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Aquifer Hydraulic Conductivity Determination from Grain Size Analysis in Parts of Old Port Harcourt Township, Nigeria

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ABSTRACT

This study aims at the determination of aquifer hydraulic conductivity from grain size analysis in parts of Port Harcourt, Nigeria. Laboratory analysis of soil and aquifer materials tests were carried out on soil samples from some boreholes based on British Standards and ASTM standards. The hydraulic conductivity calculated from Hazen formula. Hydraulic conductivity (K) values for Boreholes are: Churchill Road, BH-1 (3.24×10^{-3}cm/sec); Borokiri Sand fill, BH-2 (3.62×10^{-3}cm/sec); Marine Base, BH-3 (9.61×10^{-3}cm/sec); Aggrey Road, BH-4 (8.41×10^{-3}cm/sec); Reclamation Road, BH-5 (2.2×10^{-3}cm/sec) and Harold Wilson Drive, BH-6 (4.0×10^{-3}cm/sec), respectively. These values are high within the typical permeability values for fine to coarse sand to gravel. The implication of high K values is that the aquifer is prolific, hence have very good water transmitting properties and can sustain withdrawal of regional importance. Based on the results obtained, all of the boreholes appraised in this work can sustain water supply needs of the rapidly urbanizing, densely populated old Port Harcourt area. Concern should only be shown in its management so that no undesirable consequence of un-harmonized withdrawal is induced.

Keywords: *Hydraulic conductivity, Aquifers, Grain size analysis, Boreholes, Port Harcourt.*

1. INTRODUCTION

Port Harcourt is located within latitudes 6° 58' to 7° 6'N and longitudes 4° 40' to 4° 55'E (Fig.1). It is located within the Quaternary alluvium tidal wetlands of the Niger Delta, with strong reversing tidal currents. The geology of the Niger Delta has been extensively documented by various research including Reyment (I965), Allen (1965), Short and Stauble (1967). The Niger Delta has an area of about 75000km^2 and the overall sedimentary sequence is dominantly composed of sand, shale and clay. The sand forms the major aquifers in the area while clay/shale forms the aquitards. The water table in the area varies with season. Generally, the water table is close to the surface, ranging from 0.6m to 1.2m below ground surface from wet season to dry season. The dominant fresh water aquifer is found within the Benin Formation which consists mostly of continental sands with clay and silt. These materials are believed to have been deposited in a continental fluviatile to deltaic environment. The clay units have variable thickness ranging from 1m to as much as 15m in some places. The sand and clay intercalations constitute a system of aquifers separated by aquitards given rise to a multi-aquifer system which characterize the Niger Delta (Etu-Efeotor and Odigi, 1983; Amajor, 1989a).

Although there is substantial hydraulic conductivity data on geologic materials of the Niger Delta, most of the data have been obtained from relatively shallow water wells in the upper part of the Benin Formation. Raw field data, from which hydraulic conductivities (permeability) may be deduced for the deeper Agbada Formation, are not easily accessible from the files of the multinational companies.

Like hydraulic conductivity, porosity has been evaluated for geologic materials of the Niger Delta by many researchers (Etu-Efeotor and Odigi 1983; Akpokodje 1987; 1988; Ngah 1990; Etu-Efeotor and Akpokodje, 1990; Izeze, 1990; Nwankwoala, et al., 2008). Akpokodje et al., (1996), determined porosity for these materials solely from sonic logs using the Raymer-Hurt method after correcting for compaction effects. The porosity values obtained ranged from 20-36%, and compared very well with those reported in the earlier studies. Because of the high cost of pumping tests, data is generally very scarce on pumping tests in the Niger Delta. Secondly, the general attitude of the clients is that the moment water is 'gushing' out of the well, the contractor is under pressure to demobilize from site. It hardly ever matters to them whether necessary post-installation tests are carried out or not. This is the rationale for this study.

