened by the unreliable and limited quantity of surface water sources. Most surface water sources (streams, lakes, impoundments, rivers, etc.) have become ephemeral due partly to climate change's impact on surface water (Akudo & Otaru, 2023).

Because of the foregoing, it is, therefore, pertinent to regularly assess and reassess groundwater potentials in an area. To safely harness groundwater for sustainable use and manage the resource to provide for the intended uses, it is imperative to understand the geohydraulic properties of aquifers in the affected areas (Mjemah et al., 2009). Geohydraulic properties such as transmissivity, hydraulic conductivity, specific capacity, etc. are intrinsic properties of the aquifer materials and reveal so much about the capabilities of the aquifer to provide water for the intended purposes. Since aquifers are hosted in geologic Formations, the geohydraulic properties are defined to a large extent by the geology of the aquifer and the overlying vadose zone respectively. The hydraulic conductivity for

instance defines the architecture and interconnectivity of pores and the flow of water in and out of the aquifer system (Jalil et al., 2021).

Three approaches have been largely deployed for evaluating groundwater potentials namely: the use of electrical resistivity measurements data, grain size analysis data, and pumping test data respectively. Of these methods, the estimation of aquifer geohydraulic parameters using electrical resistivity measurements have gained the most prominence among many authors globally (Akinbiyi et al., 2019; Aweto & Akpoborie, 2015; George et al., 2015; Nyaberi, 2022; Oguama et al., 2020; Okiongbo & Mebine, 2014; Tijani et al., 2021; Ugbe et al., 2021; Urom et al., 2021); followed by those who utilized pumping test data to derive the values of aquifer hydraulic parameters (Ali et al., 2022; Jalil et al., 2021; Mjemah et al., 2009); still others derived hydraulic parameters from grain size analysis data (Akpoborie & Efobo, 2014; Oborie et al., 2018); while others deployed a combination of data to accomplish the same task (Anomohanran & Iserhien-emekeme, 2014; Chiyem et al., 2023; Ebong et al., 2014; Mgbolu et al., 2019; Musa et al., 2023; Nwankwo et al., 2023; Ofomola et al., 2022).

The seeming popularity of the electrical resistivity techniques is expected because it is inexpensive, easy, and fast to deploy (Anomohanran, 2015). However, the pumping test technique although cumbersome, remains the most reliable method of estimating aquifer hydraulic parameters (Musa et al., 2023). The resistivity method is an indirect way of obtaining

subsurface information, and as such remains less reliable except if combined with pumping test data. In the study area, pumping test data is scarce since most boreholes are drilled by unqualified people who cannot acquire the required data or carry out pumping tests of these boreholes. With the expansion of cities and villages within the study area, many more boreholes are being drilled without downhole records. This research, therefore, aims to utilize geological data to adequately represent and interpret the hydrogeology of the aquifer system of the study area and estimate aquifer geohydraulic parameters from pumping test data accordingly.

Study Area

Location and Physical Features

The study area is the Western part of the Niger Delta basin and is located between latitudes 5.33°N - 6.67°N , and longitudes 5.33°E - 7.0°E (Fig. 1) respectively. The Western Niger Delta, which comprises Delta and Edo States, is flanked on the south by Rivers and Bayelsa states, and to the East by the other two remaining States of the Niger Delta namely Cross River and Akwa-Ibom States (Hassan et al., 2019) respectively. The study area is covered by dense forests and characterized by an extended rainy season. It is described as a rain forest belt often affected by perennial flooding. Rain falls nearly all through the year but most of the rains occur between March to October while the dry season is usually between November to February each year. The mean annual rainfall measured at Warri for a period of ten years (2001-2010) is 2,725.25 mm (Fig. 2) with a mean monthly rainfall of 272.1 mm. The

range of temperature is between 23°C – 33°C with the temperature attaining a peak value of 34°C in April and minimum values of 18°C during June to July when the rains are most severe. Because of the presence of a plethora of luxuriant trees in the forests, evapotranspiration is high as reported by (Akpoborie et al., 2011; Omoko et al., 2023), reaching a mean annual value of over 1000 mm. Currently most of the forests are already lost to urban expansion and industrialization, thereby presenting the region with abnormally high temperatures and extreme rainfall or irregular patterns of climate reminiscent of climate change impacts.

The area is predominantly marked by low-lying landforms due largely to the nature of the drainage network. The elevation in the area is between 2.7 m to 159 m respectively. Elevation is lowest in the southern part of the Basin in towns such as Warri, Koko etc., is highest in the Northern and Northeastern parts because of the presence of hills in that part where towns such as Okada, Benin, Ogwashi – Uku, Abavo, Iguoba, and Asaba respectively are situated. The major towns in the study area (Benin, Warri, and Asaba) are drained by important rivers. The Niger River which enters Asaba through Onitsha along with the Anambra River is responsible for bringing in recent sediments that overlies the underlying Formations in the area (Akpoborie, 2011).

The Niger River which flows southwards connects with other rivers like the Anwai River and empties its contents down south where there are rivers like the Ethiopie River around Abraka and Umuaja; Warri River, Escravos Rivers, and numerous freshwater

swamps in the Warri axis; and Benin River which descends Ikpoba hill and drains Benin City. The influence of these rivers is

prominent because they account for bringing in massive alluvium sediments that characterize the upper lithology of the Basin.

