VERTICAL ELECTRICAL SOUNDING APPLIED TO HYDROGEOLOGIC AND ENGINEERING INVESTIGATIONS: A CASE STUDY OF KADUNA POLYTECHNIC STAFF QUARTERS,NIGERIA

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Abstract

Sixty-six Schlumberger Vertical Electrical Soundings (VES) were carried out at Kaduna Polytechnic Senior Staff Quarters using Direct Current Electrical Resistivity method. The objectives were to determine different subsurface Geoelectric layers, the aquifer units and their hydrogeological parameters, identifying suitable areas for siting high-rise buildings, sewage and waste disposal sites. The results of the investigations are presented as surface and subsurface contour sections from the interpretation of the sounding curves. 3-4 Geoelectric layer situations were obtained from analysis and interpretation of the field curves by computer modeling. This includes the topmost layer which consists of laterite, river sand and gravel. This formation is followed in succession by clayey sand, weathered transition zone/ fractured layer and the fresh basement. Qualitative interpretation indicates that the weathered layer and weathered/fractured basement constitutes the main aquifer units. Aquifer resistivity range from 15 ohm-m to 650 ohm-m with maximum thickness of 84.2m. Based on the model obtained, aquifer Transmissivity was calculated and was used to delineate the study area into prospective low and high groundwater potential zones. The competent zones where the basements rocks are highly resistive have been recommended for siting of high-rise buildings and roads. Similarly, areas where the basement rocks lie deepest are recommended for siting sewage and disposal sites. The low resistive areas located mostly near the stream flow lines which correlate with the weak zones have also been identified.

Keywords: *Kaduna, hydrogeological, transmissivity and high rise building*

Introduction

From various electrical methods, theDirect-current (DC) resistivity method for conducting a vertical electrical sounding such as Schlumberger sounding is effectively

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used for groundwater and geotechnical studies due to the simplicity of the technique, and easy interpretation . The technique is widely used in soft and hard rock areas (Sharma and Baranwal, 2005). One of the common methods for evaluating aquifer characteristics such as Hydraulic conductivity, Transmissivity is pumping test, which however is very expensive and time consuming. Surface direct current (DC) resistivity measurements can provide rapid and effective techniques for aquifer characteristics evaluation. Works on these could be cited from previous studies (Niwas and Singhal, 1985; Mbonu *et al.*, 1991; Dan-Hassan and Olorunfemi, 1999) Aquifer characteristics are important properties for determining the natural flow of water through aquifer, its response to fluid extracts, contaminants land assessments and for safe construction of civil engineering structures (Mbonu *et al.*, 1991and Singh, 2005)

Theory of D.C resistivity technique

The fundamental physical law used in resistivity surveys is Ohm's Law that governs the flow of current in the ground. The equation for Ohm's law in vector form for current flow in a continuous medium is given by

$$J = \sigma E \quad (1)$$

where σ is the conductivity of the medium, J is the current density and E is the electric field intensity. In practice, what is measured is the electric field potential. We note that in geophysical surveys the medium resistivity r, which is equals to the reciprocal of the conductivity, $\left(\rho = \frac{1}{\sigma}\right)$ is more commonly used. The relationship between the electric potential and the field intensity is given by

$$E = - \sigma \Phi \quad (2)$$

Combining equations (3.1) and (3.2), we get

$$J = - \sigma \nabla \Phi \quad (3)$$

In almost all surveys, the current sources are in the form of point sources. In this case, over an elemental volume ΔV surrounding the a current source I, located at (x_s, y_s, z_s) the relationship between the current density and the current (Dey and Morrison, 1979a) is given by

$$\nabla J = \left(\frac{1}{\Delta V}\right)\partial(x - x_s)\partial(y - y_s)\partial(z - z_s) \quad (4)$$

where ∂ is the Dirac delta function. Equation (4) can then be rewritten as

$$-\nabla \bullet [\sigma(x, y.z)\nabla\phi(x, y, z)] = \left(\frac{1}{\Delta V}\right)\partial(x - x_s)\partial(y - y_s)\partial(z - z_s) \quad (5)$$