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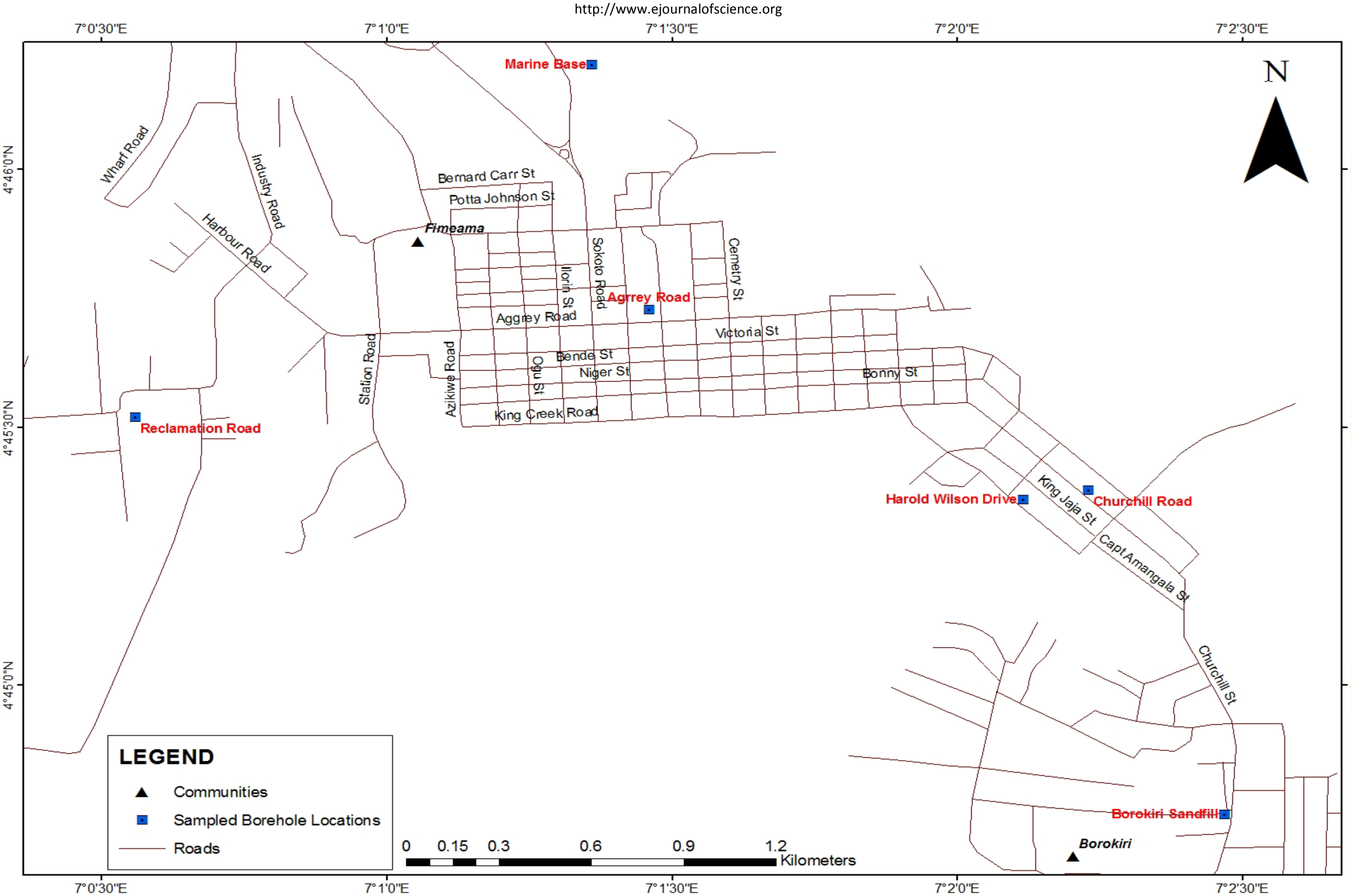

Fig 1: Map of Port Harcourt showing Study locations

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2. METHODS OF STUDY

2.1 Determination of Aquifer Hydraulic Conductivity, K (Permeability)

Depending on availability of data, two methods are available for determining hydraulic conductivity of aquifer materials, namely from pumping tests and from gain size analysis of the aquifer materials. In this study, grain size analysis was used.