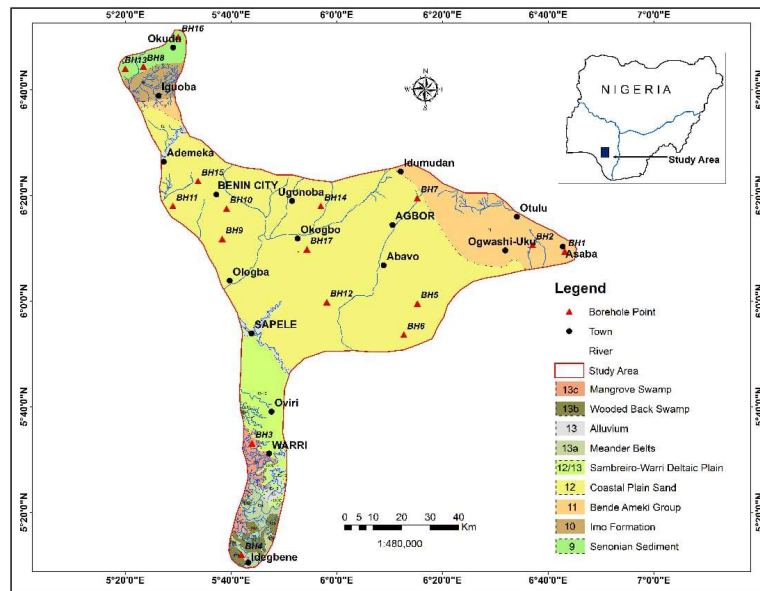


Figure 1: Geologic and Borehole Location map of the study

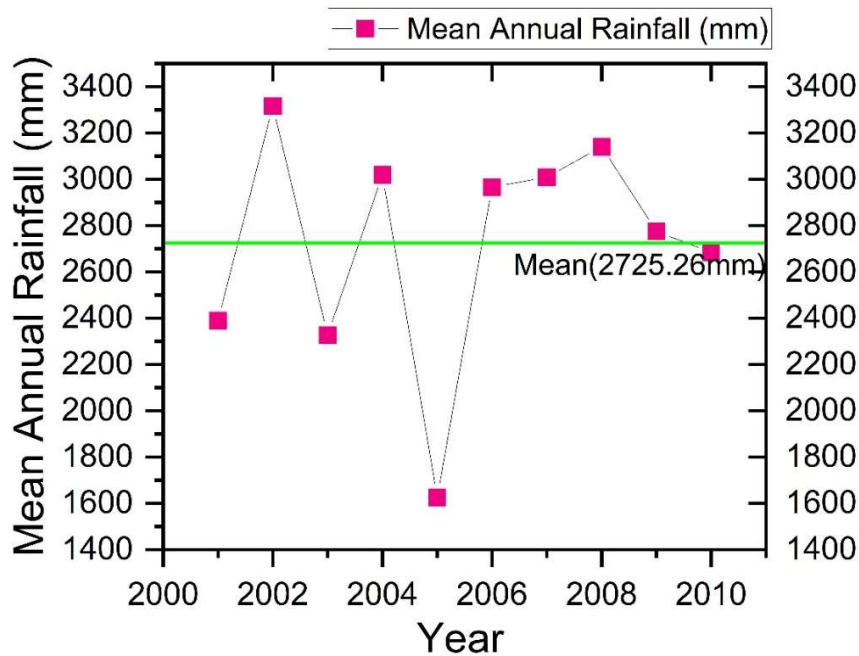


Figure 2: Mean annual rainfall (2001-2010) for the study area

Geology and Hydrogeology

The geology of the Niger Delta Basin has been rendered thoroughly in many published articles, books, reports, etc. by sundry authors (Asseez, 1989; Murat, 1972; Oomkens, 1974; Short & Stauble, 1967). There seems to be a clear consensus among all the aforementioned authors that the basin is made up of three Formations namely: Akata (oldest), Agbada, and Benin (youngest) Formations respectively. As shown in Figure 1 and Table 1 (Nwankwoala & Ngah, 2014), the Western Niger Delta has the same geology with the Niger Delta basin generally. The Akata Formation includes over-pressured but partially compacted shales with only a paltry one-tenth of the sediments made up of sand. It is thought to be deposited between Eocene and Recent in marine settings. The surface equivalents of the Akata Formation in the immediate study area are the Senonian sediments and the Imo shales outcropping at Okude and Iguoba (Fig. 1) respectively. The next Formation that rests on top of the Akata Formation as conformable strata is the Agbada Formation considered to have accumulated between the Eocene and Pleistocene periods. It includes multiple and repeated sequences of sands and shale beds. At the surface, the deposits of the same characteristics as the Agbada which lies below the Benin Formation are the Bendel Ameki Group and Ogwashi-Asaba Formation respectively. In the study area, these Bendel Ameki and Ogwashi-Asaba outcrops at Ogwash-Uku, Asaba, Idemuda, etc. The deposits that make up the rock exposures at Asaba specifically is the Ogwash-Asaba Formation, which is a surface reflection of the Agbada Formation. The last Formation which rests over the Agbada

Formation in a conformable manner is the Benin Formation said to be recent in age and believed to have been accumulated in continental settings (Akpoborie, 2011; Akpoborie et al., 2011; Asseez, 1989). The Benin Formation remains the most prominent of the three Formations and contains sands, gravels, and silts with sand making up nine-tenths of the total sediment accumulations. Because of little reworking of the sediment accumulations, the sequences show poor sorting characteristics generally. The modern-day equivalents of the Benin Formations include Coastal plain sands, mangrove swamps, Sombreiro-Warri deltaic, wooded black swamp deposits, Alluvium, meander belts, and largely sandstones respectively. These sediments occupy the central and southern parts of the study area (Fig. 1).

The hydrogeology of the Basin shows that two aquifer types are abstracted by Boreholes in the study area. The Benin Formation and its exposed equivalents remain the most prolific water-bearing beds in the area. The thickness of the Benin Formation is > 2000 m and this massive pile of sediments is made up largely of fine-medium-coarse sands and can yield water from Boreholes even as shallow as 20 m in depth (Abam & Nwankwoala, 2020; Aweto & Akpoborie, 2015; Hassan et al., 2019). Of all the recent sediments that cap the Benin Formation, alluvium sediments emerge top as the most harnessed by boreholes for water supply in the study area (Chinyem, 2013). The aquifers in the upper layer are usually unconfined and well recharged by precipitation. The deep aquifers that exceed a depth of 100 m are semi-confined to confined aquifers with such

aquifers occurring in Ogwashi-Asaba and Ameki Formation respectively. The shales in the Ameki and Ogwashi-Asaba limit the productivity of wells drilled to such aquifers and recharge to such aquifers is slowed down

by the depth of the aquifers and the impermeable nature of the vadose zones (Akpoborie & Efobo, 2014; Chiyem et al., 2023).

Table 1 Geology and Stratigraphy of the Study Area, modified after (Nwankwoala & Ngah, 2014)

Exposed Units	Underlying Units	Present-time Equivalent
Benin Formation	Benin Formation	Coastal plain sands, mangrove swamps, Sombreiro-Warri deltaic sands, wooded black swamp deposits, Alluvium, meander belts, largely sandstones
Ogwashi-Asaba Formation	Agbada Formation	Brackish water, alternations of sandstones and shales
Bende Ameki Group		
Imo Shale	Akata Formation	Marine sediments largely of clays
Senonian sediments		

MATERIALS AND METHODS

Data Acquisition and Analysis

Geological data and Pumping test data of 17 Boreholes (Fig. 1) strategically drilled in different parts of the Western Niger Delta Basin, were both provided by Benin-Owena Basin Development Authority, Benin City, Nigeria. The geological data includes borehole lithological logs, static water level, elevation above mean sea level, coordinates, etc. As reported by Benin-Owena River Development Authority, GPS was used to measure the elevation and coordinates, a water level dip meter was utilized to record the static water level, the logging was done

with a down-hole logger during drilling, while rotary rig was deployed to drill the wells. With the information about the rock cuttings encountered at each depth provided, Surfer 8 was used to draw accurate log sections reflecting the underlying rocks and the aquifer materials, while ArcGIS 10.5 software was deployed to spatially represent the borehole depth, static water level, and hydraulic head respectively. These data were then carefully studied to provide a detailed interpretation of the subsurface geology, and the hydrogeology of the Formation encountered underneath.

