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AQUIFER MORPHOLOGY IN BENIN CITY AND ENVIRONS, SOUTHERN NIGERIA

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ABSTRACT

Water-bearing formations underlying Benin city and its environs in Southern Nigeria were investigated to determine their shapes, thicknesses, areal extent and water storage parameters. The area is underlain by the Coastal Plain Sand formation of Miocene to Pleistocene ages. The methodology adopted involved correlation of stratigraphic horizons from forty-five boreholes using graphic software packages. Aquifer thicknesses and transmissivities were calculated from data obtained. Panel and fence diagrams, as well as isopach maps, were constructed for the area. The major stratigraphic units identified are clayey sands, clay, sands and gravelly sands. Two major aquifer horizons were delineated. The upper horizon is characterized by sands of fine to medium textures having average thickness of 31.72m, average transmissivity of 1,820.23m^2/day and mean hydraulic conductivity of 54.48m/day. It occurs under unconfined conditions at depths between 19.58m and 55.16m below ground surface. The lower aquifer unit is characterized by gravelly sands of medium to coarse textures having average thickness of 36.74m, average transmissivity of 2,197.27m^2/day and mean hydraulic conductivity of 62.19m/day. It occurs at depths between 45.27m and 100.31m below ground surface. Clay unit of about 3.05 to 24.38m thick constitutes the confining stratum which separates the upper from the lower aquifer. Hydraulic pressures in the lower aquifer varies from 1.3 to 2.8 atmospheres. The pressures are not sufficient to raise the piezometric plane to the ground surface. This aquifer condition is therefore sub-artesian and it is present at Egor, Iguoshodi, Ikpoba, Ugbowo, and Iyowa parts of the study area.

KEYWORDS: Aquifer, Confining pressure, Hydraulic conductivity, Transmissivity, Fence diagram

INTRODUCTION

In the last four decades, Benin City had witnessed a phenomenal increase in population and urbanization as capital of Edo State with population of 762,717 according to the 1991 National Population Census with a projected population of 1.3 million by 2010at 2.9% growth rate. Benin is a popular pre-colonial City and had served as headquarters of defunct Mid-Western Region andBendel State.Today, the City is so urbanized and densely populated that efforts by all relevant arms of government could no longer cope with adequate public water supply in terms of both quality and quantity (Adedhor, et al 2011). In response to acute shortage in supply, a series of water supply projects based on groundwater resource exploration and exploitation of the Coastal Plain Sands aquifers had been embarked upon by both public and private sectors.The drive of this research is to support those projects by investigating the subsurface hydrogeological conditions and morphology of aquifers in the underlying Coastal Plain Sands with the objectives of determining stratigraphic horizons, thicknesses, shapes and storage parameters of the aquifers present.

THE STUDY AREA

Benin City,the study area, lies between Latitude 6^{0}30’N to 6^{0}45’N, and longitude 5^{0}15’E to 5^{0}30’E (Fig.1).It has an estimated land area of about 500 square kilometres (Erah, et. al, 2002), with elevation of about 150m above the mean sea level at the highest point. It is located in the humid tropical rainforest belt of Nigeriaand has an annual rainfall of above 2000 mm, with mean monthly temperature and relative humidity of 28°C and 80%, respectively. The Ikpoba River in the north eastern part and the Ogba River in the southwestern part constitute the major drainage system in the area.

GENERAL GEOLOGY

Benin City is underlain by sedimentary formation of the Miocene-Pleistocene age often referred to as the Benin Formation. The formation extends from the area immediately east of the Okitipupa ridge across the whole of Niger–Delta area (Fig.2).It is made up of top reddish clayey sand capping highly porous freshwater bearing loose pebbly sands and sandstone with local thin clays and shale interbeds which are considered to be of braided stream origin (Omatsola and Adegoke 1981).The Formation is about 2,100 m thick.

PREVIOUS WORKS

A number of researchers have used hydrogeological and geophysical methods to determine thicknesses, shapes, horizons and subsurface layers in both crystalline and sedimentary terrains. Longe et al., (1987) used well logs, pumping tests, borehole yields and water quality data in Lagos Metropolis to subdivide the subsurface into three aquifer horizons. The first aquifer is the water table aquifer with average thickness of 8m while the other two aquifers are confined with thicknesses of 10-25 and 20-35m, respectively. Average values of transmissivity (T) were 305.0, 25.5and 28.4 m^2/dayfor the first, second and third aquifers, respectively.