Laboratory Analysis of Soil and Aquifer Materials tests were also carried out on soil samples from some boreholes based on British Standards (B.S) 1377 and ASTM (1975) standards. The particle size distribution was determined by washing a known weight of oven-dried sample through ASTM sieve No.200 (0.074mm), vibrated with a shaker until no fines were retained. The hydraulic conductivity of the aquifer materials was determined from gain size analysis of the aquifer materials. The percentage passing through the successive sizes were found from the difference between the initial weight and the weight retained by each sieve. The percentage passing's were plotted against grain size to obtain grain size distribution curves. The curves were used to calculate permeability of uniform sands with the empirical formula as proposed by Hazen (1893):

$K = Cd_{10}^2$

where

K = hydraulic conductivity (cm/s)

C = Constant (if k is in cm/s and D_{10} in mm, C = 1 (Freeze and Cherry, 1979)

d_{10} = Effective diameter (mm) defined as the diameter such that 10% by weight of the porous matrix consists of grains smaller than it.

In determining the size distribution, the following procedure was followed:

(1) Air-dry the samples;
(2) Obtain dry representative sample and reduce it to elemental particles by disaggregating with motar and pestle (if necessary);
(3) Sieving the particles through a stack of sieves and weighing quantity retained on each of the sieves;
(4) Computing the percentage passing each sieve based on the cumulative weight retained on any sieve and the total sample weight;
(5) Plotting the percentage passing versus the sieve opening on a semi-log graph paper.

After plotting, the d_{10} value is obtained and substituted into Hazen's formula to obtain the hydraulic conductivity. However, the value of hydraulic conductivity so obtained is only an estimate.

2.2 Results of Sieve Analyses for Samples in the Study Area

Summary of sieve analysis result

Sample No. A

Location: Churchill Road (BH-1)
Sample Depth =67. 05m
Mass of sample analyzed = 78.3 grammas

Sieve Diameter (mm)	Mass Retained (g)	Mass Passing (g)	% Passing
2.000	0.0	78.3	100.0
1.000	0.4	77.9	99.5
0.425	23.5	54.4	69.5
0.250	37.9	16.5	21.1
0.150	11.2	5.3	6.8
0.063	4.8	0.5	0.6

Sample No. B

Location: Borokiri Sand fill (BH-2)
Sample Depth =73. 05m
Mass of sample analyzed = 81.5grammes

Sieve Diameter (mm)	Mass Retained (g)	Mass Passing (g)	% Passing
2.000	0.1	81.2	99.8
1.000	0.2	81	99.6
0.425	30.7	50.3	62.0
0.250	36.6	10.7	17.1
0.150	9.6	1.1	5.3
0.063	0.7	0.4	4.4

Sample No. C

Location: Marine Base (BH-3)
Sample Depth =85. 3m
Mass of sample analyzed = 36.5grammes

Sieve Diameter (mm)	Mass Retained (g)	Mass Passing (g)	% Passing
2.000	0.0	36.5	100.0
1.000	4.7	31.8	87.1
0.425	25.1	6.7	18.4
0.250	5.5	1.2	3.3
0.150	1.0	0.2	0.5
0.063	0.2	0	0

Sample No. D

Location: Aggrey Road (BH-4)
Sample Depth =88. 38m
Mass of sample analyzed = 44.1grammes

Sieve Diameter (mm)	Mass Retained (g)	Mass Passing(g)	% Passing
2.000	0.2	43.9	99.5
1.000	6.0	37.9	85.9
0.425	28.6	9.3	21.1
0.250	5.8	3.5	7.9
0.150	1.0	2.5	5.7
0.063	0.0	2.4	5.7

Sample No. E

Location: Reclamation Road (BH-5)
Sample Depth =90.10m
Mass of sample analyzed = 79.02 grammas

Sieve Diameter (mm)	Mass Retained (g)	Mass Passing (g)	% Passing
2.000	0.3	80.6	99.63
1.000	0.5	87.4	90.0
0.425	21.5	58.5	72.8
0.250	38.4	19.9	26.0
0.150	13.5	6.5	9.5
0.063	5.9	0.7	2.3

Sample No. F

Location: Harold Wilson Drive (BH-6)
Sample Depth =100.03m
Mass of sample analyzed = 98.07grammes

Sieve Diameter (mm)	Mass Retained (g)	Mass Passing (g)	% Passing
2.000	0.5	79.3	99.38
1.000	0.4	92	98.9
0.425	20.7	60.2	73.0
0.250	46.8	12.6	14.5
0.150	9.7	1.3	2.4
0.063	0.6	0.2	1.6

3. RESULTS AND DISCUSSIONS

The hydraulic conductivity calculated from Hazen formula is stated in Table 1. From Table 1, K values for Boreholes are: BH-1 (3.24 x 10^{-3}cm/sec), BH-2 (3.62 x 10^{-3}cm/sec), BH-3 (9.61 x 10^{-3}cm/sec), BH-4 (8.41 x 10^{-3}cm/sec), BH-5 (2.2 x 10^{-3}cm/sec) and BH-6 (4.0 x 10^{-3}cm/sec) (Table 1). These values are high within the typical permeability values for fine to coarse sand to gravel (Garg, 2005). The implication of high K values is that the aquifer is prolific.