The pumping test data provided was reported to have been done adopting the constant rate pumping methods with single wells serving as both the pumping and observation wells respectively. To analyse the pumping test data, the time-drawdown graphs drawn with a Microsoft Excel 2016 package was used in line with Cooper-Jacob's (Cooper & Jacob, 1946) straight-line graph. The X-axis representing time during the pumping test is expressed as a logarithmic scale while the Y-axis is expressed as an arithmetic scale. According to (Singh & Tripura, 2022), Cooper-Jacob's methods is adequately

suitable for the analysis of pumping test data in situations where there was no observation well and in which case drawdown is measured in the pumping well. The gradient of the graph means the change in drawdown or a log cycle ($\Delta S = (S_o - S)$) (Anomohanran, 2015). The derived change in drawdown ΔS is part of the input data for calculating Transmissivity which is one of the geohydraulic parameters. After the (Theis, 1935) equation is simplified and modified, Cooper-Jacob's (Cooper & Jacob, 1946) equation used to calculate Transmissivity (T) becomes:

$$T = \frac{2.3Q}{4\pi\Delta(S_o - S)} \dots \dots \dots (1)$$

Where T = Transmissivity (m^2/day); Q = Discharge or flow rate (m^3/day); $\Delta(S_o - S)$ = change in drawdown over a log cycle (m).

that defines the ease with which it permits the passage of water out. When the saturated layer of a Formation (b) is known, this parameter can be substituted into equation 2 below to calculate the Hydraulic Conductivity (Nghah & Eze, 2017):

The Hydraulic Conductivity also referred to as permeability coefficient (K), is a characteristic of a saturated geologic material
 $T = Kb \dots \dots \dots (2)$

Since T is already determined in equation (1), Hydraulic Conductivity (K) is calculated as equation (3) below:

$$K = \frac{T}{b} \dots \dots \dots (3)$$

Where b= Thickness of saturated layer (Aquifer) (m); K = Hydraulic Conductivity (m/day)

relationship with drawdown, which means that when drawdown increases, specific capacity decreases, and as such attains peak value when drawdown reaches zero (Nghah & Eze, 2017). The Specific Capacity (Cs) is, therefore, calculated using equation (4) below:

The specific Capacity of the aquifers which is the well discharge or yield per unit drawdown was also computed accordingly. This parameter displays an inverse

$$Cs = \frac{Q}{S} \dots \dots \dots (4)$$

Where Cs = Specific Capacity (m³/hr./m)

RESULTS AND DISCUSSIONS

Interpretation of Borehole Lithological Logs and other Geological data

Borehole lithological logs (Fig.3) drawn with data obtained during drilling were selected to represent and reflect the geology of the different Formations that make up the study area, with particular emphasis on the water-bearing layers. The hydrostratigraphic layout of the study area reveals that the recent sediments that cap the Benin Formation, and the Ogwashi-Asaba Formation respectively, are the major aquiferous units. The eastern part of the Western Niger Delta (e.g. BH1 and BH 7) is made up of the Ogwashi-Asaba Formation comprising sandstones and shale alternations. For instance, borehole drilled and completed in Asaba Township revealed a shallow depth to the water table (< 40m) with boreholes in that part of the town abstracting water from a topmost aquifer generally less than 40 m to the surface. The geological material that makes up the aquifer is believed to be recent terrace sediments (consisting of fine sands, coarse sands, and lateritic materials all in an alternating pattern) that are supplied by the Niger River. As adduced by (Akpoborie et al., 2011), there are areas in Asaba and environs with deeper aquifer tapping from the second aquifer believed to be semi-confined Ogwashi-Asaba Formation. The lithological logs in the southern part (e.g. BH 3) reveal that the underlying materials are made up of fine-medium-coarse sediments of Sombreiro-Warri deltaic plains believed to be recent sediments that have capped the Benin

Formation and serve as aquifers for towns like Warri, Koko, etc. and environs. The sediments are usually not well sorted because of their recent deposition, and they reflect a sequence that is fining upwards. Boreholes in the central part of the study area reflect the dominance of coastal plain sands believed also to overlie the Benin Formation (e.g. BH 9). These sediments account for the aquifer materials in these areas and bear resemblance with the Benin Formation. A correlation of the aquiferous units of the study area indicates that Boreholes such as BH 8, BH 9, and BH 11 shows that a semi-confined aquifer situation prevails with Shales and a thick layer of fine sands overlying the aquifer layers respectively. The lithological logs drawn and carefully studied agrees with the works of others who also investigated the lithological units within the Niger Delta (Akpoborie et al., 2011; Chiyem et al., 2023; Ebong et al., 2014).

Borehole depth values (Table 2) represented as depth map (Fig. 4) of the study area reveal that the depth ranges from 38.5 m–189 m respectively. The spatial distribution shows that the southern and central parts of the study area have predominantly shallow aquifers with most of the boreholes < 100 m in terms of total drilled depth.

Table 2 Hydrogeological parameters from well logs and calculated geohydraulic properties from pumping test

Borehole NO.	Location	Total Borehole Depth (m)	SW L (m)	Hydraulic Head (m)	Drawdown (m)	Change in drawdown, ΔS (m)	Transmissivity T (m ² /day)	Hydraulic Conductivity K (m/day)	Specific capacity, S (m ³ /hr./m)
BH 1	Asaba, Town	38.5	19.3	39.3	1.28	0.26	138.23	14.86	31.43
BH 2	Ibusa, Town	75	52.2	60.79	0.7	0.05	0.76	0.09	0.17
BH 3	Ekpan, Warri	58	2.51	0.59	0.67	0.24	6.6	0.93	1.5
BH 4	Koko Town	189.5	0.4	2.3	4	1.0	976.85	93.03	222.1
BH 5	OLIOGO Town	45.7	25.3	22.7	2.02	0.36	0.11	0.01	0.024
BH 6	Ebedei Town	42	7.2	40.8	0.82	0.10	0.38	0.05	0.087
BH 7	Aliokpu, community	102	58.7	119.8	0.52	0.16	0.24	0.02	0.054
BH 8	Okada Community, Okha Ikpoba	120.5	7.2	93.8	0.82	0.10	0.38	0.04	0.087
BH 9	Obazogbon, Ikpoba	95.3	25.3	65.3	5.75	2.60	540.12	80.62	122.8
BH 10	Evbolekan, Benin City	112.5	33.2	25.35	2.16	0.80	65.31	7.96	14.85
BH 11	Urhehue community	92	41.6	17.31	2.89	0.048	5145.47	677.04	1170
BH 12	Usen Community	121	47.0	23.88	2.02	0.90	536.54	73.5	122
BH 13	Isua Community	125.4	116.4	18.22	2.65	1.20	224.29	30.72	51
BH 14	Ideogbagbo	97.5	62.6	48.4	2.2	0.64	0.1	0.1	0.000053
BH 15	Iguoghor Community	132	47.0	84.98	2.02	0.72	670.67	93.15	152.5
BH 16	Apana Community	105.78	36.1	37.9	9.1	2.40	122.04	15.85	27.75
BH 17		122	51.5	108.2	8.2	2.60	21.92	3.91	4.985

SWL = Static Water Level; BH = Boreholes

Table 3 Computed Transmissivity (T) Potentials compared with Gheorghe (1978) Standards

Borehole No.	T range (m ² /day)	Transmissivity Potentials
BH4, BH9, BH11, BH12, BH15	>500	High Potential
BH1, BH10, BH13, BH16	50-500	Moderate Potential
BH3, BH17	5-50	Low Potential
BH5, BH6, BH7, BH8, BH14	<0.5	Negligible

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BH5, BH6, BH7, BH8, BH14	<0.5	Negligible

The very deep boreholes with depths exceeding 100 m are situated in the extreme south like Idegbene and the Northcentral and the far Northern part such as Okogbo, Benin, Iguoba, and Okudu respectively. In the Northern part, the high depth of the boreholes

is a result of a thick pile of overburden recent materials that cap the Benin formation. In the extreme south, the high depth drilled is due to the massive fine sediments and the search for coarse and aquiferous sediments.