This is the basic equation that gives the potential distribution in the ground due to a point current source. A large number of techniques have been developed to solve this equation. This is the "forward" modeling problem, i.e. to determine the potential that would be observed over a given subsurface structure. Fully analytical methods have been used for simple cases, such as a sphere in a homogenous medium or a vertical fault between two areas each with a constant resistivity. For an arbitrary resistivity distribution, numerical techniques are more commonly used. For the 1-D case, where the subsurface is restricted to a number of horizontal layers, the linear filter method is commonly used (Koefoed,1979). Figure 1 shows the simplest case with a homogeneous subsurface and a single point current source on the ground surface. In this case, the current flows radially away from the source, and the potential varies inversely with distance from the current source. The equipotential surfaces have a hemisphere shape, and the current flow is perpendicular to the equipotential surface. The potential in this case is given by

$$\phi = \frac{\rho I}{2\pi r} \qquad (6)$$

where r is the distance of a point in the medium (including the ground surface) from the electrode. In practice, all resistivity surveys use at least two current electrodes, a positive current and a negative current source. The potential value caused by a pair of electrodes in a medium is given by

$$\phi = \frac{\rho I}{2\pi}\left(\frac{1}{r_{C_1}} - \frac{1}{r_{C_2}}\right) \qquad (7)$$

where r_{C1} and r_{C2} are distances of the point from the first and second current electrodes. In practically all surveys, the potential difference between two points (normally on the ground surface) is measured. A typical arrangement with 4 electrodes is shown in Fig. 2. The potential difference is then given by

$$\Delta\phi = \frac{\rho I}{2\pi}\left(\frac{1}{r_{C1P1}} - \frac{1}{r_{C2P1}} - \frac{1}{r_{C1P2}} + \frac{1}{r_{C2P2}}\right) \qquad (8)$$

The above equation gives the potential that would be measured over a homogenous half space with a 4-electrode array.

Site description

Sabo area of the southern part of Kaduna metropolis has witness an upsurge in infrastructural development and in human population in recent years. The demand for provision of potable water for human consumption and agricultural needs has grown tremendously over the years. Presently, the provision of potable water via water supply scheme for the area is grossly inadequate for the needs of the people especially during the dry season with temperature reaching up to 32°C.

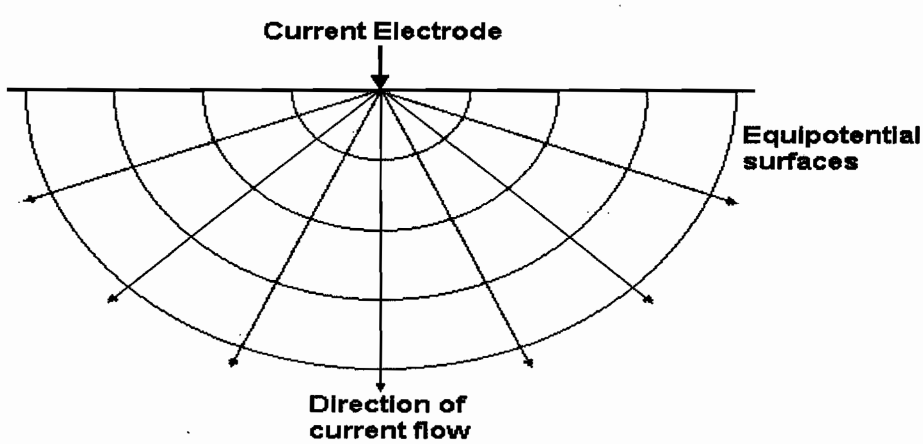


Fig .1: The flow of current from a point current source and the resulting potential distribution.

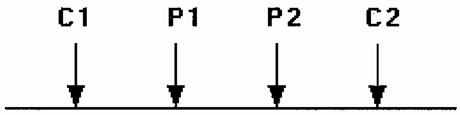


Fig. 2: A conventional array with four electrodes to measure the subsurface resistivity

the year many rivers and streams in the area dry up and this creates problem of availability of water.

Study objectives

The objectives of this study were to determine different subsurfacegeoelectric layers, the aquifer units, estimation of aquifer parameter (transmissivity) as well as identifying suitable areas for siting high-rise buildings, sewage and waste disposal sites at the Kaduna Polytechnic Senior Staff Quarters, Sabo area of Kaduna State using direct current resistivity method.

Physiography - GeologicandHydrologic Settings

They study area lies approximately between latitudes 10°25'N and 10°30'N and longitudes 7°25'E and 78°30'E covering an area of about 500,000m^2(Fig.3).