Similarly, other researchers have reported values of 3.9 x10^{-4} to 4.1 x 10^{-4}m/s (Amajor, 1989b); 4.2 x10^{-4} to 4.1 x 10-4 (Etu-Efeotor and Akpokodje, 1990); Etu-Efeotor and Odigi, 1983), 7.0 x 10^{-5} to 1.0 x 10^{-4}m/s for channel sand, 2.0 x 10^{-5} to 5.0 x 10^{-5}m/s for upper shore facies, and 4.0 x 10^{-6} to 5.0 x 10^{-6}m/s for lower shore facies (Akpokodje et al., 1996). In similar geologic materials outside the Niger Delta, hydraulic conductivities have also been estimated to range from 4.4 x 10^{-5} to 1.5 x 10^{-4}m/s (Onuoha and Mbazi, 1988), for the Ajali sandstone aquifer north of the Niger Delta.

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Table 1: Summary of sieve analysis results

Sample No.	BH No.	Study Location	Sample Depths (m)	Medium Sand (%)	Fine (%)	Fines (%)	D_{10} (mm)	D_{30} (mm)	D_{60} (mm)	C_u	C_c	K (cm/sec)
1	BH 1	Churchill Road	102.5	30.52	68.84	0.64	0.18	0.35	0.39	2.17	1.75	3.24×10^{-3}
2	BH 2	Borokiri Sand fill	90.3	38.04	57.55	4.42	0.19	0.295	0.41	2.16	1.12	3.61×10^{-3}
3	BH 3	Marine Base	87.2	81.64	18.36	0.00	0.31	0.5	0.7	2.26	1.15	9.61×10^{-3}
4	BH 4	Aggrey Road	96.4	78.91	15.42	5.67	0.29	0.49	0.7	2.41	1.18	8.41×10^{-3}
5	B H 5	Reclamation Road	90.10	27.20	70.49	2.32	0.15	0.27	0.38	2.53	1.28	2.2×10^{-3}
6	B H 6	Harold Wilson Drive	100.3	27.00	71.38	1.63	0.2	0.29	0.38	1.90	1.11	4.0×10^{-3}