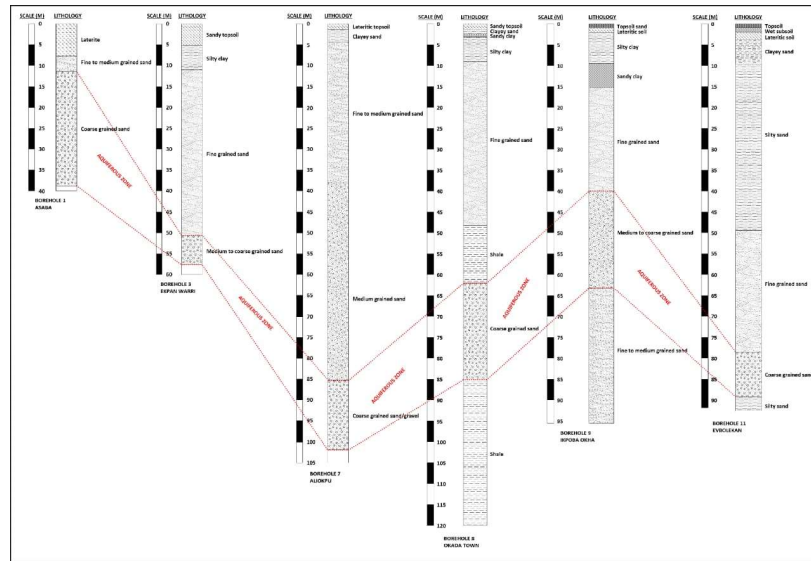


Figure 3: Borehole lithological logs of the study area

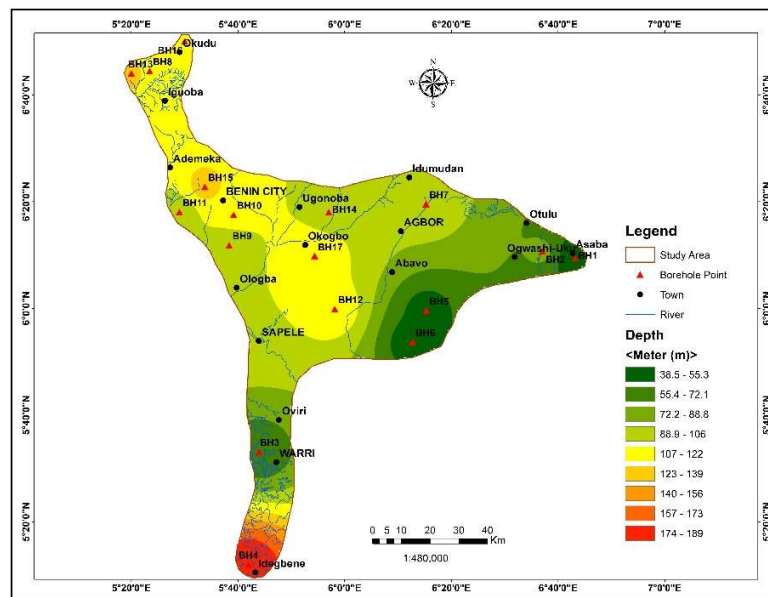


Figure 4: Borehole depth map in the study area

The static water level (SWL) which is the depth to the water table in a well at a particular time was displayed in Table 2 and represented spatially in Figure 5. The values of the measured SWL in the boreholes range from 0.40 m – 116 m respectively. The southern and western part of the area has low SWL which implies that water is very close

to the surface and that it is easily accessible from the surface. Such areas with low SWL equally have shallow wells as is shown from the borehole litholog and Figure 3. In places like Ugonoba, Agbor, Okude, etc. in the Eastern and Northern part of the Basin respectively, displayed high SWL indicating the water is far from the surface and these are

boreholes with high total drill depth as well. The implication of this is that a lot is expended on drilling to reach aquifers. The advantage though, is that boreholes whose total drill depth are high, are better protected

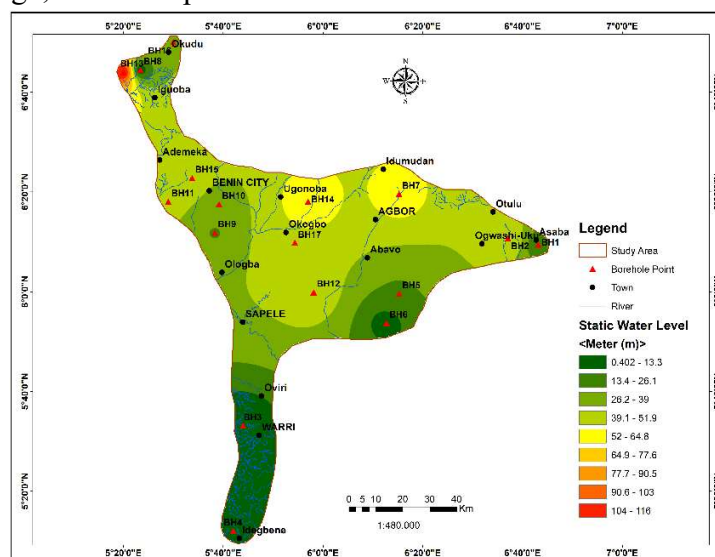


Figure 5: Static water level map of the boreholes in the study area

The hydraulic head is another hydrogeological parameter that must be determined from measurements taken in the field. The hydraulic head (Table 2) is the energy or potentials of the hydrological system usually determined as the difference between the elevation above mean sea level and the static water level. As shown in Figure 6, the hydraulic head in the study area is lowest in the southern and central part and highest in the extreme North and Eastern parts of the basin with a range of 0.60 m – 120 m respectively. Water moves from points of high potential to points of low potential,