Asiwaju-Bello and Oladeji (2001) used geologic well logs, pumping test data and static water levels to construct the hydrostratigraphic model for Lagos metropolis

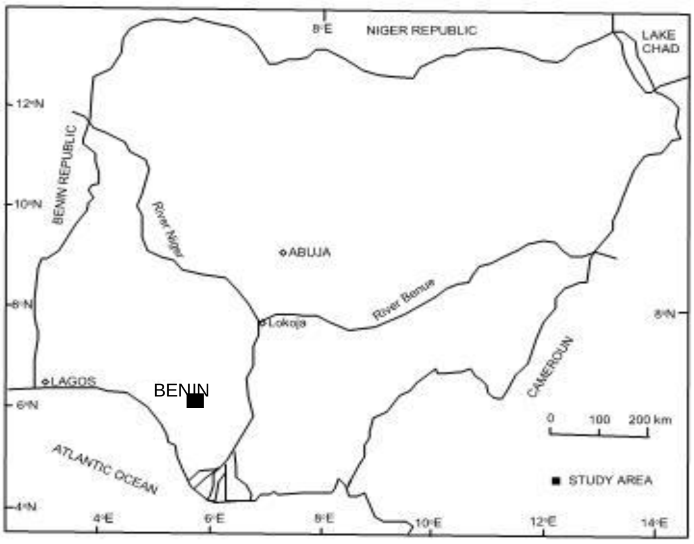


Fig.1: Map of Nigeria showing Benin City, the study area.

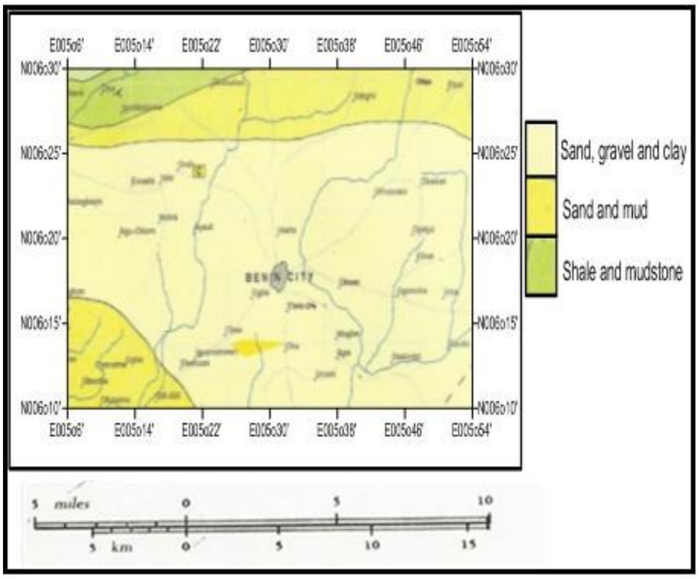


Fig.2: Geological Map of Benin City (After Nigeria Geological Survey Agency, 2006)

The result showed that Lagos metropolis is underlain by three-layer aquifer systems with varying hydrogeological properties. Akujieze and Oteze (2002) reported that Benin Formation aquifer is very prolific with good specific yield ranging from 1000 to 2000 m^3/day and transmissivity values ranging from 880 to 2,799m^2/day. They reported unconfined to semi-confined conditions in certain places.

Offodile (2002) used lithologic logs and pumping test data from Benin Formation to conclude that the aquifer of Benin Formation is very thick, extensive, coarse and unusually very permeable. He also concluded that Benin Formation is the most aquiferous formation in southern Nigeria withtransmissivity of 880 to 30,000m^2/day, storage coefficient of 1.53 – 3.16 x $10^{-3}$and average porosity of 30%.

Alile*et al*.(2012)reported that sands constitute the major aquifer in Ikpoba-Okhaarea of Benin cityand lies between the depths of 59.8 and 95.4 metres.

METHODOLOGY

In this study, borehole information were employed as an alternative approach to investigatethe subsurface geological framework instead of the conventional geophysical techniques.

Data Collection

Forty-five (45) water boreholes were selected randomly to cover Benin City and its environ. The spatial distribution of the wells within the study area is shown in Fig.3. Lithologic logs and subsurface hydrogeological data of the chosen boreholes were collected from well-owners who were either Edo State Water Board, Benin-Owena River Basin Development Authority, or private companies.