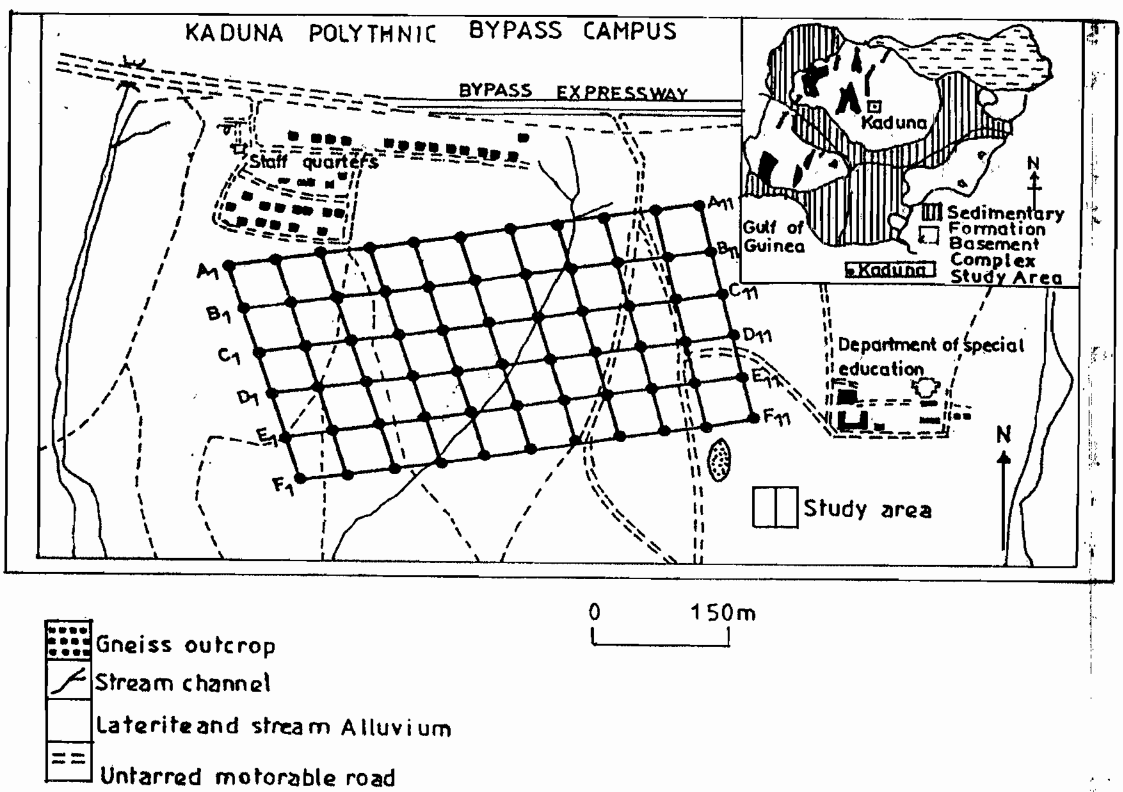


Fig. 3: Map of study area

Precambrian basement complex rocks underlie the entire area of Kaduna and they consist of migmatite gneiss complex, metasediments/ metavulcanics (mostly schist, quartzite, amphibolites and banded iron formation, pan African granitoids and calc-alkaline granites, and volcanics of Jurassic age (McCurry, 1976). A stream which forms part of River Kaduna draining system cut across all the profiles. The relief of the area ranges between 370 and 650m (Aboh, 2002: Mamman, 1992). Lower relief is occupied by the stream and river valley (Jatau, 1998). Groundwater in the area has not been adequately developed and as such data relating to their magnitude and mode of formation are lacking. However in the Basement complex, the permeability and storativity of the groundwater system are dependent on structural features such as the extent, and volume of fractures together with thickness of weathering (Eduvie, 1998; Clark, 1985). The relatively high annual rainfall (1270mm) and temperature (32^{0}C) in Kaduna, which has resulted in the formation of deep weathered zone in addition to high density of fractures have contributed tremendously to constituting large reservoirs of groundwater, good aquifers and high yields of boreholes (Eduvie, 1998). Geophysical investigation and borehole drilling reports have clearly established two major aquifers. These are the overburden weathered aquifer and the fractured crystalline aquifer (Eduvie, 1998 and Dan-Hassan, 1999). Both aquifers at some places are interconnected and form a hydro geological unit of water table surface.