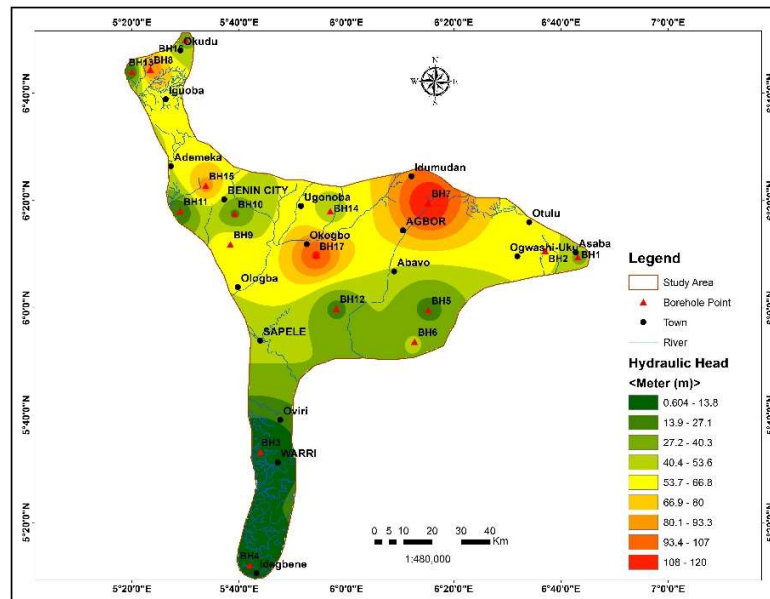


Figure 6: Hydraulic head map of the study area

Pumping Test Results and Calculated Geohydraulic Parameters

The drawdown recorded during the pumping tests in all the boreholes in the study area (Table 2), has a range of 0.52 m – 9.1 m respectively. It is observed that the two boreholes with the highest drawdown (BH 16 and BH 17) are wells that have a total depth of > 100 m respectively. Although this is not a general trend as the boreholes are spread over the entire study area, it is seen that the semi-confined and confined aquifers produced high drawdown during the pumping tests. Drawdown is more often

decided by the geologic materials that make up the aquifer as this influences the rate at which the well responds to pumping. The drawdown values which were spatially presented in Figure 8, indicate that the boreholes in the central and extreme North revealed high drawdown values. The estimated changes in drawdown $\Delta(S_o - S)$ generated from the slope of the Cooper-Jacobs straight line graph (Fig. 9 - Fig. 9ii) were utilized as input to the mathematical equations already highlighted above to compute the Transmissivity (T), Hydraulic Conductivity (K), and Specific Capacity (S).

