USING HYDROLOGIC CHARACTERISTICS OF AQUIFERS IN EVALUATING THE GROUNDWATER RESOURCES OF PORT HARCOURT AND ITS ENVIRONS, SOUTH-EAST, NIGERIA

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Abstract
Hydrostratigraphic and hydraulic characteristics of the aquifer in Port Harcourt and its environs were established using lithologic logs, pumping test data, and grain-size technique. Sediments of Agbada and Benin formations made up essentially of sand of varying texture, and clay and other low permeability materials constitute the surface geology of the area. Analysis of the pumping test data using Cooper-Jacob straightline method provided important information on the aquifer properties of the area. Two (2) groups of aquifer units were delineated based on depth of occurrence. The shallow unit ranges in depth from 15 metres to about 70 metres whereas the deeper units range from 125 metres to over 220 metres. The transmissivity and hydraulic conductivity computed from pumping test data range respectively from 5.18 x $10^{-4}m^2/s$ to 1.98 x $10^{-2}m^2/s$ and 7.58 x 10^{-6}m/s to 3.62 x10^{-4}m/s. Analysis of grain-size data using grain-size technique for estimating elastic storage coefficient for sand aquifers, provided storativity in the range of 5.69 x 10^{-3} to 1.13 x 10^{-2}.

Keywords: Aquifer, Groundwater, Drawdown, Transmissivity, Hydraulic Conductivity, Storativity.

1.1 Introduction

The rapidly increasing human population and industrialization of Port Harcourt has led to a sharp rise in the demand for water for various uses. Presently, demand is somehow met from groundwater and surface water sources. Groundwater consists mainly of developed domestic, industrial and government sponsored water wells which tap the underlying aquifer to various depths. Supply from groundwater sources is however inadequate resulting to severe shortages of potable water. Attempts are uncoordinated as various governmental and non-governmental agencies, community and individual efforts chart their own separate courses and end up with failed water schemes and huge financial losses.

Two (2) major factors stand out as limitations to achieving a sustainable level of water supply quantity and quality wise.

These include:

-Lack of knowledge of the aquifer architecture including their layout (aquifer unit succession), hydrologic characteristics, and avoidable lapses in the design and implementation of borehole programmes.

This paper presents the hydrologic characteristics of aquifers in Port Harcourt and its environs as a basis for evaluating the groundwater resources in the area with a view to provide a database for more complete understanding of the water resource potential necessary for planning and sustainable management of the resource. Aquifer unit succession (layout) as presented in this work would be useful for proper design and implementation of borehole schemes in the area.

1.2 Physiography and General Geology

The study area is situated within the Niger Delta sub region of Nigeria between latitudes 4° 20' and 4° 45' N and longitudes 6° 58' and 7° 02' E (see figure 1).

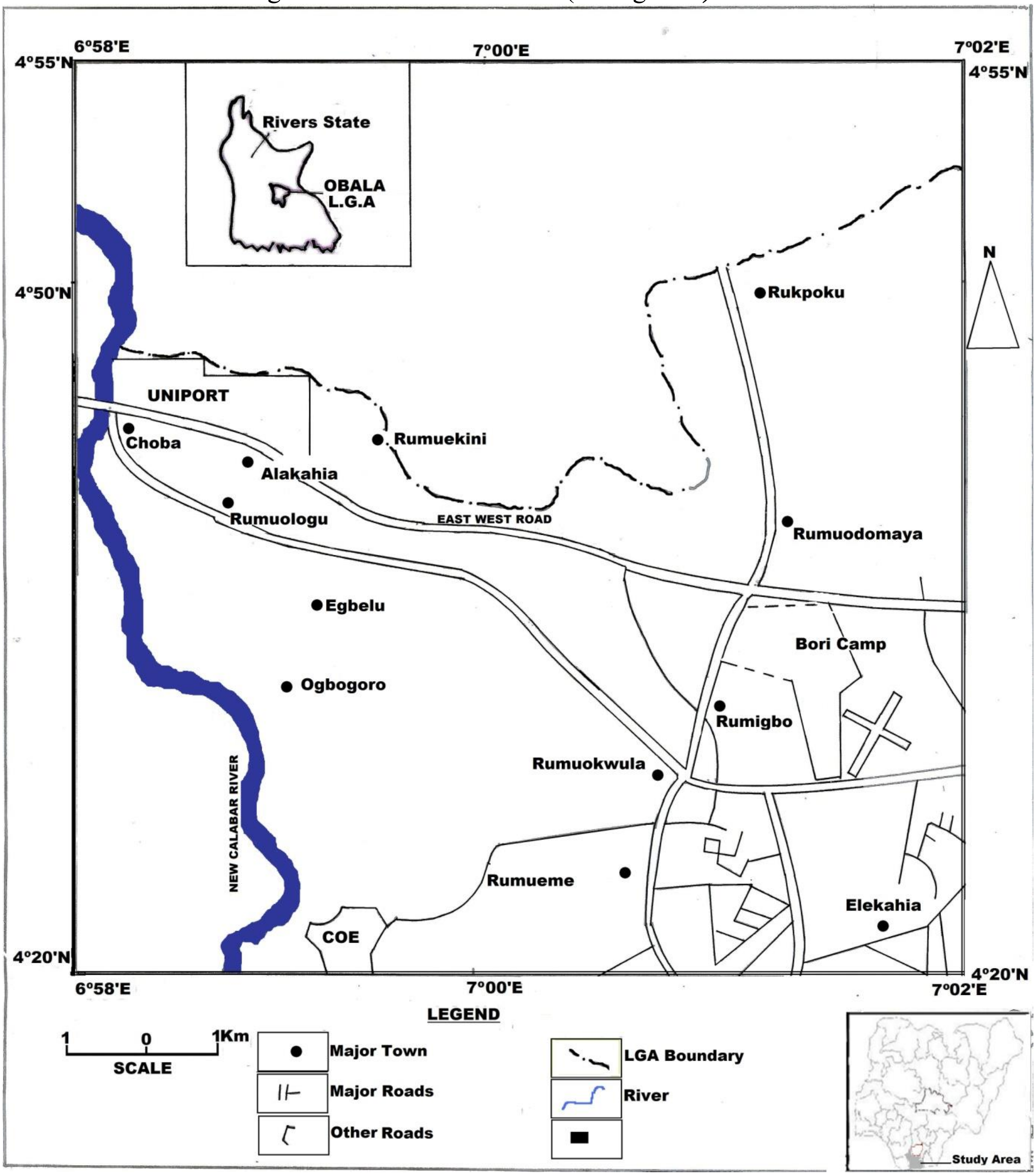

Figure 1: Location map of the area.