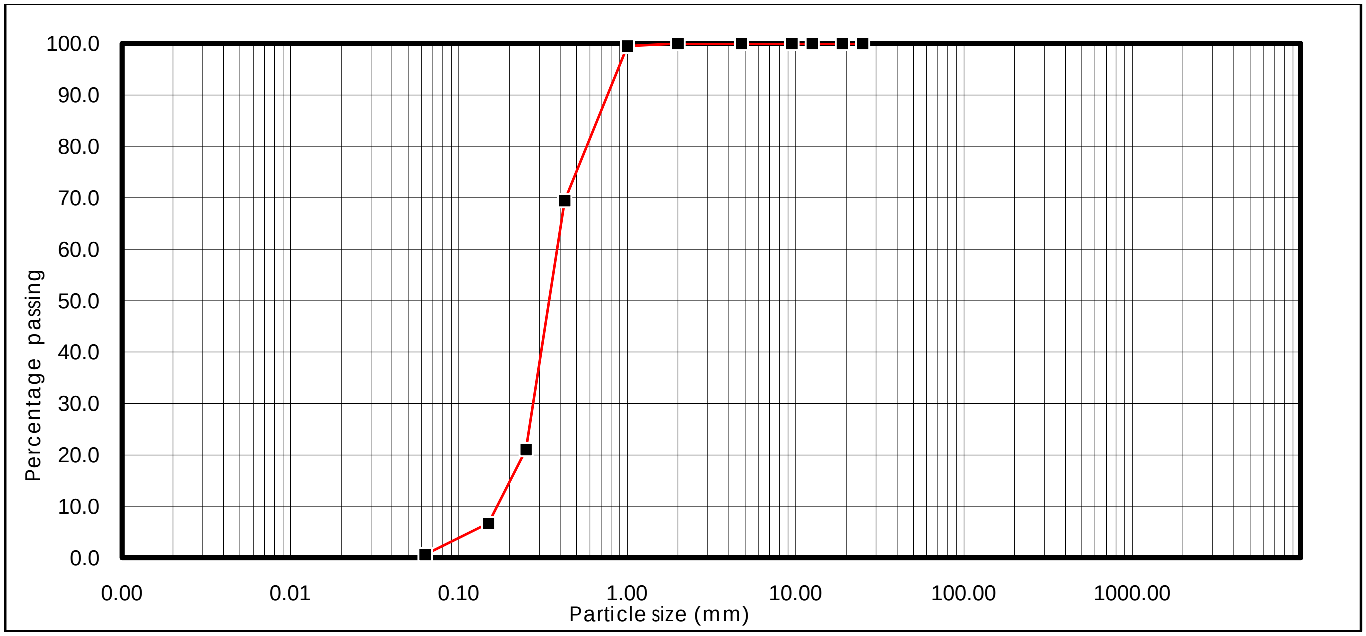

Fig 2: Grain size distribution curve of BH 1 @ 67.05m

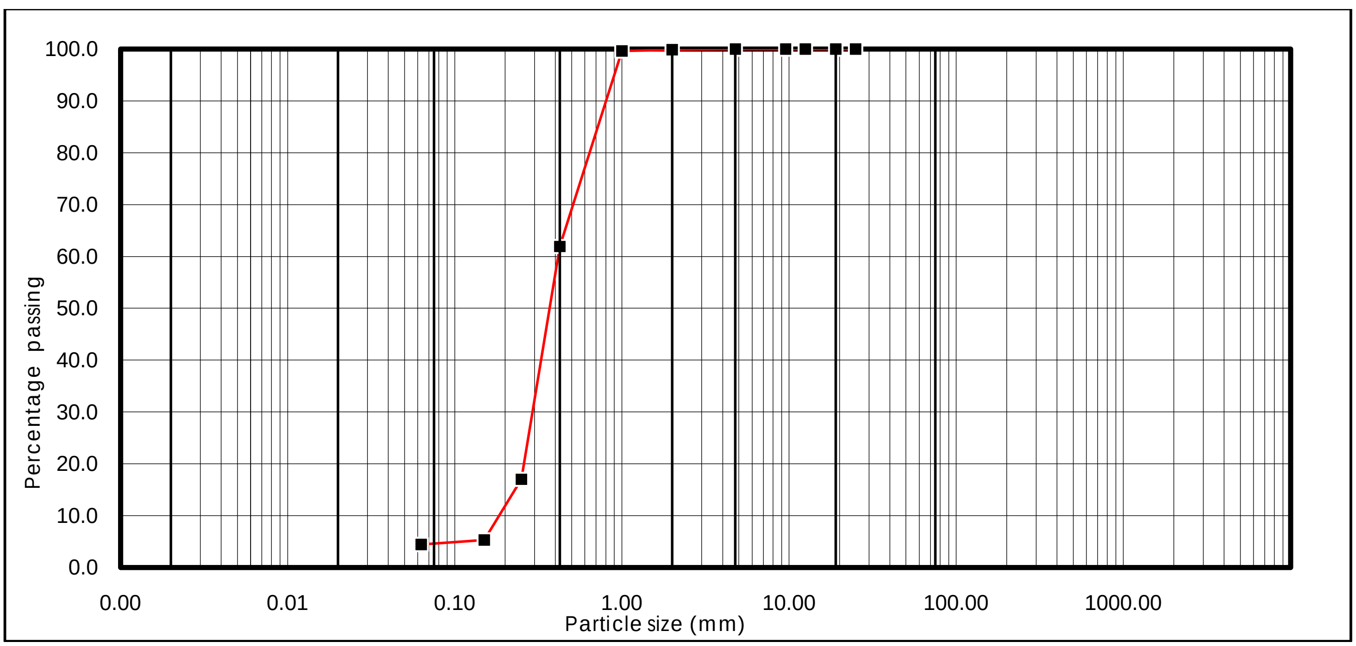