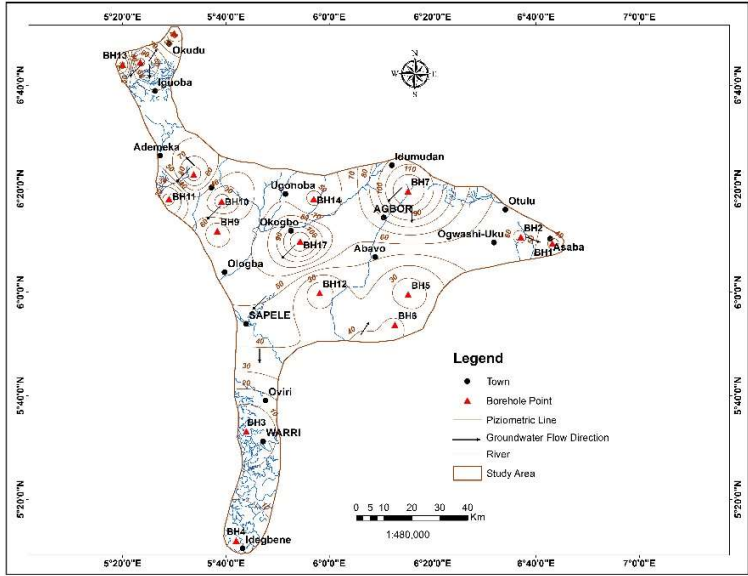


Fig. 7 Groundwater flow direction map of the study area

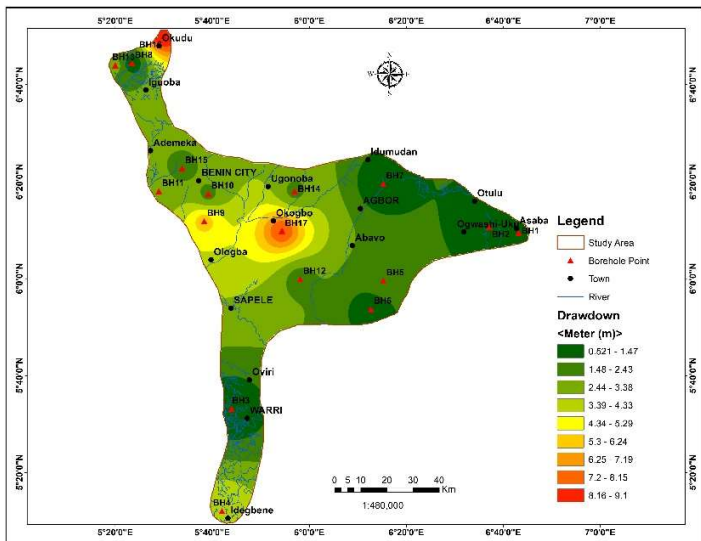
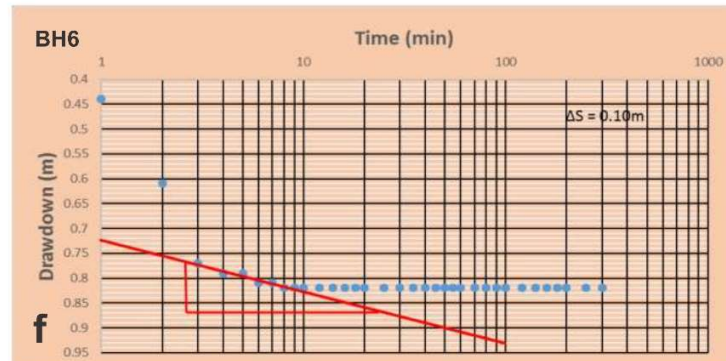
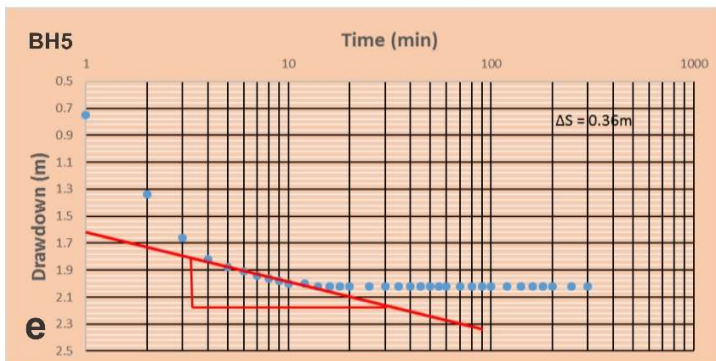
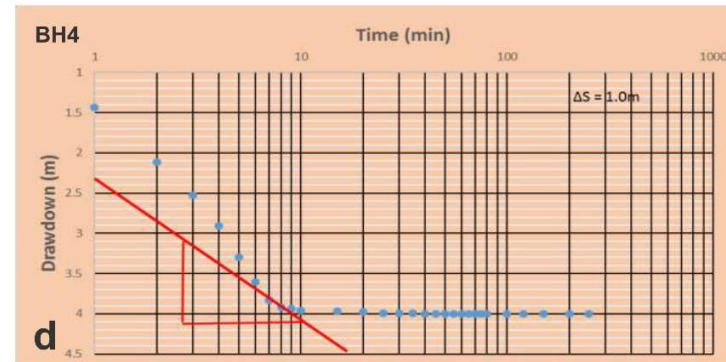
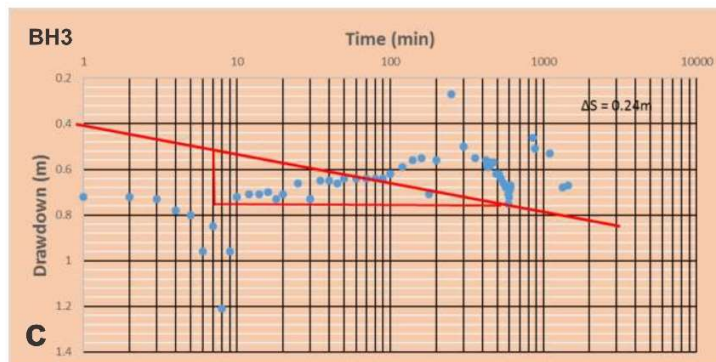
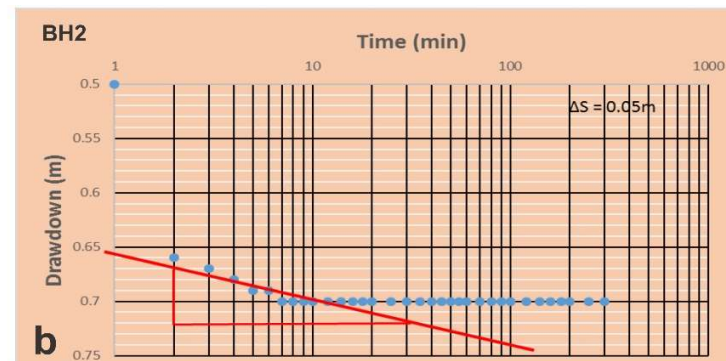
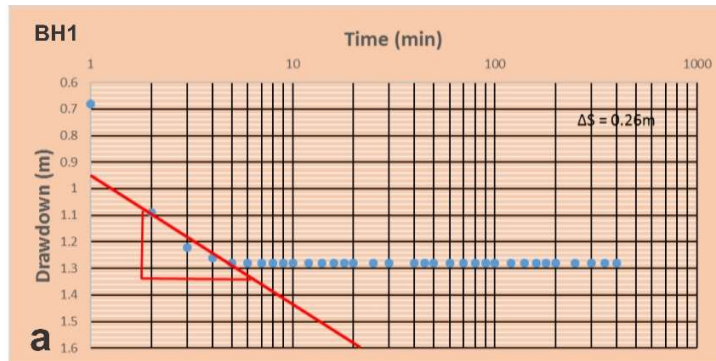
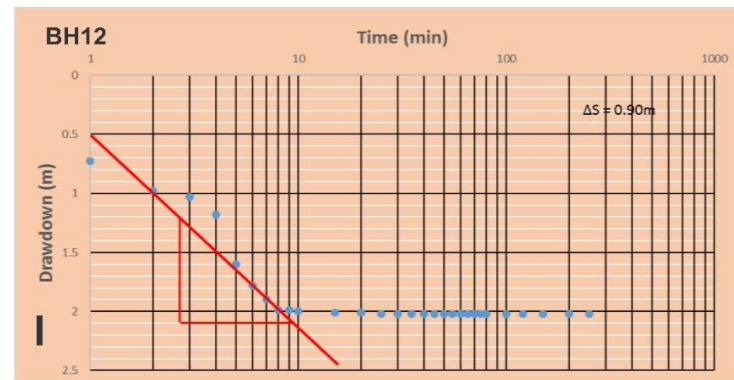
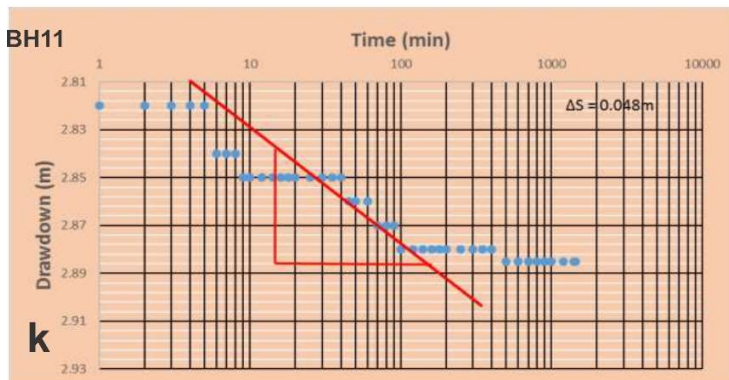
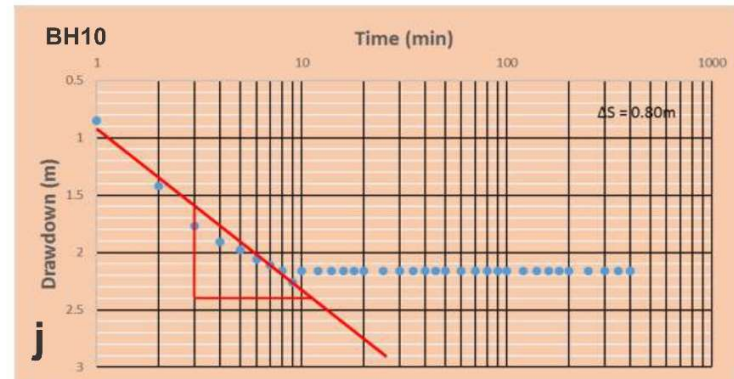
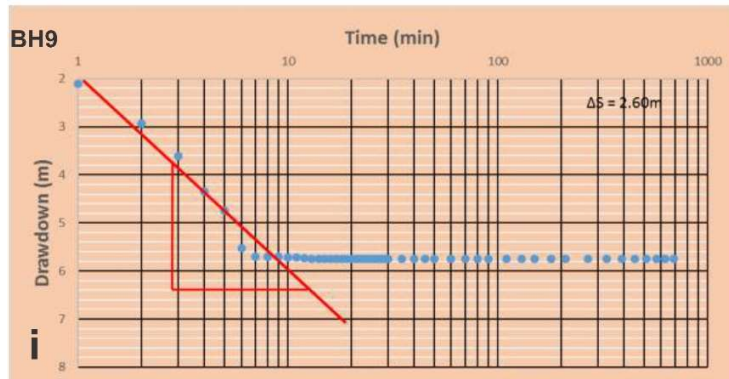
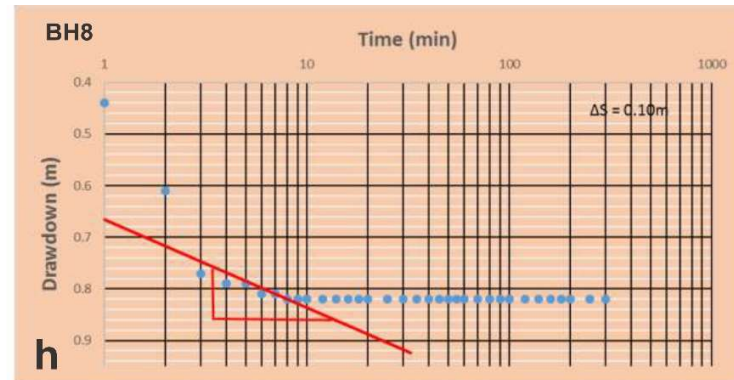
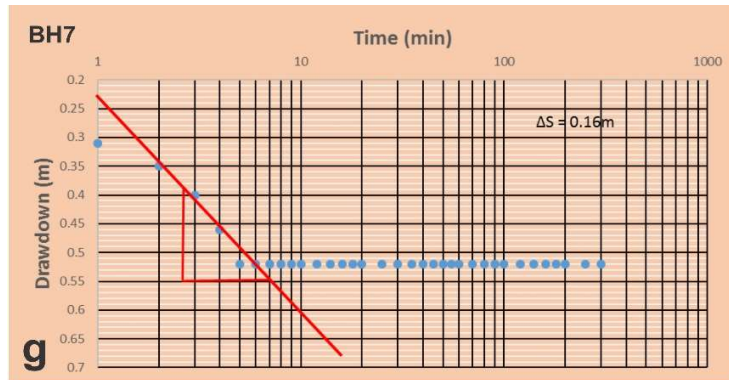