Hydraulic conductivity, K,(m/day) values were also acquired from well owners and were multiplied by saturated thickness of the aquifers to obtain transmissivity, T, (m^2/day).

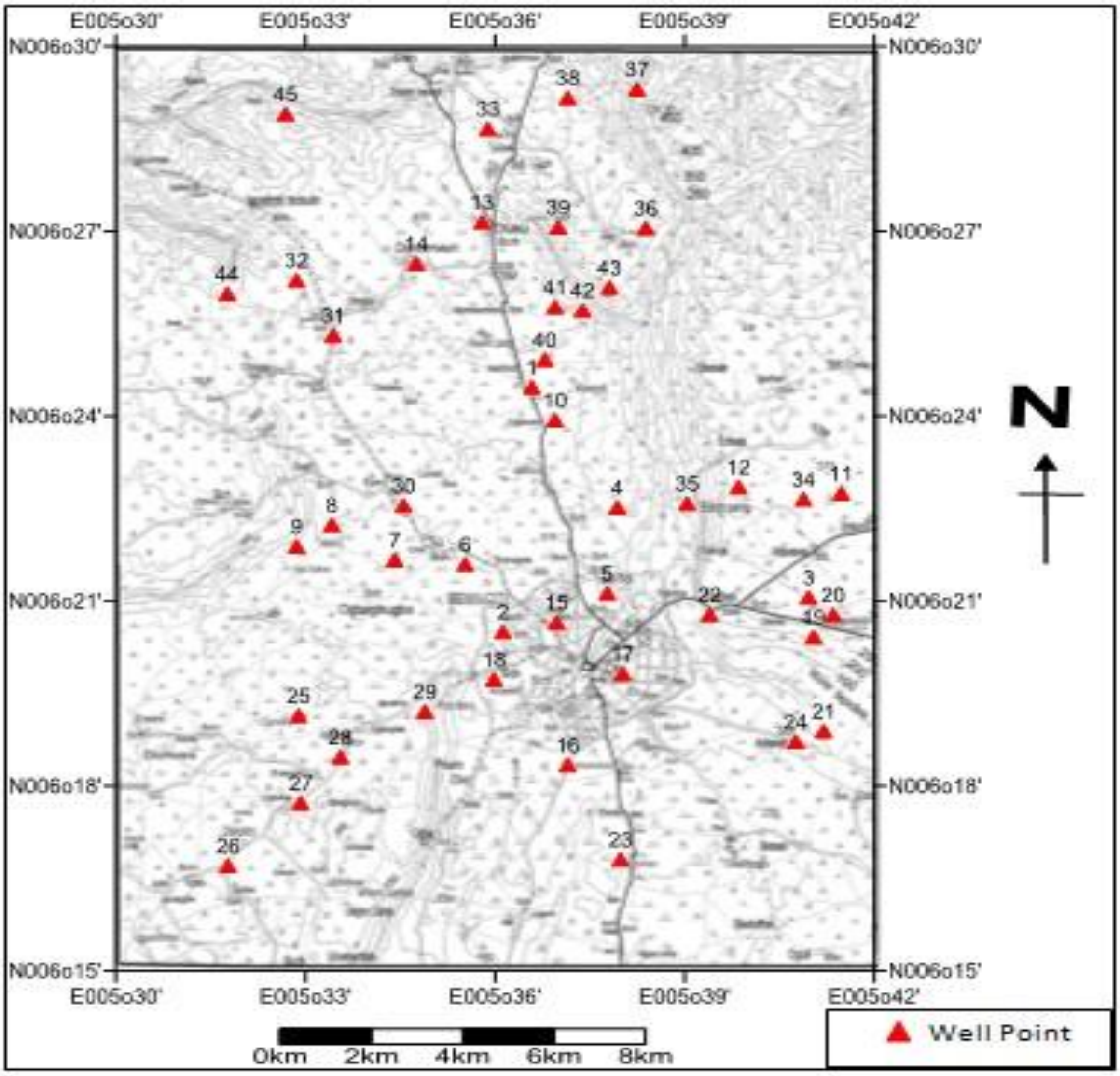
Data Analyses

The lithologic logs were used to model the stratigraphic sequence by subjectingthe logs to qualitative graphic analyses using SURFER,WINFENCE, WINLOG and STRATA EXPLORER software packages. The stratigraphic horizons werecorrelated along six selected traverse lines (Fig. 4) for construction of 2-D and 3-D subsurface panel diagrams.