The relief in the coastal area is a few meters above mean sea level (M.S.L.). Drainage is of dendritic to deranged network; a dendritic pattern obtains in the upper region of the Niger Delta area, but nearer the coastline area, drainage is typically of a deranged pattern. The New Calabar River is the major surface water drainage system within the area. The flow is perenial, and toward the south-east direction, emptying into the Bonny River and ultimately into the Atlantic. The channel has meanders and exhibits significant width variations over some segments of flow. It has a maximum average discharge of 15.1m^3/s in the rainy season and 3.0m^3/s in the dry season.

Available records show that rainfall in the study area averages between 1000mm and 2000mm and peaks in the months of July and October with the rainy season occurring between mid - April and early November. On the other hand, the dry season starts around mid – November and ends by March or early April. It is characterized by hazy, dry and dusty winds called the North-East Trade winds or Tropical Continental Air Mass emanating from the Arabia – Eurasia high pressure belt. Expectedly, the vegetation in the area is a rain – forest vegetation as the rainfall is quite high.

The study area is located within the Niger Delta Basin. Geologically, rocks of the Niger Delta are subdivided into three formations which are Akata, Agbada and Benin Formations (Nwankwoala, Udom, and Ugwu 2011). The Benin Formation is underlain by Agbada and Akata Formations.

The Benin Formation consisting predominantly of massive highly porous sands and gravels with locally thin shale/clay interbeds, forms a multi-aquifer system in the Delta (Nwankwoala etal, 2011). Etu-Efeotor (1981) noted that the thin clay units of the Benin Formation have resulted to a multi-aquifer system in most parts of the Niger Delta where the formation outcrops. Weber and Daukoru (1975) noted that the Benin Formation (Miocene to Recent) consists of freshwater continental alluvial sands and gravels, with occasional clay layers and overall thickness of 2100 meters at the basin center. It is the most prolific in the study area.

Overlying the Benin Formation are the quaternary deposits (40 to 50 meters thick), an unconfined aquifer sequence comprising rapidly alternating sequences of sand and silt/clay, with the latter becoming increasingly prominent seawards (Etu-Efeotor and Akpokodje, 1990; Ngah, 2002).

The Akata Formation consists of low density, high pressure, shallow marine to deep shales (Schield, 1978). Nwankwoala et al (2011) noted that the formation consists of uniform shale rocks. The Agbada Formation consists of alternating deltaic (fluvial, coastal, fluviomarine) sands and shale (Nwankwoala and Udom, 2011). Nwankwoala et al (2011) observed that the three formations (Akata, Agbada and Benin) of which the Niger Delta Basin is characterized consist primarily of regressive tertiary age deposits. Figure 2 shows the geologic map of the study area.

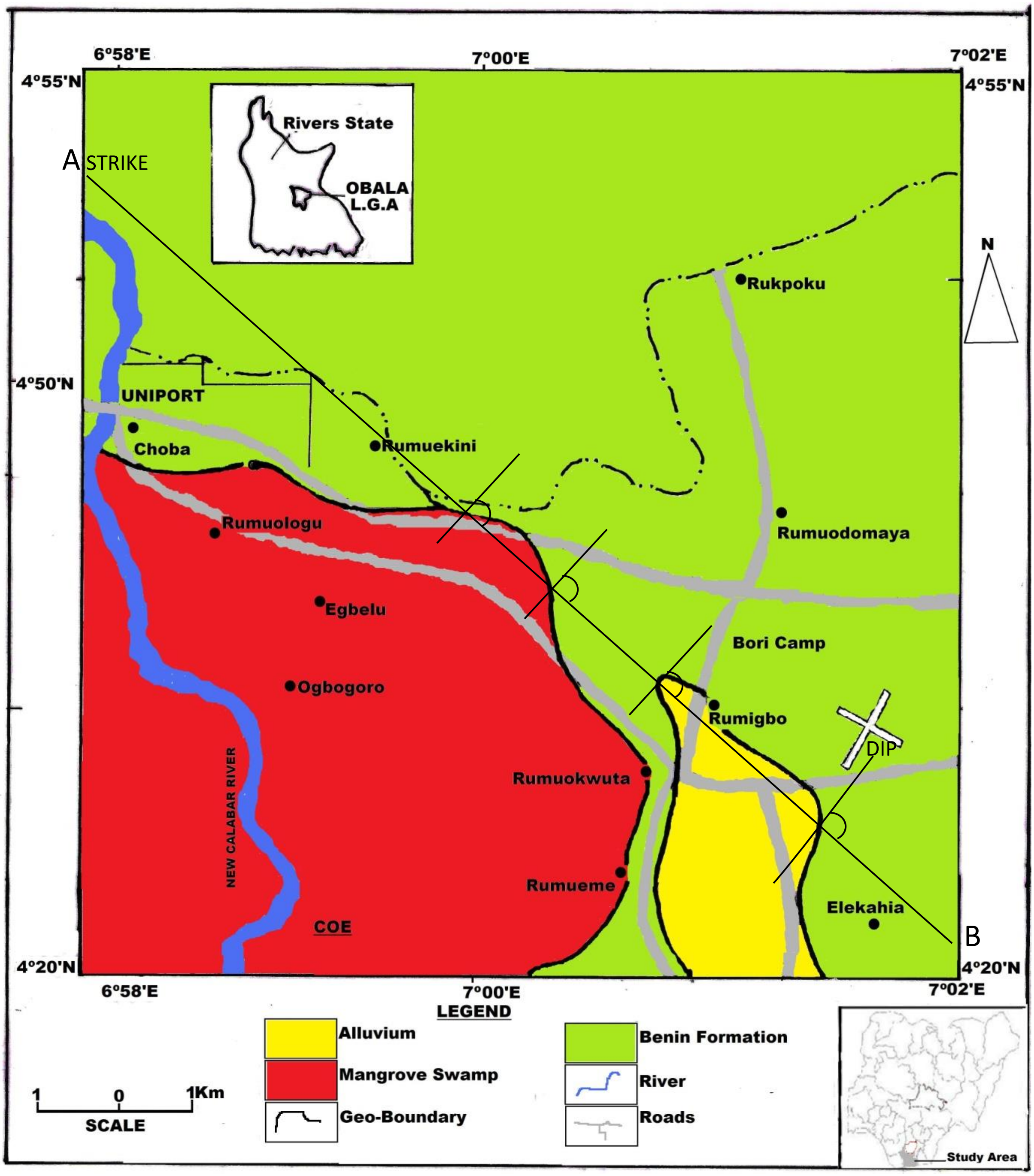

Fig. 2: Geologic Map of Port Harcourt and Its Environs (Source: Nigeria Geological Survey Agency, 2011*).*

2.0 Materials and Methods

The data, some of which were obtained from the Rivers State Water Board, Port Harcourt, comprise of pumping test results and lithologic logs for ten (10) boreholes in the area as well as grain-size data for four (4) out of the ten (10) boreholes. For the purpose of this work, these boreholes are designated 'PH 1- 10'.