Fig. 8 Drawdown map of the boreholes in the study





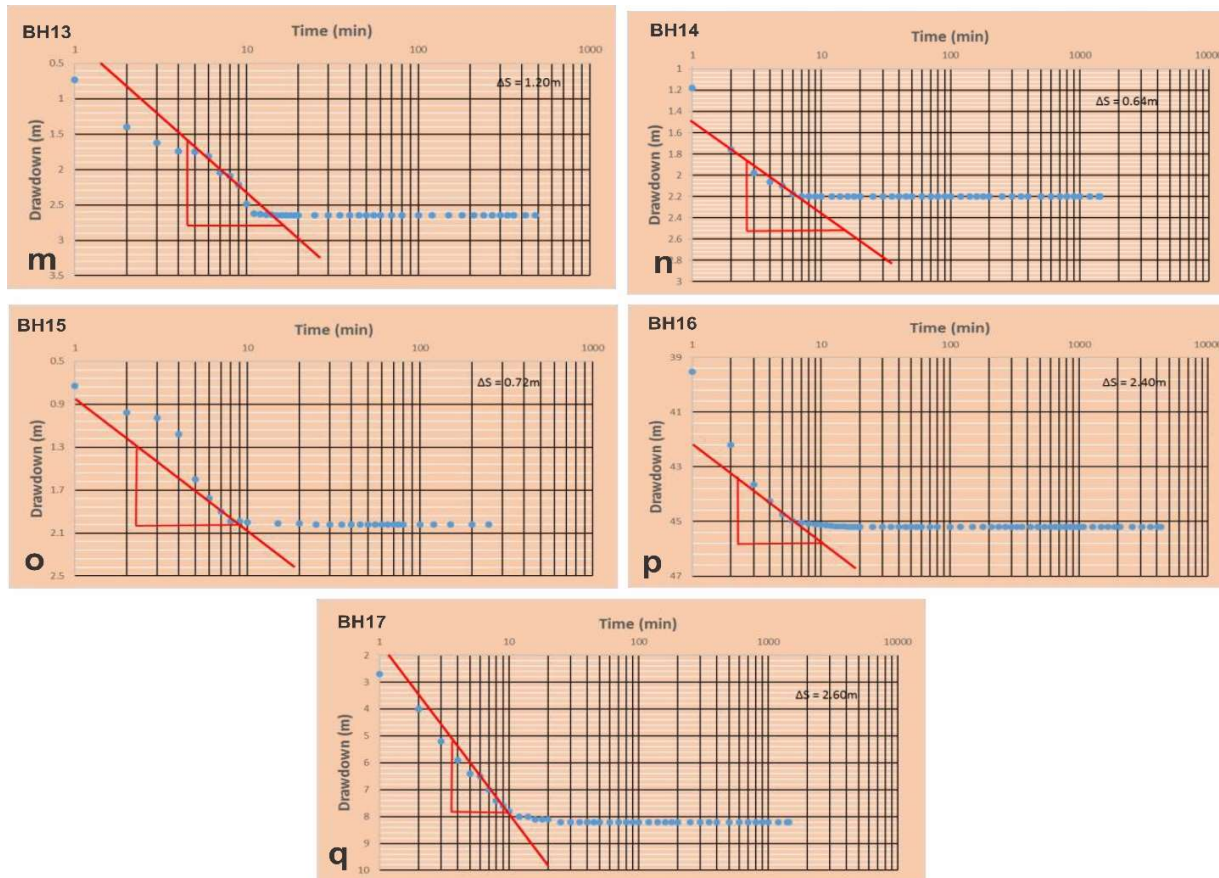


Figure 9-9ii: Time-drawdown graph for the constant pumping rate test for boreholes in the study area

The transmissivity values obtained after calculations as explained above range from $0.1 \text{ m}^2/\text{day} - 5145.47 \text{ m}^2/\text{day}$ ($2.7 \times 10^{-9} \text{ m/sec} - 5.96 \times 10^{-2} \text{ m/sec}$) respectively in the study area (Table 2). The transmissivity was further represented geo-spatially to provide a vivid picture of the values in different boreholes sampled within the study area (Fig. 10). The calculated Transmissivity values show that the lowest value was obtained in BH 14 while the highest value was obtained in BH 11 respectively. The calculated values in this present research were substantiated by the findings of others who also obtained similar estimates of transmissivity within the Niger Delta Basin (Akpoborie et al., 2011; Anomohanran, 2015; Ngah & Eze, 2017; Okiongbo & Odubo, 2012). Following the scheme of Gheorghe (1978), explained in

(Singh & Tripura, 2022), classes were assigned to the T values calculated in this present research (Table 3). This scheme of classification assigns T values to be $> 500 \text{ m}^2/\text{day}$, $50\text{-}500 \text{ m}^2/\text{day}$, $5\text{-}50 \text{ m}^2/\text{day}$, $0.5\text{-}5 \text{ m}^2/\text{day}$, and $< 0.5 \text{ m}^2/\text{day}$ to refer to high, moderate, low, very low, and negligible potentials respectively. The calculated T values for this study, therefore, are grouped as high (BH4, BH9, BH11, BH12, BH15), moderate (BH1, BH10, BH13, BH16), low (BH3, BH17), and very low (BH5, BH6, BH7, BH8, BH14) potentials respectively. Given, these results, most of the aquifers except those with very low potentials, possess a very good capacity to yield sustainable quantity of water for water supplies of regional, local, and private significance.