Hydraulic Pressure

The hydraulic pressure (kg/m^2)was calculated by multiplying vertical thickness of the confining clay unit in the lithologic logs with the characteristic bulk density (kg/m^3)of the formation materials (Elizabeth, 1983). Confined condition occurs in an aquifer where hydraulic pressure is greater than 760mmHg or 1 atmosphereor 10,332 kg/m^2(Lohman et. al., 1972). The obtainable piezometric head of water above a confined aquifer is calculated using Marsily (1986) equation

$$\text{Head of water (m)} = \frac{Confinepressure}{Specificweightofwater}\ \frac{(kg/m^2)}{(kg/m^3)}$$



RESULTS

The 2-D panel diagrams developed fromlithologic logs are presented in fig.5 while the 3-D fence diagram is in fig. 6. Isopachmaps of depths to top and bottom of aquifers, mean thickness as well as spatial distribution of transmissivityof upper aquifer are presented in fig.7.Calculated confining pressure conditions in the lower aquifer are presented in Table 1.

Panel Diagrams

Within each of the six traverse sections, there exist four correlatable sand and gravel layers at different horizons (Fig. 5). These include a topmost unit of reddish to brownish coarse sands (25-38m thick) overlying fine-grained white sands (28-48m thick). The fine-grained sand layer has some overlying discrete lenses of clay in some sections (A-A1, B-B1 and D-D1). Underlying the fine-grained sand horizon is a prominent layer of impervious clays (3-24m thick). This clay unit is underlain by a layer of coarse-grained white sands (20-56m thick).

Below the coarse-grained sands are horizons of either gravel bodies (up to 32m thick) or discrete lenses of clays in some places.

Aquifer Types and Classes

Two aquifer horizons were identified in the study area. The upper aquifer is composed of reddish to brownish sands and the fine-grained white sands while the lower aquifer consists of coarse-grained white sands and the underlying gravelly bodies. The two aquifers are separated by the impervious clay layer. Aquifer parameters and conditions vary with localities (Table 1) but all the aquifers generally fall within the high potential aquifer class (Gheorghe, 1948; Bouwer, 1978; Heath, 1984). The upper aquifer is under unconfined condition everywhere in the study area, i.e.it is under water table condition, with average thickness of 31.72m, average transmissivity of 1,802.23m^2/day and average hydraulic conductivity of 54.48m/day. It occurs at depths between 19.58m and 55.16m below ground surface.

The lower aquifer is under unconfined to confined conditions depending on the locality. It has average thickness of 35.51m, and generally occurs at depths between 45.27m and 100.31m below ground surface.The confining clay unit at its top, about 3 to 24m thick, exerts confining pressures between 0.3 and 1.8 atmospheres on aquifer giving sub-artesian conditions at Iguoshodi, Ikpoba, Ugbowo, Egor and Iyowa localities.

DISCUSSION

The lithologic units in the study area consist mainly of fine to coarse brownish to whitish sands, clays, clayey and gravelly sands. This is typical of Coastal Plain Sand Formation. These extensive sand units expectedly have good groundwater storage and high yield potentials (Oteri and Atologbe, 2003), and are thus very good aquifers.

In the upper aquifer, hydraulic conductivity varied from about 35m/day in Edoh locality to about 75m/day in Egor area while transmissivity varied from about 1,350m^2/day in Edoh locality to over 2,400m^2/day at Ring-road area. These properties are expectedly controlled by the local geology of the area (Davis and Dewiest, 1966; Schwartz and Zhang, 2003; Chatterjee, 2005).

Idowu et al. (1999) reported similar results in multilayer aquifer systems in the Dahomey Basin of Southwestern Nigeria.