Basic aquifer parameters like transmissivity (T), and hydraulic conductivity (K) were determined for eight (8) boreholes. It was not possible to compute storativity or storage coefficient (S) using pumping test analysis because the data were obtained from single-well pumping test. However, this parameter was determined using grain-size data following the technique developed by Nwankwor (1995).

Data on the time – drawdown measurements were analyzed using the Cooper – Jacob's modification of the Theis equation in which

$$T = \frac{0.183Q}{\Delta S} \quad \ldots\ldots (1)$$

Where:
T is transmissivity (m^2/s),
Q is pumping rate (m^3/min), and
Δ S is change in drawdown.

Drawdown was plotted against time on a semi-logarithmic scale. A line of best–fit was drawn through the data points. The increase in drawdown over one (1) log cycle was then substituted in the Cooper – Jacob equation to calculate T.

The hydraulic conductivity (K) was calculated from the relation;

$$T = Kb \quad \ldots\ldots (2)$$

And

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

where b is the aquifer thickness (in metres).

The storativity or storage coefficient (S) was determined using grain-size technique. The equation for the determination is of the form:

$$S = \ell g (\propto + \beta n)\, b \quad \ldots\ldots (4)$$

where b is the aquifer thickness, ℓ and β are the density and compressibility of water respectively, g is the gravitational acceleration, n is the porosity of the aquifer and $\propto$ is the compressibility of the aquifer matrix.

Coefficient of uniformity which provides the basis for the determination of prerequisite textural parameters such as porosity and aquifer compressibility, required for the calculation of storativity from grain-size technique, was obtained from grain-size plot. Holtz and Kovacs (1981) defined it as:

$$Cu = D_{60} / D_{10} \quad \ldots\ldots (5)$$

where Cu is coefficient of uniformity, and D_{60} and D_{10} are grain–size diameters (mm) corresponding respectively to the grain – size that is 60% and 10% finer by weight. The values as obtained for some locations were used to determine the respective porosity and aquifer compressibility values using Composite Graphical Model as provided by Nwankwor (1995). Figure 3 shows the Model.

The lithologic logs were used to determine the lithologic succession. This enabled the delineation of the aquifers and construction of hydrostratigraphic columns for all the borehole locations.

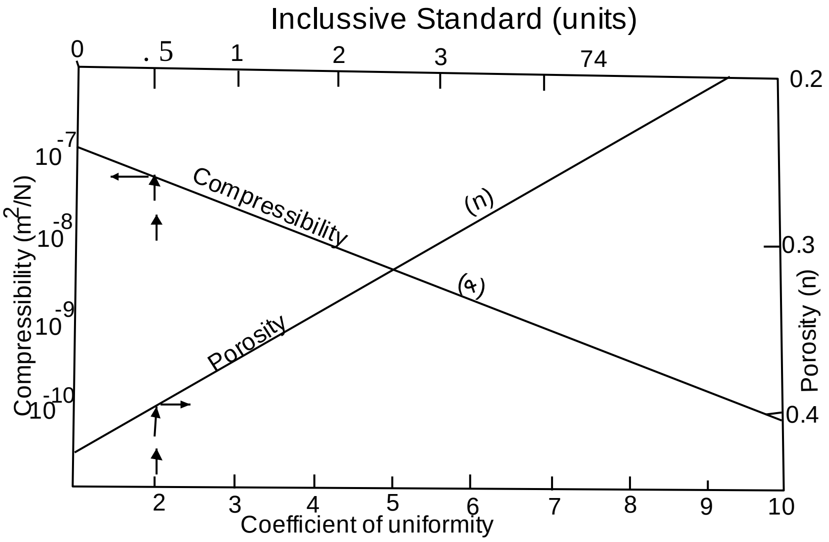

Fig.3: Composite graphical model showing the sorting – porosity – compressibility relation. Source: G.I. Nwankwor (1995).

3.0 DATA ANALYSIS AND RESULTS

3.1 Hydrostratigraphy and aquifer units

Figure 4 (a-c) show elevation and lithoprofiles for some of the locations, and as correlated along sections A-B, A-C, and B-C (see figure 5). The lithoprofiles show that the geologic units consist predominantly of sand. Other units are clay, sandy clay, clayey sand, gravelly sand and gravels. The sands are fine to medium to coarse to very coarse texturally, and are occasionally gravelly. Sorting index analysis from grain – size distribution curve shows two (2) sand unit systems that are well sorted. Generally, the sand units are relatively thick across the study area; the thickness ranges from 15 metres to over 200 metres. The clay units vary in thickness from 2 metres to 15 metres. Peat units occur in the southeastern corner of the study area at depths of about 80 meters. However, some distinct stratigraphic units are not evident in some locations and this suggests lateral termination of stratum.

Depth to water table in the area varies from 4.0 meters (in the coastline area) to about 16 meters further (into the hinterland). As could be deduced from the stratigraphic columns, and based on the depth of occurrence, shallow and deep aquifers are the two (2) groups of aquifer units found in the area. The shallow units range in depth from 15 meters to about 70 metres whereas the deeper units range from 125 metres to over 220 meters. The shallow units occur under unconfined and partially unconfined conditions. Multi-aquifer systems occur at the southernmost portion of the study area precisely at location 7.

The shallow aquifer units range in thickness from 25 metres in the northeastern portion to 60 metres in the southeastern portion whereas the deeper units range from 20 metres in the southernmost portion to 185 metres in the northwestern portion.