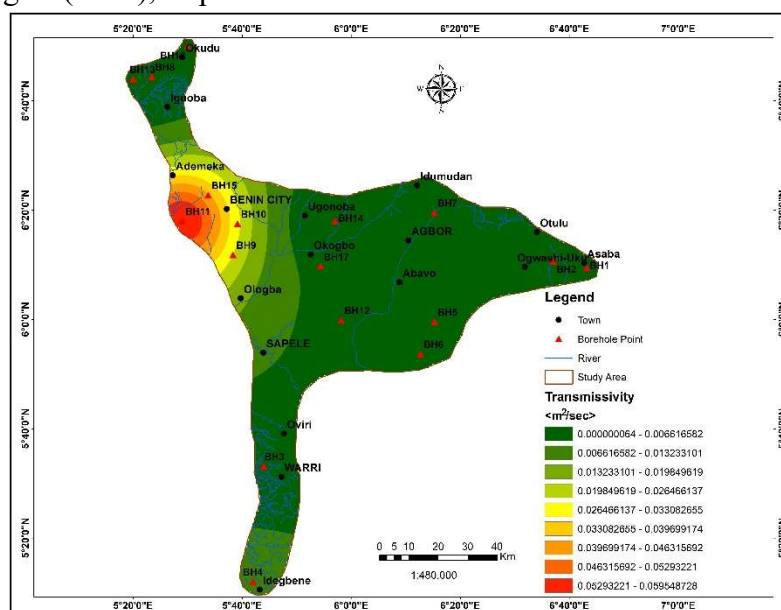


Figure 10: Spatial distribution of Transmissivity values in the study area

The hydraulic conductivity (K) revealed a range of $0.01 \text{ m/day} - 677.04 \text{ m/day}$ respectively. The lowest value of K was recorded in BH 5 while the highest value was recorded in BH 11 in Table 2, with the spatial distribution of K values within the study area displayed in Figure 11. The

hydraulic conductivities obtained showed high variations principally due to the differences in geologic materials that define the aquifers within the Niger Delta. A review of the hydrostratigraphy of the Niger Delta basin by Hassan et al., (2019) and (Abam & Nwankwoala, 2020) posited

a similar range of values of K, which affirms the credibility of the findings of this research. According to (Chiyem et al., 2023), values of hydraulic conductivity > 8 m/day suggests that the aquifer materials are consisting of sand in greater amount. In a similar manner to that of T values, the values of K obtained were compared with

the values outlined in the standard classification scheme of Bouwer (1978), which assigns geologic materials to different values as shown in Table 4. The classes the K values obtained in the research fell into (Table 4) revealed T values of good aquifer properties and potentials.

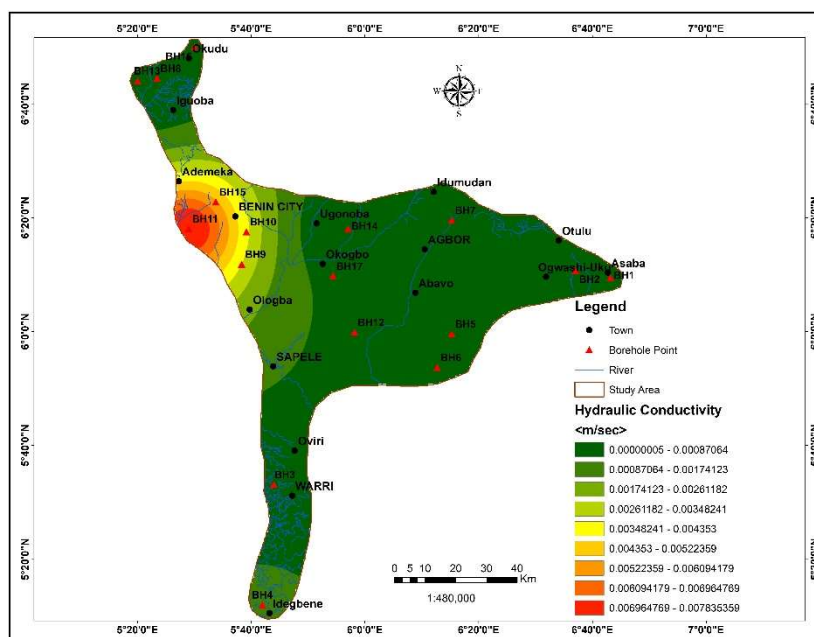


Figure 11: Spatial distribution of Hydraulic conductivity values in the study area

The specific capacity (S) is a parameter of an aquifer that usually provides insight into its productive capacity. The range of values of the specific capacity is from 0.000053 m/hr/m to 222.1 m/hr/m respectively. The lowest S values were recorded in BH 14 while the highest is that of BH 4 accordingly.

S values in this range have been reported in a published article in a recent study within the Western Niger Delta (Chiyem et al.,

2023) giving credibility to the one reported in this research. The study opines that this range of values of S means that such aquifer can be relied on for prolonged pumping for regional scale water supply purposes. S values are one of the very important geohydraulic parameters because it is usually relied upon when an aquifer behaviour is to be monitored over a prolonged period as this will assist in making sustainable aquifer management decisions.

Table 4 Computed Hydraulic Conductivity (K, m/day) values compared with the characteristics of materials according to Bouwer (1978) standards

Bouwer's Standard (K, m/day)	Computed (K, m/day)	Borehole No.	Materials
0.2	-	-	Clay soil (surface)
10^{-8} – 10^{-2}	0.09; 0.02; 0.05; 0.04	BH2, BH6, BH7, BH8	Deep clay beds
0.1-1	0.93; 0.1	BH3, BH14	Loamy soils
1-5	3.91	BH17	Fine sand
5-20	14.86; 7.96	BH1, BH10	Medium sand
20-100	93.03; 80.62; 73.5; 30.72	BH4, BH9, BH12, BH13	Coarse sand
100-1,000	677.04	BH11	Gravel
5-100	14.86; 93.03; 80.62; 7.96; 73.5; 30.72; 93.15; 15.85	BH1, BH4, BH9, BH10, BH12, BH13, BH15, BH16	Sand and gravel alternation
0.001-0.1	0.01; 0.1	BH5, BH14	Clay, sand and gravel alternation

CONCLUSIONS

This study provided a comprehensive insight into the hydrogeological framework and evaluated the geohydraulic parameters of the aquifer system of the Western Niger Delta Basin, southern Nigeria. The geological data (lithological logs, well depth, static water level, hydraulic head, etc.) were studied to portray a vivid representation of the hydrostratigraphic units within the study area. The hydrostratigraphic layers revealed that the water-bearing layers are the recent deltaic sands, alluvium, coastal plains etc., which are unassigned equivalents of the Benin Formation, and Ogwashi- Asaba Formation

believed to be exposed units of the deep-lying Agbada Formation in areas where they occur. The geohydraulic parameters computed using data obtained from the pumping test indicated a range of 0.1 m²/day – 5145.47 m²/day, 0.01 m/day – 677.04 m/day, and 0.000053 m/hr/m to 222.1 m/hr/m for Transmissivity, Hydraulic conductivity and Specific capacity respectively. The values of geohydraulic parameters obtained in this study were also significantly corroborated by previous and recent findings of other researchers in the study area. The results showed that except few boreholes within the study area, the majority of the boreholes possess geohydraulic parameters indicating that

they can survive prolonged pumping and can provide water at regional, local, and private scales respectively.

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