Data Acquisition and Interpretation

Geophysical investigations consisting of 66 vertical electrical sounding (VES) using the Schlumberger four-electrode array were taken within the study area. Six profiles numbered A-F were established covering an area of 0.5km^2. A station interval of 100m was used to established the various sounding points along each profile by wooden pegs marked as A_1 ------F_{11}. The current electrode spacing AB/2 was made to change from 1-100m with the potential electrode MN changing correspondingly from 0.5-15m. The measurements were made with ABEM Terrameter units. Field data were interpreted by using fast computer assisted program, DCINV (version 1.5). The observed depth sounding curves reflect, geo-electrically a three and four-layer curve types. Figure 4. Shows a typical computer interpretation.

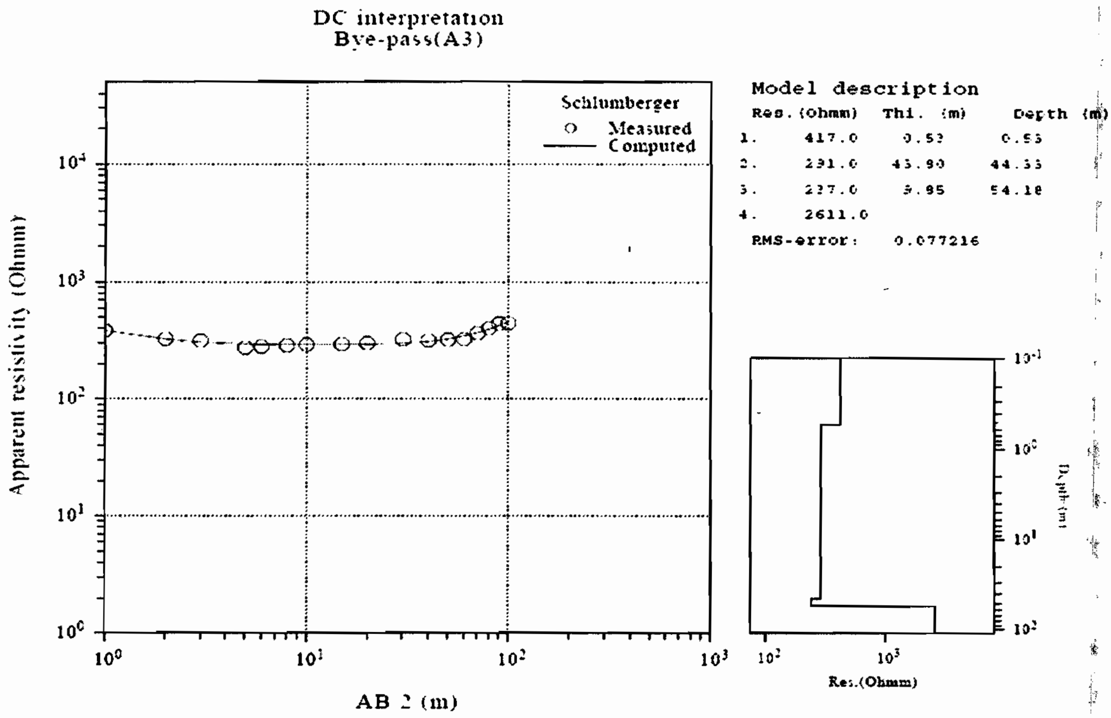


Fig.4: Typical computer interpretation for VES A_3

Subsurface sequence

Geologic sections were constructed using the results of borehole logs after Dan- Hassan, (1999) and Eduvie, (2003).Four geologic layers were delineated in the study area, these includes the top most layer which varies in composition from Laterite to river sand and gravel. The resistivity value varies from 127 ohm-m to 3738ohm-m, while the thickness varies between 3m to 9m.The second layer has resistivity values between 200 700 ohm-m. It typifies clayey sand and has thickness between 6m to 18m.The derived geologic sections suggest that the third layer, which consists mostly of weathered layer, varies in composition from clay, to sandy clay, clayey sand and sand. Its resistivity values range from 15 to 650 ohm-m with most occurring resistivity in the 150-250 ohm-m range. It has a maximum thickness of 84.2m and a minimum thickness of 0.6m.The resistivity of the basement, which forms the 3rd or 4th layer, range from 1500 ohm-m to 32, 0000 ohm-m. The relatively low resistivity value (< 2000 ohm-m) of the basement rock beneath some VES points represents fractures in the crystalline bedrock. The thickness is infinite. Basement aquifers occur within the weathered residual overburden (regolith) and the fractured bedrock, thus, the weathered layer and weathered / fractured bedrock form the aquifer units in the study area. Fig 5 shows the interpretated geo-electric sections of VES C_1-C_3.