Table 4 shows the ground surface elevation (above mean sea level), and depth to water table for the various locations. The elevation ranges from 6.10 metres (in the coastline area) to 15.22 metres (in the hinterland). Elevation and static water table measurements were used to calculate the hydraulic head for the various locations; the values are in the range of 1.2 metres to 6.2 metres. The result shows that the hydraulic head decreases towards the coastline.

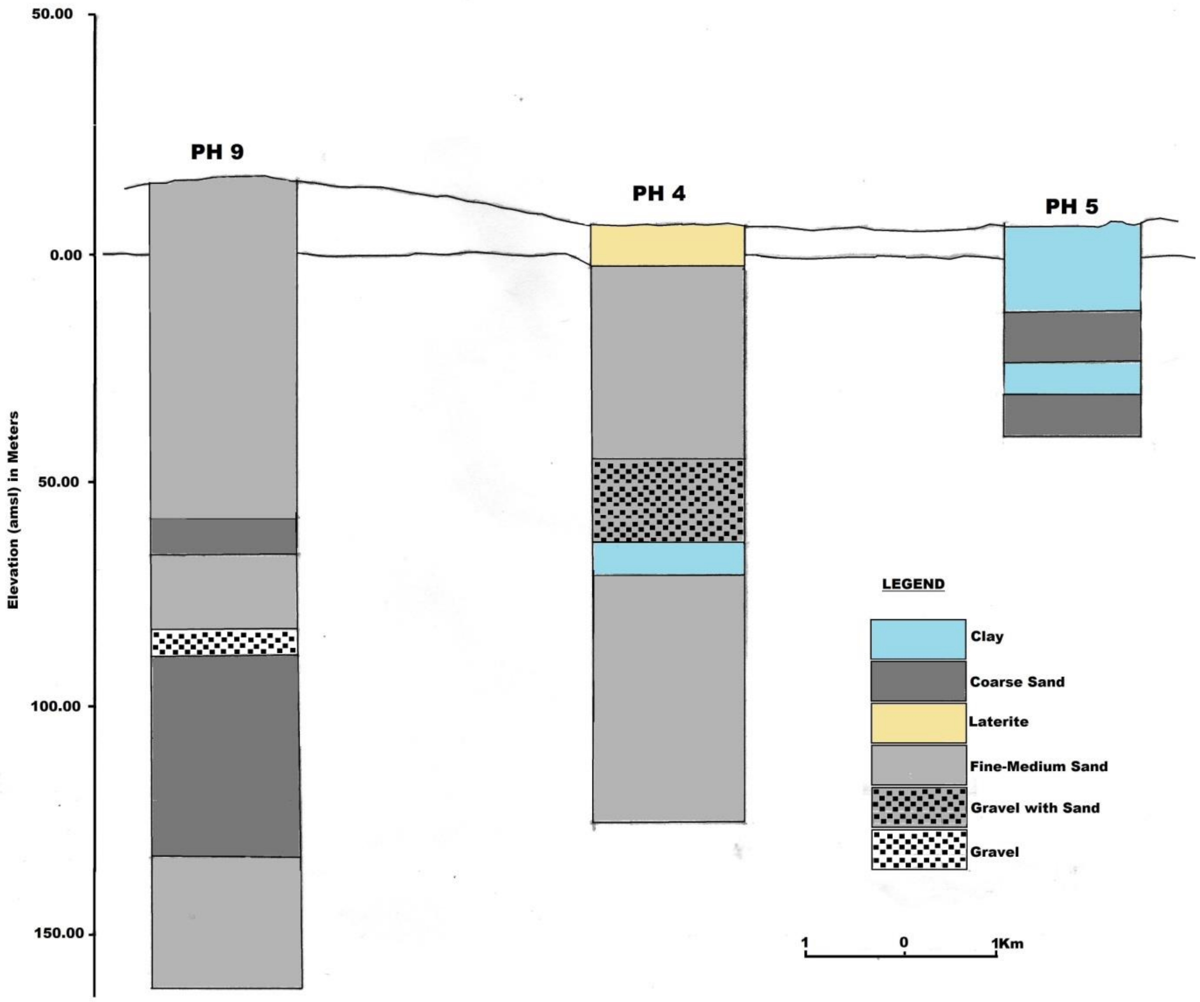

Fig. 4(a): Elevation and Lithoprofiles for PH 9, 4, and 5

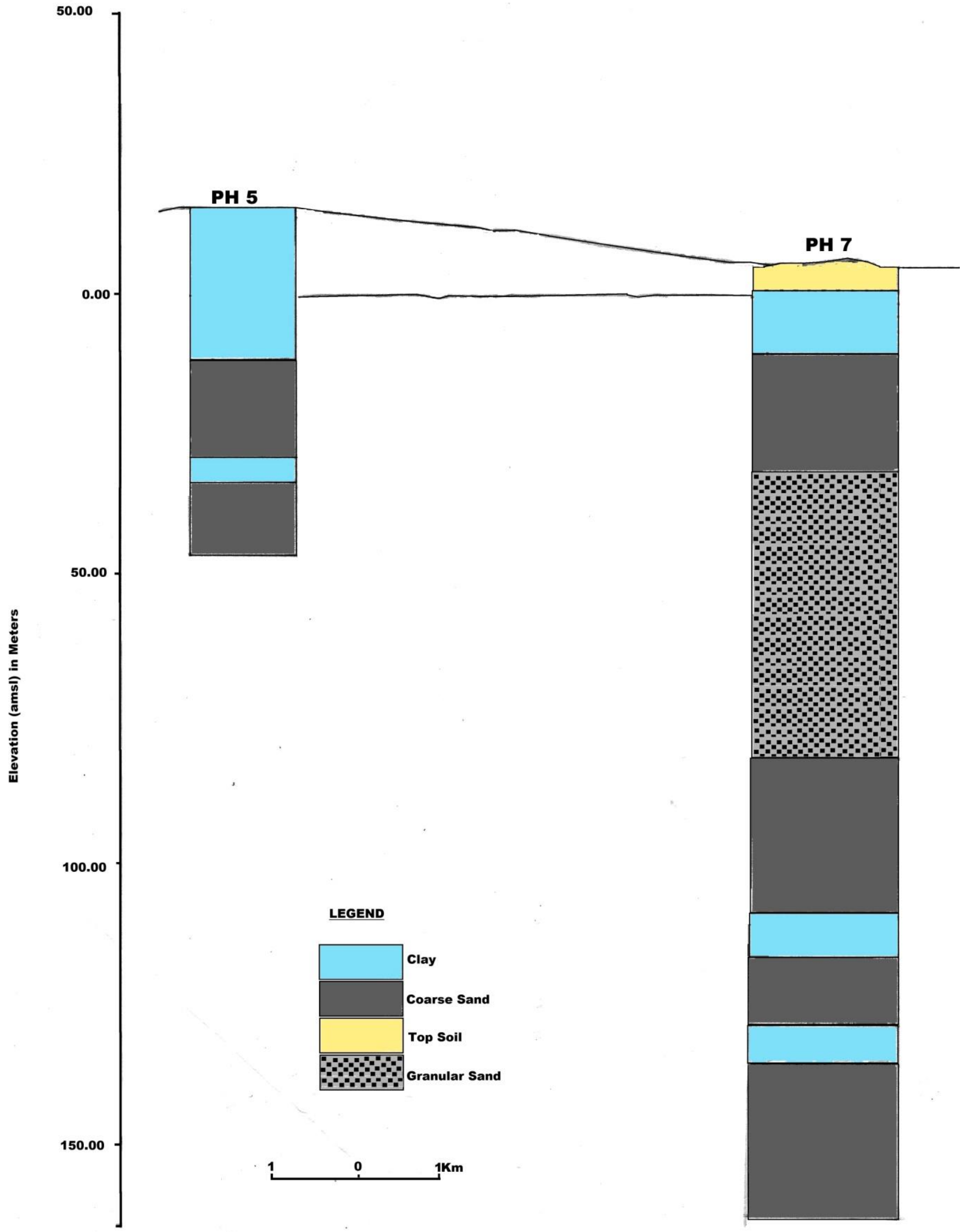

Fig. 4(b): Elevation and Lithoprofiles for PH 5 and 7

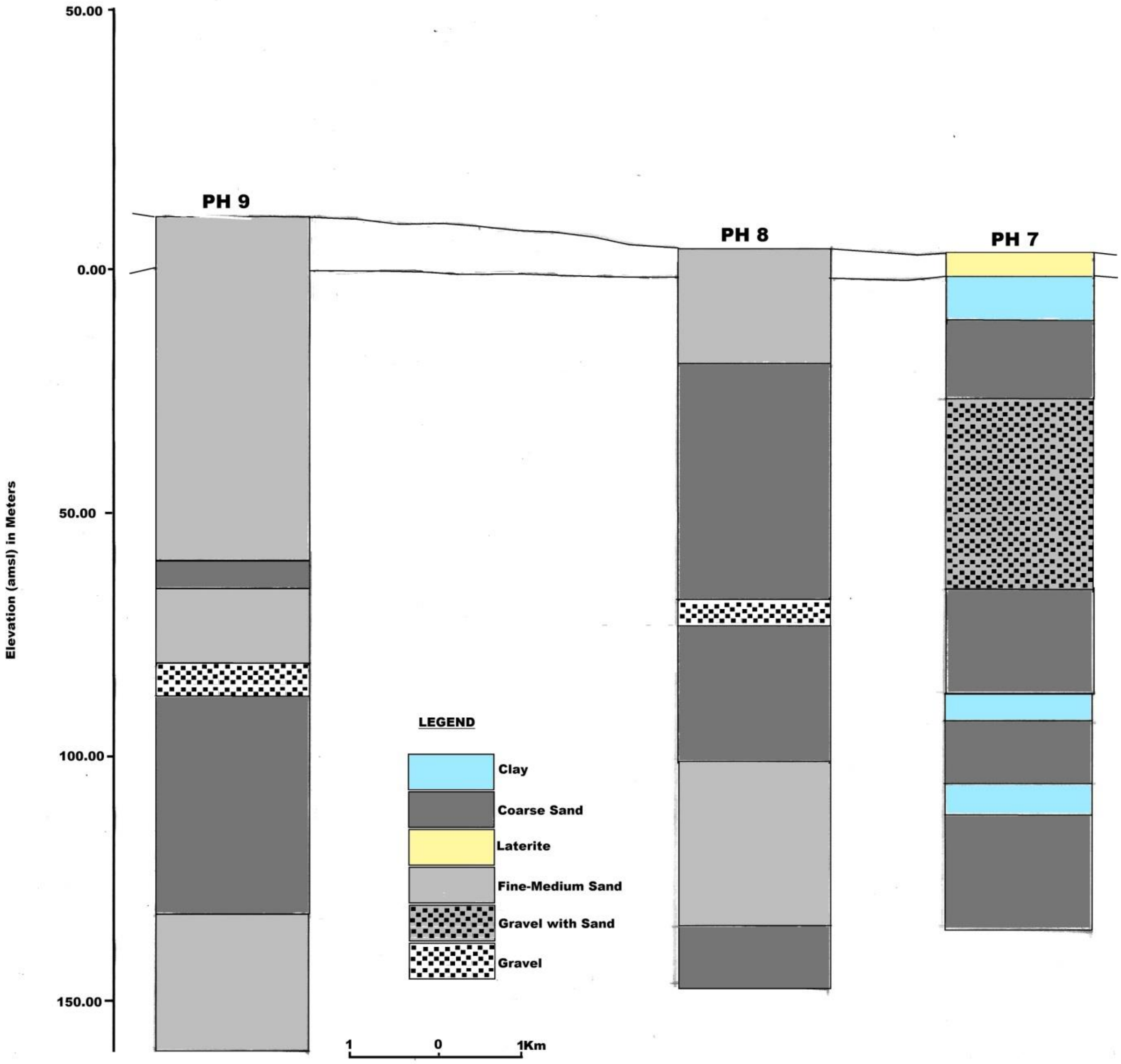