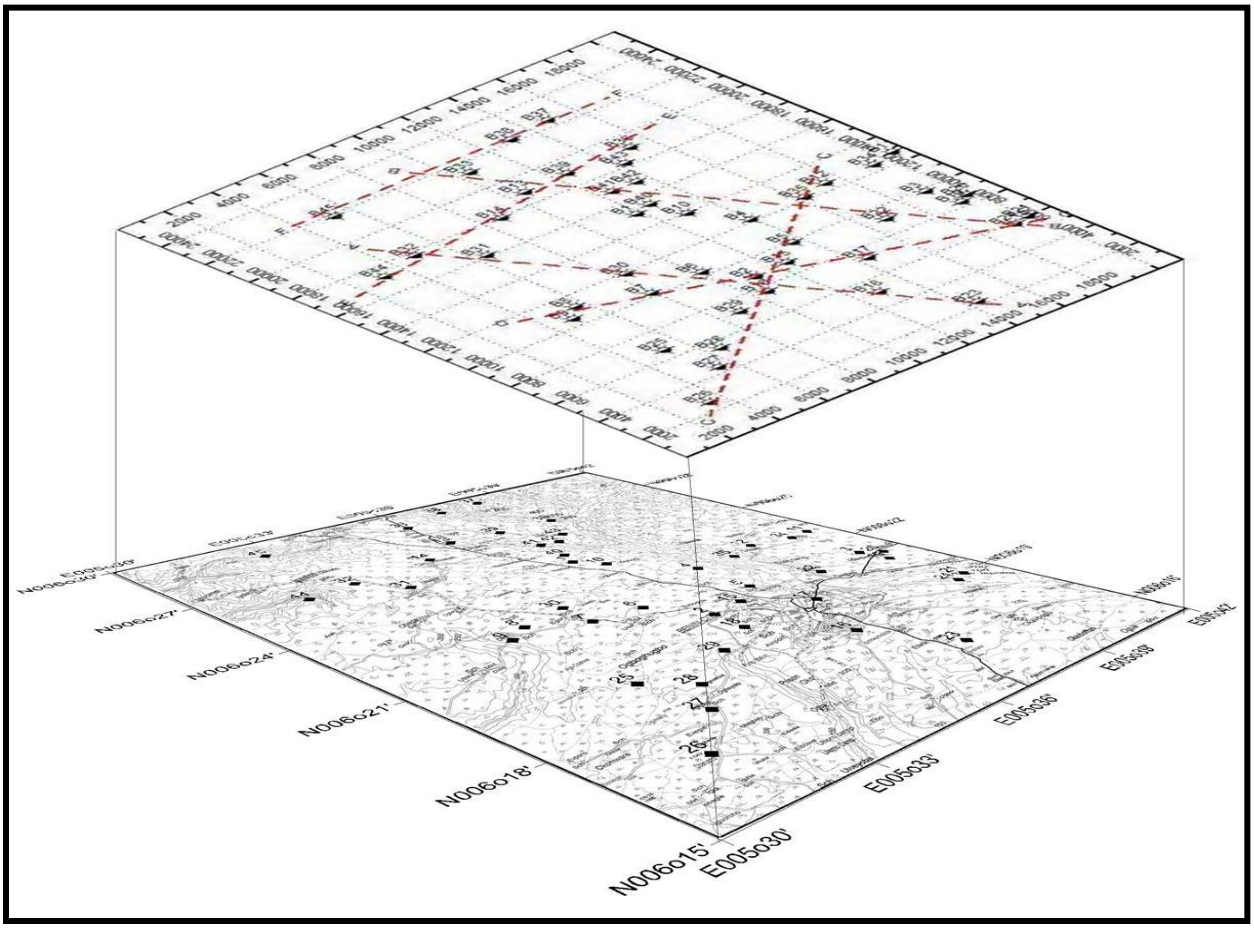


Fig.4: Lines of sections established for the study

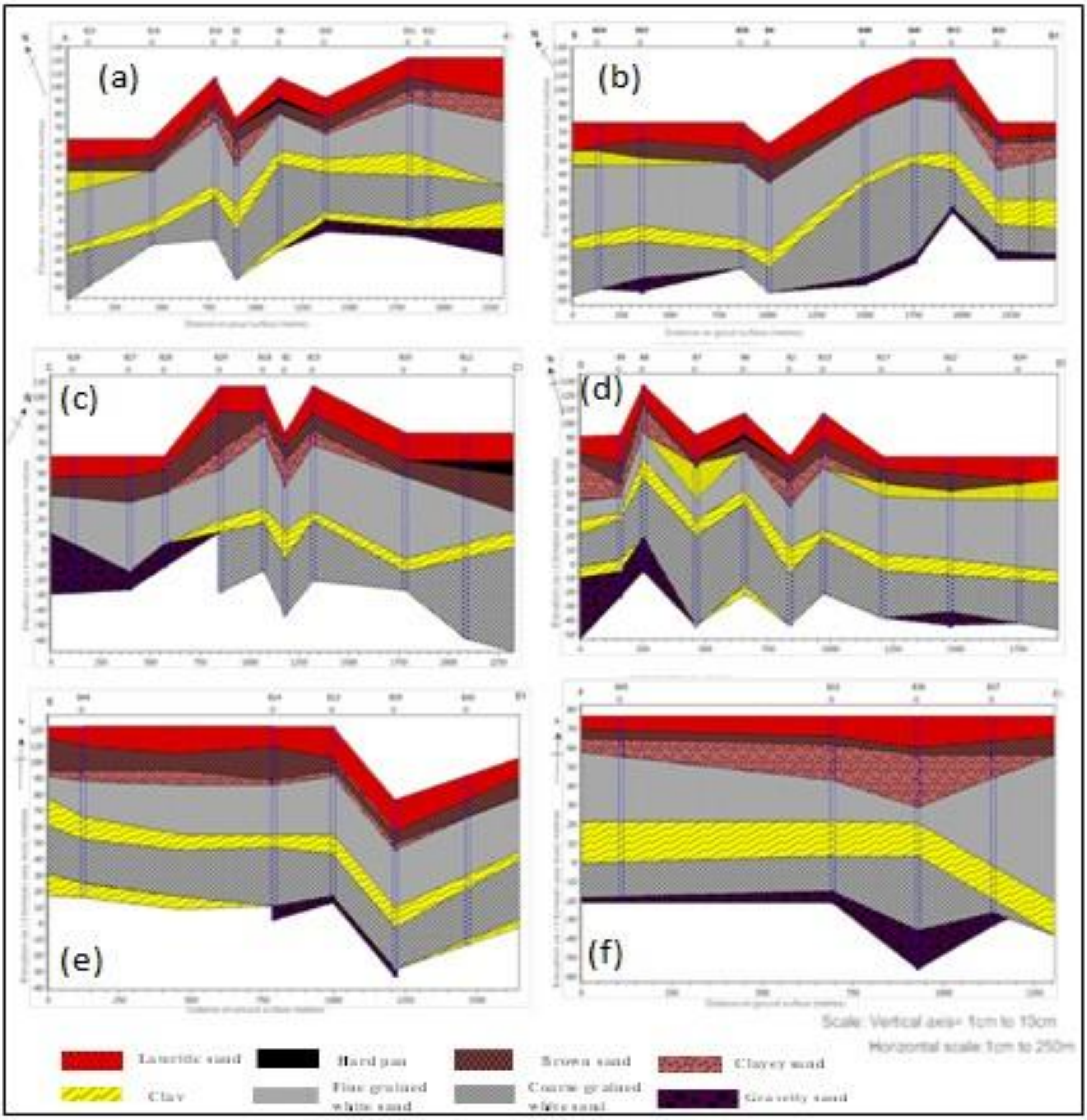


Fig.5: Panel diagrams along the section (a) A-A1; (b) B-B1; (c) C-C1; (d) D-D1; (e) E-E1 and (f) F-F1.