Evaluating Transmissivity of the Aquifer

Niwas and Singhal (1981) studied the relationship between hydraulic parameters and electrical parameters. They showed that as reported by (Dan-Hassan *et al.*, 1999) in a porous medium

$$T = KR = KS = Kh \qquad (8)$$

where T is the Transmissivity, K is the hydraulic conductivity, the layer conductivity, R the transverse resistance, S longitudinal layer conductance, layer resistivity and h the thickness of the aquifer respectively. According to Niwas and Singhal (1981) the practical applicability of equation 8, lies in the fact that by knowing the values of K from existing boreholes, one can estimate the Transmissivity of the aquifer from the transverse resistance and conductivity of the aquifer obtained from resistivity measurements at other locations within a basin. Using an average hydraulic conductivity of $0.61 m^2 day^{-1}$ from 60 existing boreholes within Igabi, Kaduna North, Kaduna South and Chikun Local Governments Areas which are parts of Kaduna Basin (Dan-Hassan et al, 1999 and Eduvie, 2003), Transmissivity of the aquifer in the study area was calculated using the relation

T=Kh and the values were presented as subsurface contours.

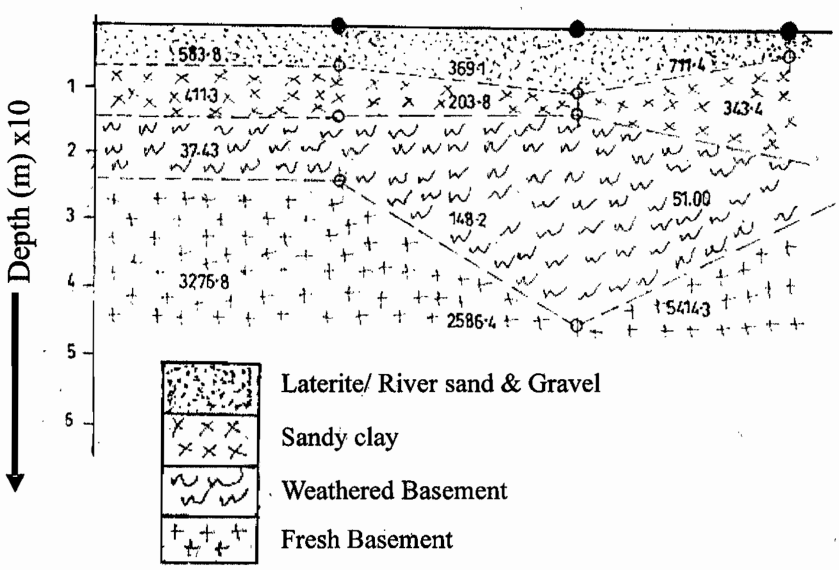


Fig. 5: Interpreted Geologic Section for VES C_1, C2 & C_3

Results and Discussion

Fig 6 shows the isopach map of the weathered layer which forms the water bearing zones (aquifer).The map plotted with Surfer (version 8.01) shows that the aquifer is highly variable in thickness, with values of 5m in the vicinity of VES points E and F while VES D_{10} with a value of 84 forms the thickest point in the survey area. This closely agrees with Dan-Hassan and Olorunfemi (1999).Their result reports the thickness of the weathered layer ranging from 3-55m. Generally, with the exception of the southwestern and lower southeastern parts of the survey area, the survey area appears thick enough for drilling productive boreholes over the entire area with values ranging from 15 84m.