Fig.4(c): Elevation and Lithoprofiles for PH 9, 8, and 7

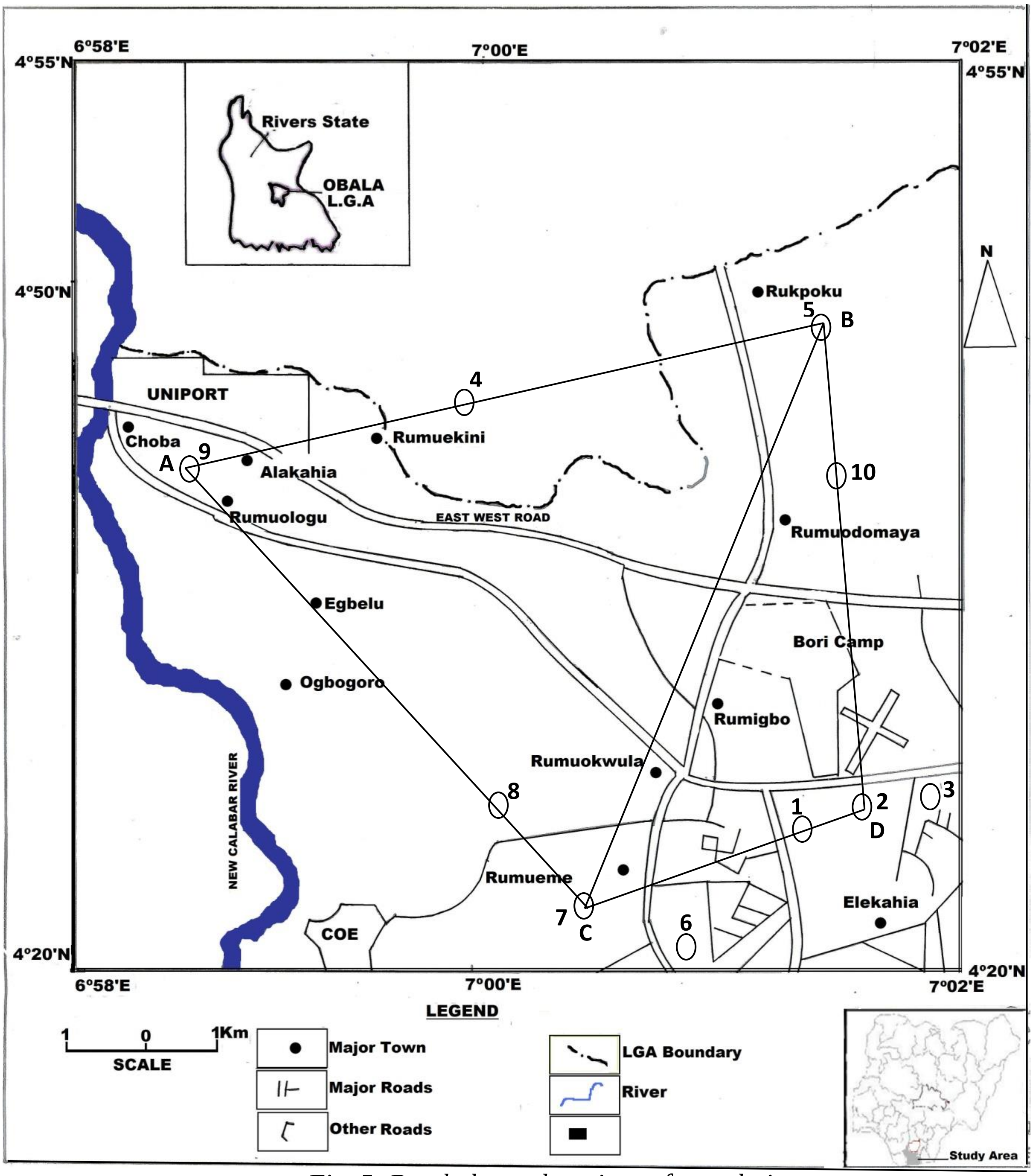

Fig. 5: Boreholes and sections of correlation

Table 1: WTD, Elevation, and Hydraulic head for the locations

Borehole Number	Water Table Depth (m)	Elevation (m)	Hydraulic Head (m)
PH 1	4.1	6.30	2.2
PH 2	4.1	6.30	2.2
PH 3	4.1	6.30	2.2
PH 4	10.0	14.21	4.2
PH 5	9.0	15.22	6.2
PH 6	4.7	5.90	1.2
PH 7	4.6	5.99	1.4
PH 8	4.0	6.10	2.1
PH 9	6.9	12.30	5.4
PH 10	6.4	12.22	5.8

3.2 AQUIFER PARAMETERS

Figures 6 a, b and c are the semi-logarithmic plots of selected time-drawdown plots as obtained in boreholes PH 3, PH 6, and PH 7 respectively. The transmissivity and hydraulic conductivity values as well as Storativity values as calculated using grain-size method are shown in table 2. Table 2 also shows drawdown, pumping rates and aquifer parameters at the various locations.

Table 2: Flow and Storage Parameters of Port Harcourt Wells

BOREHOLE NUMBER	DRAWDOWN (m)	PUMPING RATE (m^3/min)	T (m^2/s)	K (m/s)	S
PH 2	2.41	1.67	2.12×10^{-3}	4.57×10^{-5}	
PH 3	0.25	1.59	1.98×10^{-2}	3.62×10^{-4}	1.13×10^{-2}
PH 4	1.62	1.69	3.16×10^{-3}	5.49×10^{-5}	
PH 6	6.60	1.21	5.55×10^{-4}	1.95×10^{-5}	5.69×10^{-3}
PH 7	6.71	1.16	5.18×10^{-4}	1.77×10^{-5}	
PH 8	2.43	0.98	1.20×10^{-3}	7.58×10^{-6}	
PH 9	1.86	1.07	1.77×10^{-3}	7.87×10^{-6}	
PH 10	0.62	1.64	7.97×10^{-3}	1.64×10^{-4}	9.41×10^{-3}