Fig 3: Grain size distribution curve of BH 2 @ 73.05m

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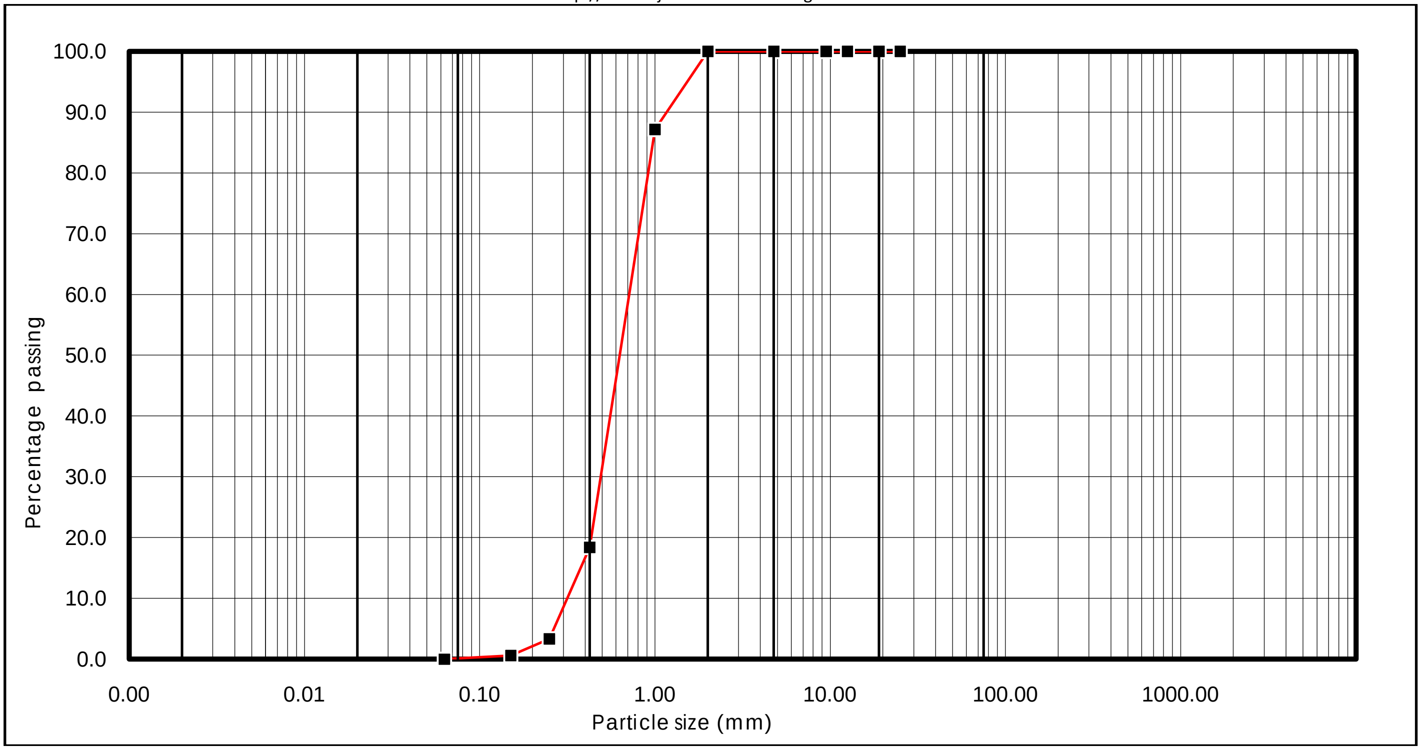