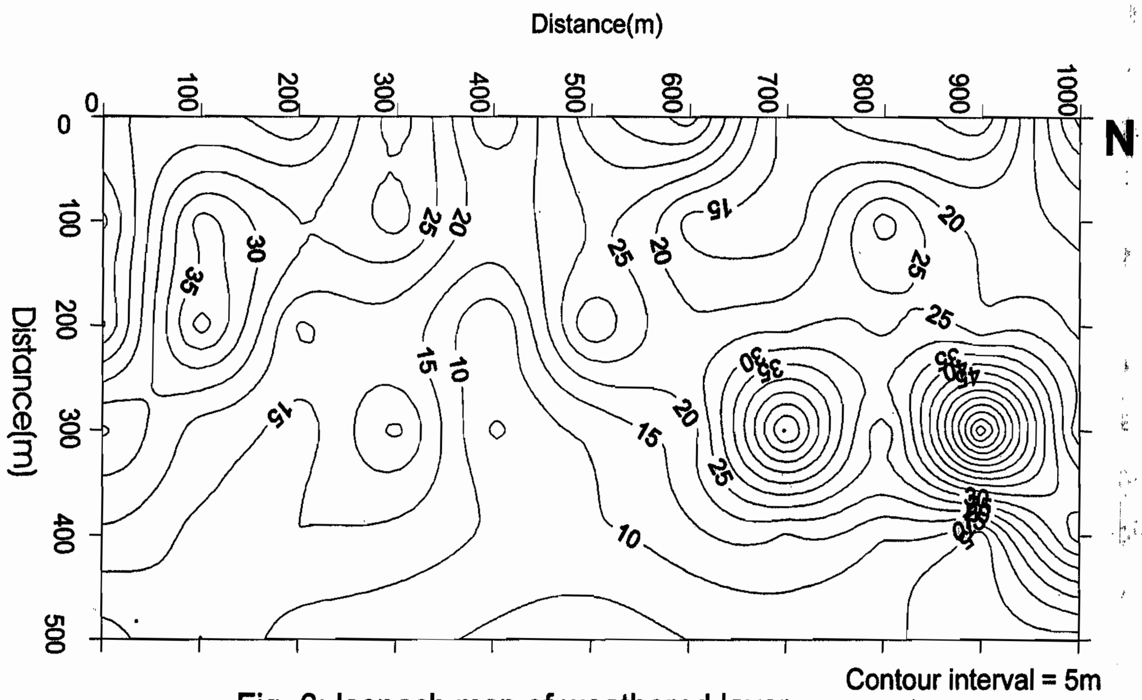


Fig. 6: Isopach map of weathered layer

The corresponding resistivity map of the weathered layer (Fig 7) shows that the resistivity value ranges from 150400 ohm-m in the northwestern, southwestern and upper parts of southeastern zones and 450-650 ohm-meter in the lower of Southeastern part of the survey area respectively. According to Odusanya and Amadi, (1990) reported by Dan-Hassan (1999), the electrical resistivity of this layer which forms the water bearing zone depends on the sand to clay ratio and degree of saturation. The zones with resistivity > 100 ohm-m is characteristics of clayey-sand and sand and it indicates good aquifer formation while the lower end (<100 ohm-m) typifies clay which lowers the aquifer potentials.