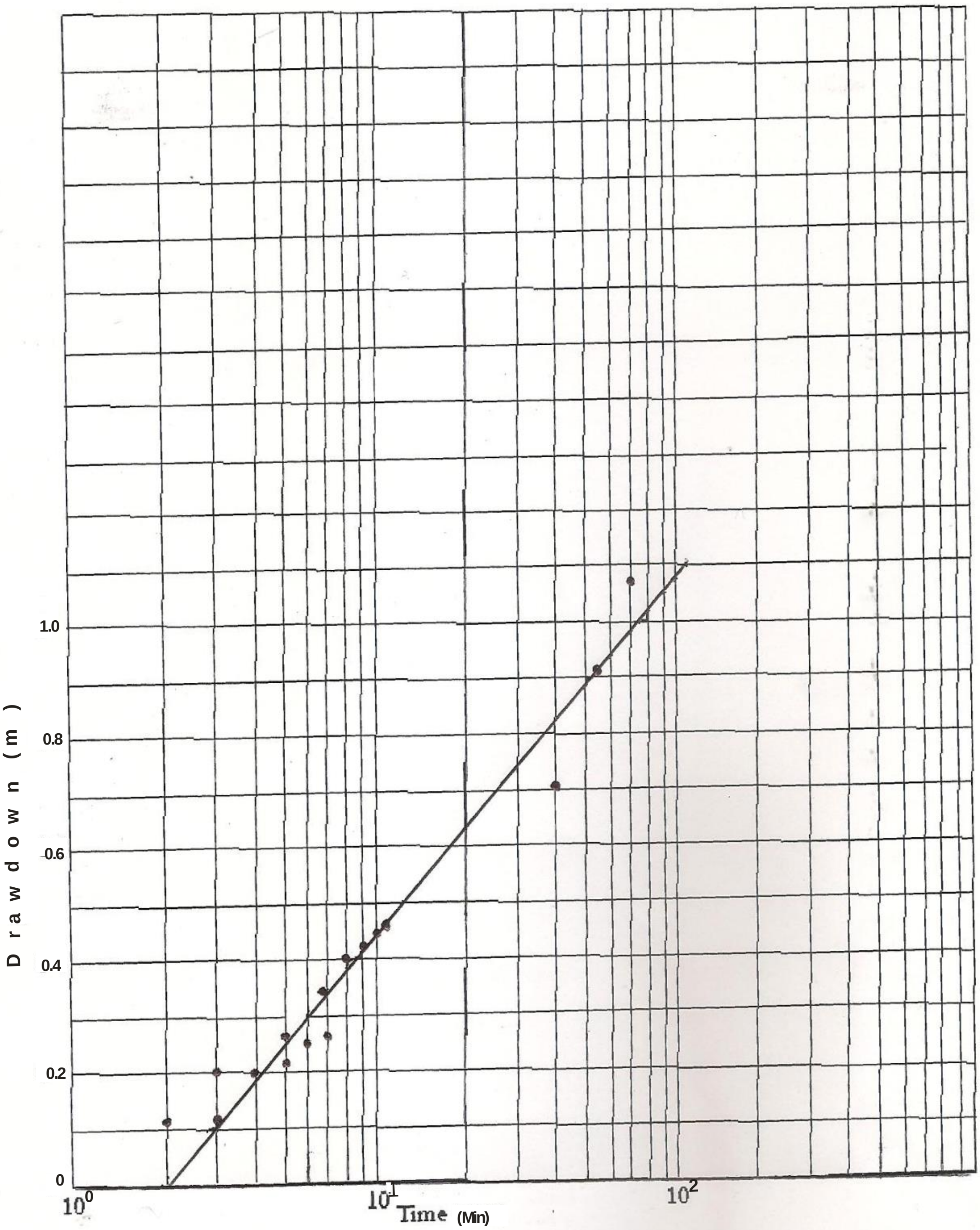

Fig.6 (a): Semi-log plot of Time versus Drawdown for PH 3

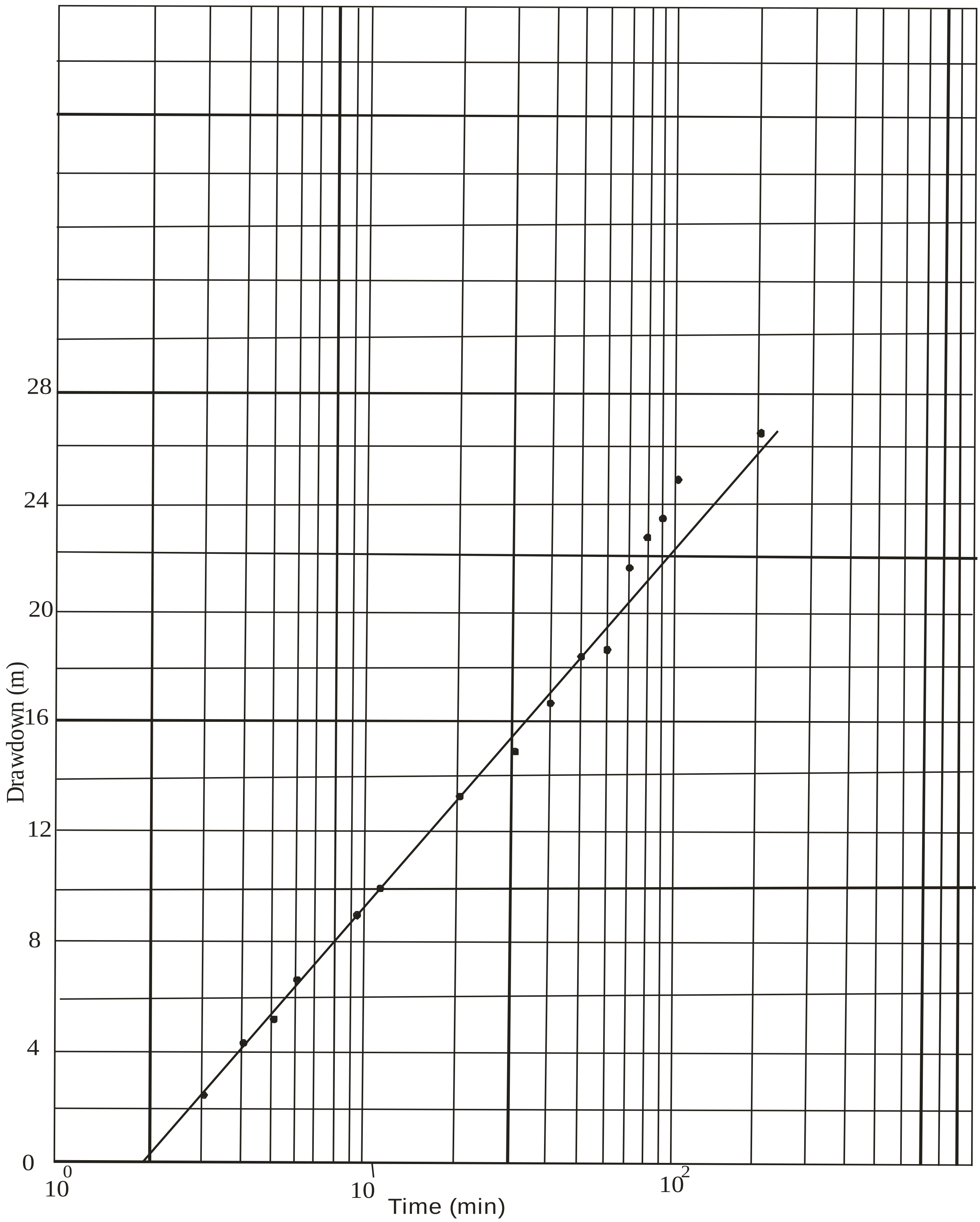

Fig. 6 (b): Semi-log plot of Time versus Drawdown for PH 6

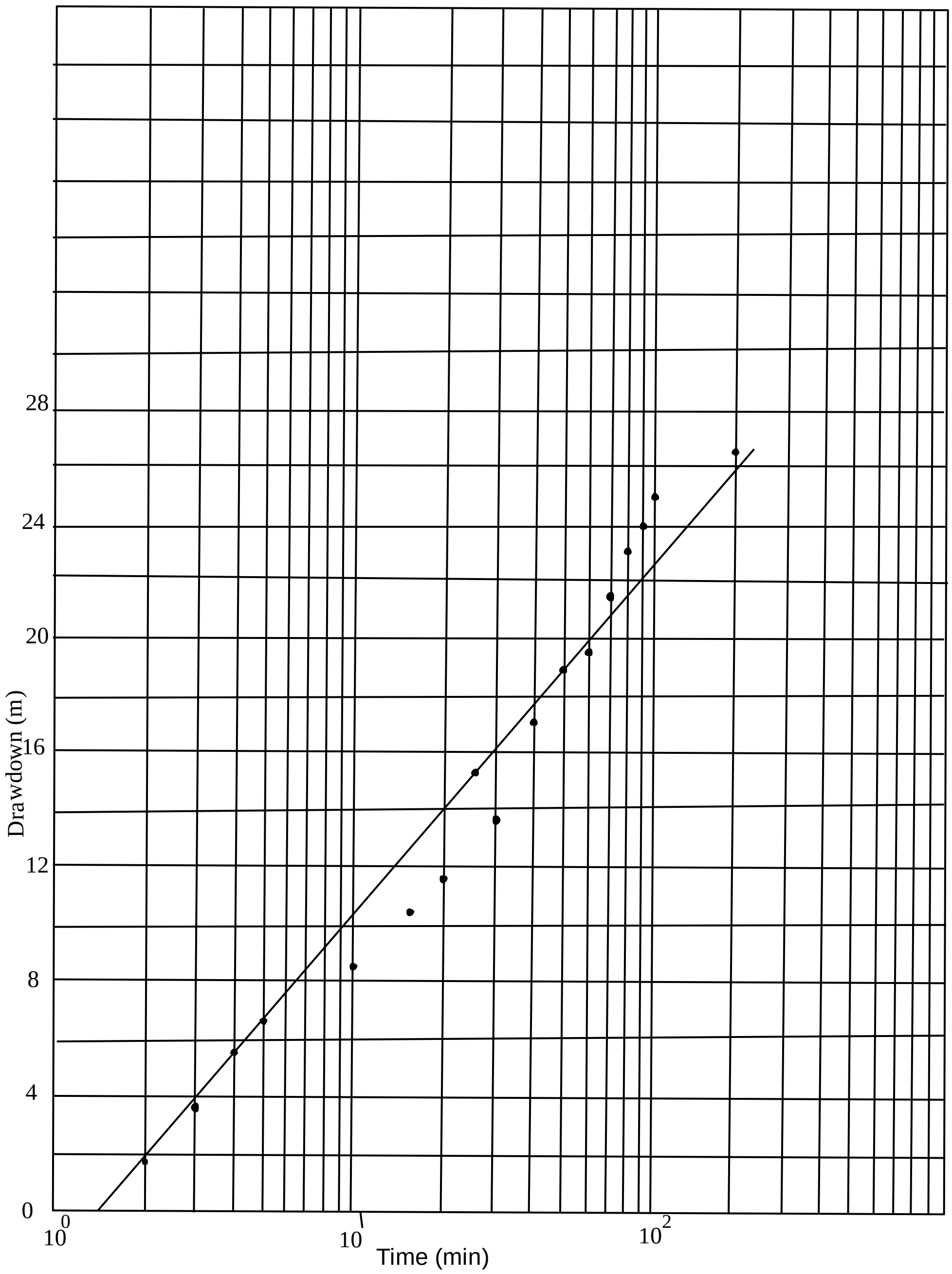

Fig. 6 (c): Semi-log plot of Time versus Drawdown for PH 7

The drawdown values range from 0.25 meters to 6.71 meters. The transmissivity and hydraulic conductivity values range respectively from 5.18 x 10-^{4}m^{2}/s to 1.98 x 10-^{2}m^{2}/s and 7.58 x 10-^{6} m/s to 3.62 x 10^{-4}m/s whereas storativity values range from 5.69 x 10^{-3} to 1.13 x 10^{-2}.

The transmissivity values are quite high. Nwankwor and Eche (1990) attribute such values to probably leakage from an overlying aquitard and unpumped aquifer units. An aquifer with transmissivity of less than 1.44 x 10^{-4}m^{2}/s can supply only enough water for domestic wells but for those with 1.44 x 10^{-3}m^{2}/s or more, well yield can be adequate for industrial, municipal or irrigation use (Driscoll, 1986).

The storativity values are in line with the production potentials of the aquifers of the area as estimated from pumping test analysis and suggest great validity for the transmissivity and hydraulic conductivity values obtained. Thus the aquifer under study is good and recommendable for groundwater exploitation and can supply adequate water not only for domestic use but also for industrial, municipal or irrigation purposes.

The very small drawdown values as measured at locations 3 and 10 suggest that the aquifers are highly productive. This is especially true if there are no recharge boundaries, and leaky confining layers as they could permit the inflow of water into the aquifer giving rise to decreased drawdown rate. Leakage from confining layers and unpumped aquifer units in a leaky multi-aquifer system results in lower drawdown (Freeze and Cherry, 1979).

4.0 Conclusion and Recommendations

4.1 Conclusion

The surface geology of Port Harcourt and its environs consists predominantly of sand beds with intercalation of clays and other low permeability materials such as clayey sand. Gravel layers and pebbles develop within the sand beds. The sand and gravel aquifers occur under confined, semi-confined, unconfined and partially unconfined conditions. Lithological variations within this formation not only govern the aquifer properties but also control the yield. The aquifers in this area are generally good and can supply adequate water not only for domestic use but also for industrial, municipal or irrigation purposes.

4.2 Recommendations

While there is the need for several boreholes in the area in view of the fact that groundwater is the main source of quality water for the inhabitants, adequate groundwater management policy should be enacted so as to prevent aquifer impairment due to over – production.

Acknowledgement

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