Fig 4: Grain size distribution curve of BH 3 @ 85.30m

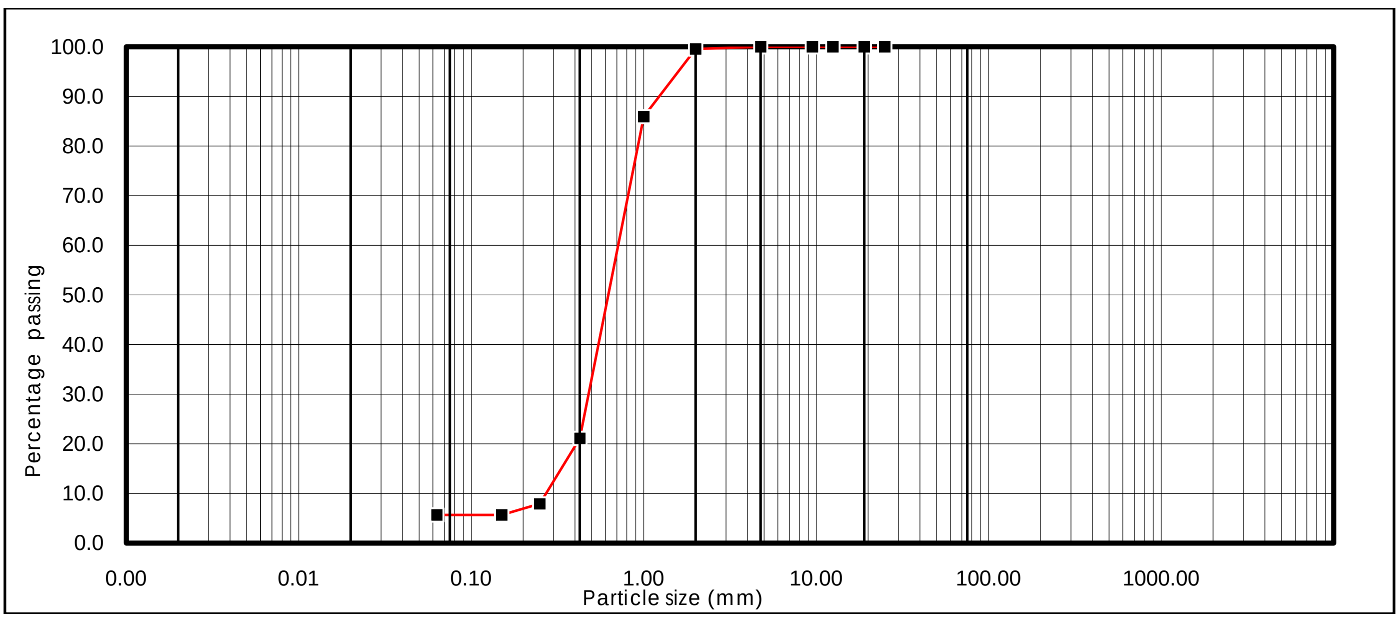

Fig 5: Grain size distribution curve of BH 4 @ 88.38m

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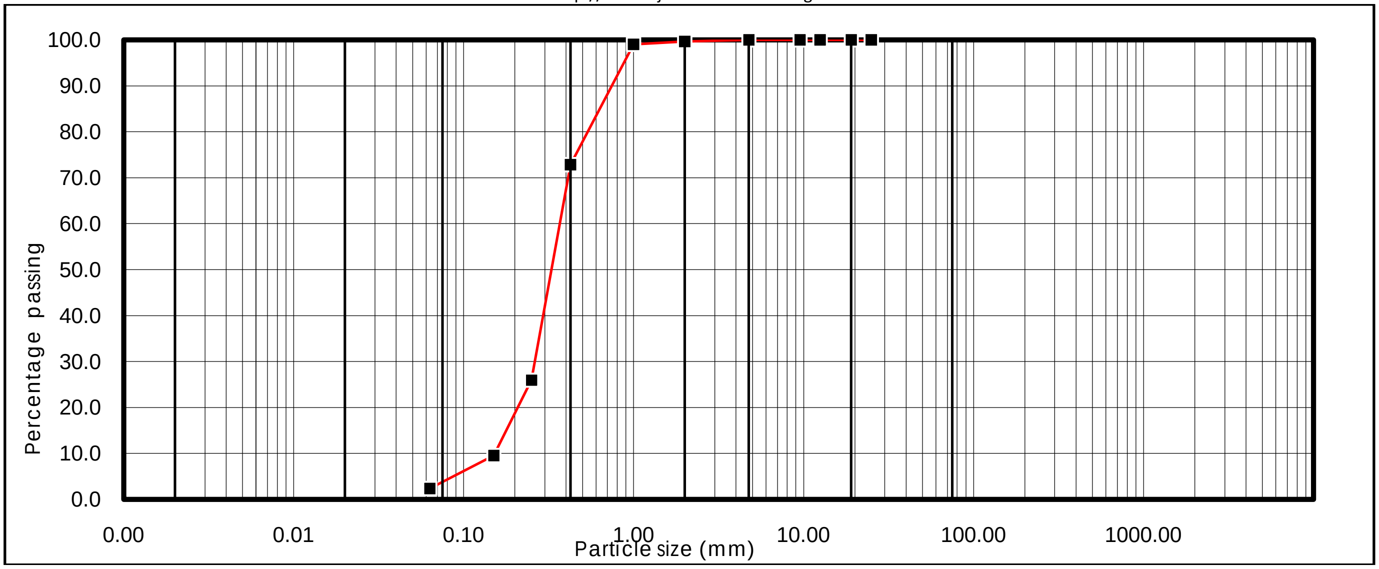