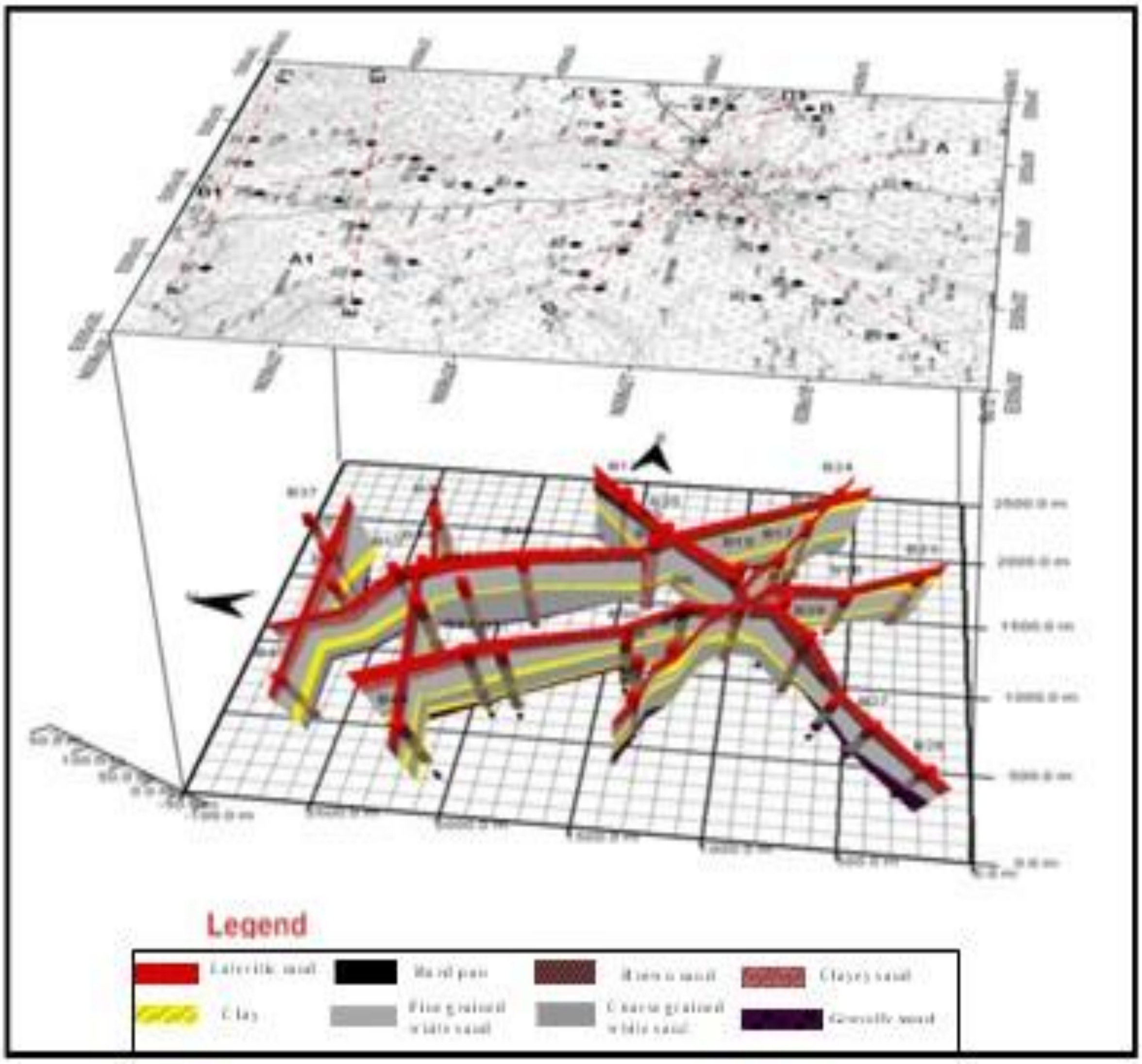


Fig. 6: Fence diagram from East-look

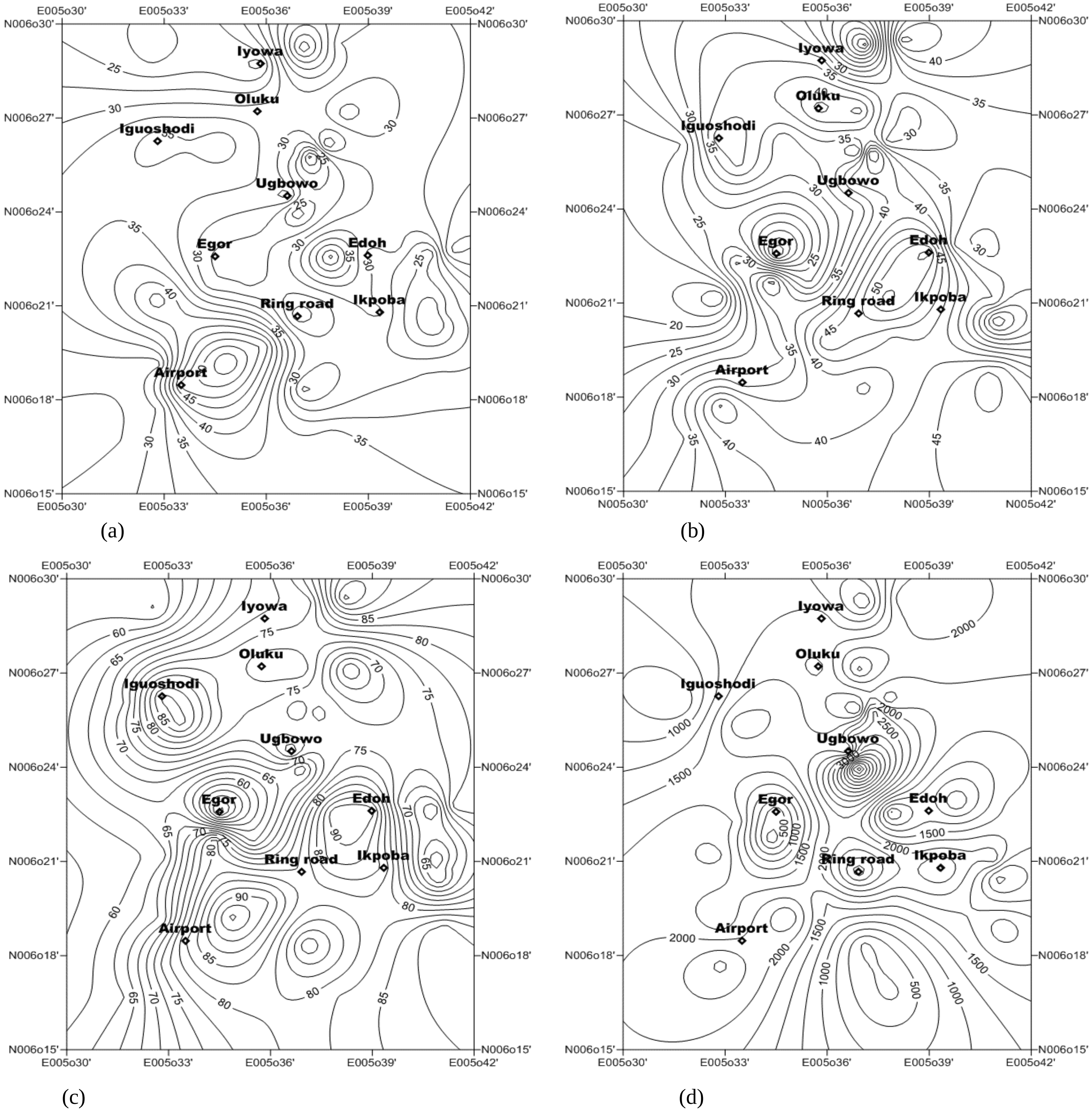


Fig.7: Isopach maps of (a) depth to top, and (b) thickness of Upper Aquifer; (c) depth to top of Lower Aquifer. (d) Spatial distribution ofTransmissivity (m^2/day) in Upper Aquifer.

The hydraulic conductivity values obtained for thisupper aquifer fall within the range classified by Heath (1984) as unconsolidated fine, medium to coarse sands.

The amount of pressures contained in the lower aquifer can only lift the piezometric plane to heights between 3and18m above aquifer horizon in few localities. With the depth of occurrence of this aquifer not less than 50m below ground surface, the confining pressures here are not sufficient to raise the piezometric level to the ground surface. This aquifer condition is therefore sub-artesian and is found at Iguoshodi, Ikpoba, Ugbowo, Egor and Iyowa localities.

CONCLUSION

This study shows that aquifer system in Benin City and its environ is characterised by two subsurface horizons of thick, extensive, fine to coarse permeable sands. The sands constitute good aquifers and have variable thicknesses. An impermeable horizon of clay formation separates the two aquifers. These aquifers are part of the Coastal Plain Sands of Southern

Nigeria which have very large freshwater storage potentials and support boreholes with high yields.

The study has provided information on the depths to the aquifers and also thickness of the upper aquifer in Benin City. Optimum depth of a proposed borehole can be pre-determined before drilling anywhere in the area without recourse to serious pre-drilling geophysical investigation.

In places like Ikpoba, Iguoshodi and Airport areas where upper lateritic sand and clay units are relatively thick, boreholes can terminate within the upper aquifer. The thick lateritic /clayey units can serve as filters to prevent pollution by infiltrating waters. However, in Oluku, Egor Camp, Ring Road, Ugbowo and Iyowa areas where the overlying lateritic/clay units are relatively thin, boreholes may have to be drilled down into the second aquifer to avoid possible contamination.

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