Fig 6: Grain size distribution curve of BH 5 @ 90.10m

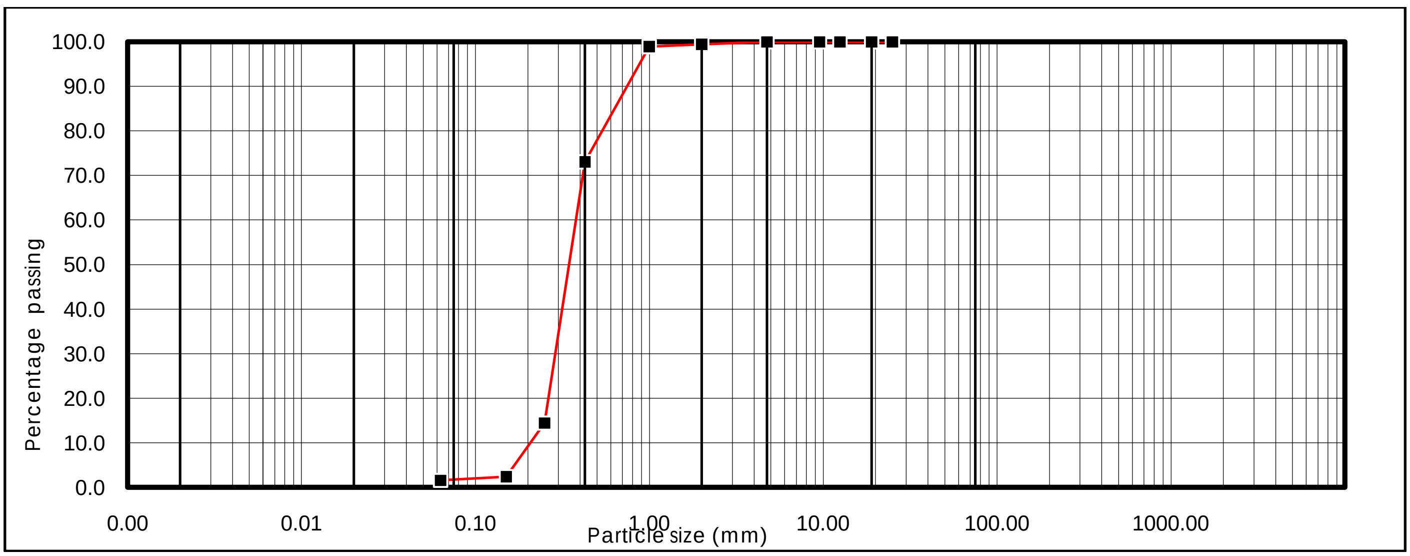

Fig 7: Grain size distribution curve of BH 6 @ 100.03m

4. CONCLUSION

This study reveals that the hydraulic conductivity (K) values for Boreholes studied includes: Churchill Road, BH-1 (3.24 x 10^{-3}cm/sec); Borokiri Sand fill, BH-2 (3.62 x 10^{-3}cm/sec); Marine Base, BH-3 (9.61 x 10^{-3}cm/sec); Aggrey Road, BH-4 (8.41 x 10^{-3}cm/sec); Reclamation Road, BH-5 (2.2 x 10^{-3}cm/sec) and Harold Wilson Drive, BH-6 (4.0 x 10^{-3}cm/sec), respectively. These values are high within the typical permeability values for fine to coarse sand to gravel. This shows the capability of the aquifer in transmitting enough water to boreholes. Earlier estimates of hydraulic parameters for boreholes in the Niger Delta (Allen, 1992, Etu-Effeotor, 2000) are in general agreement with the results from this study. It is recommended that detailed hydraulic conductivity studies using both pumping test and grain size analysis be carried in the Niger Delta.

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