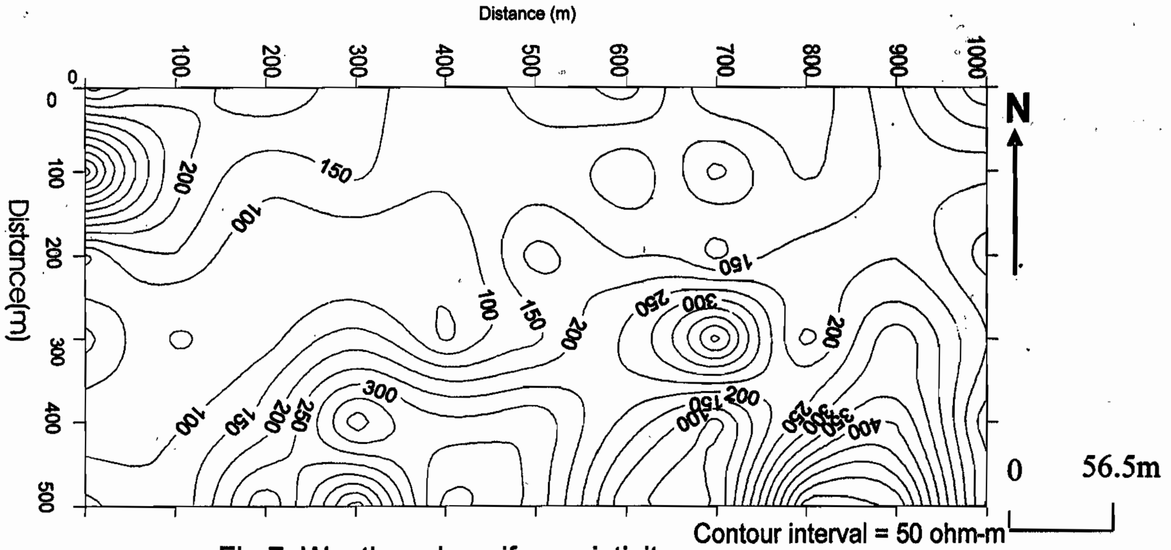


Fig.7: Weathered aquifer resistivity

Figure 8 shows the calculated transmissivity of the aquifer. Comparison of this figure with (Fig 6) shows that areas underlain by relatively thick aquifer materials have high transmissivity values than areas underlain by relatively thin materials. This relationship is expected because transmissivity is a function of thickness i.e. transmissivity increases with thickness. The calculated Transmissivity values are high over most of the northwestern southwestern and upper southeastern parts of the survey area with values between 10 52 m^2 day^{-1}. These are the zones where aquifer resistivity values ranged between 150-400 ohm-m and therefore, high yielding boreholes can be expected at these locations according to Barker et al, 1992 reported by Olorunfemi *et a.l.*, 1991.

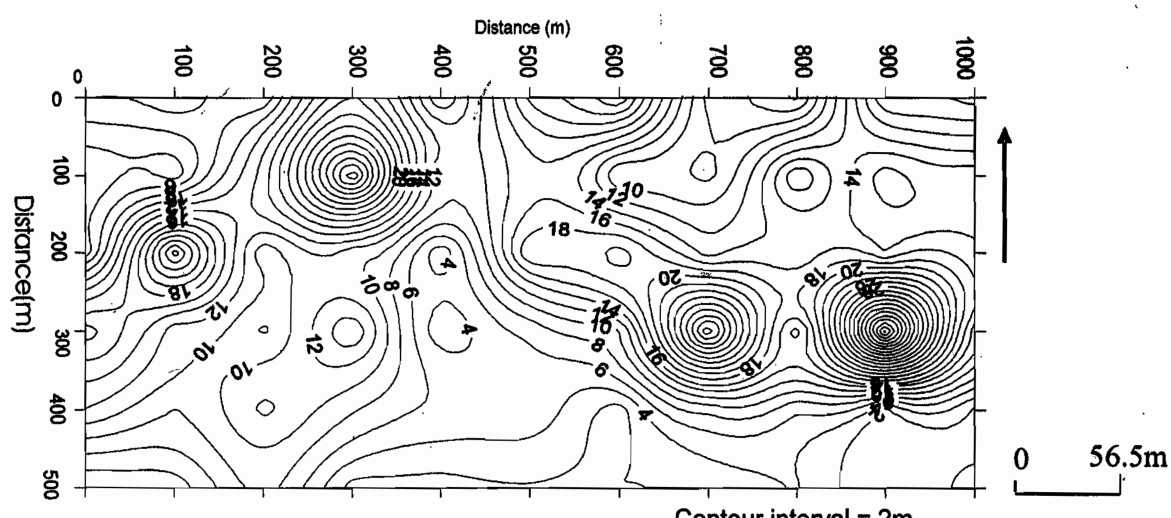


Fig. 8: Calculated transmissivity

Figure 9 shows the depthto-basement map. The map was produced by summing topsoil, clayey sand layer and the weathered/fractured basement layer. It varies between 5.2m at F_{10} , which correspond to basement highs (F_{10} is 2m where the basement outcropped) to 84.6m at D_{10}, the deepest point in the study area which correspond to basement depression. Similar results of 4.3 64m depth were reported by Dan-Hassan and Olorunfemi (1999).The overburden is deep in the north central, northwest and upper southeastern sections of the study area. The average depth-to-basement in these zones is about 32m.The overburden in the Southeast of the study area is shallow with an average depth of 12m. Fig 10 is the 3-D orthographic view of the overburden. The map is marked by high overburden values where the basement depression occurs and low values in areas marked by basement highs. Some of the deep sections of the study area such as VES C_2, A_3 and D_{10} with depth-to-basement of 45, 54 and 84.6m respectively might be buried valleys or underground structural traps. These sections of the study area might very well be suitable for usage as sewage and disposal sites since the underlying basement rocks at these points are not fractured or heavily weathered and therefore could not serve as contaminant transport pathways. The basement resistivity values at these VES points range from 3050 ohm-m 9552 ohm-m.

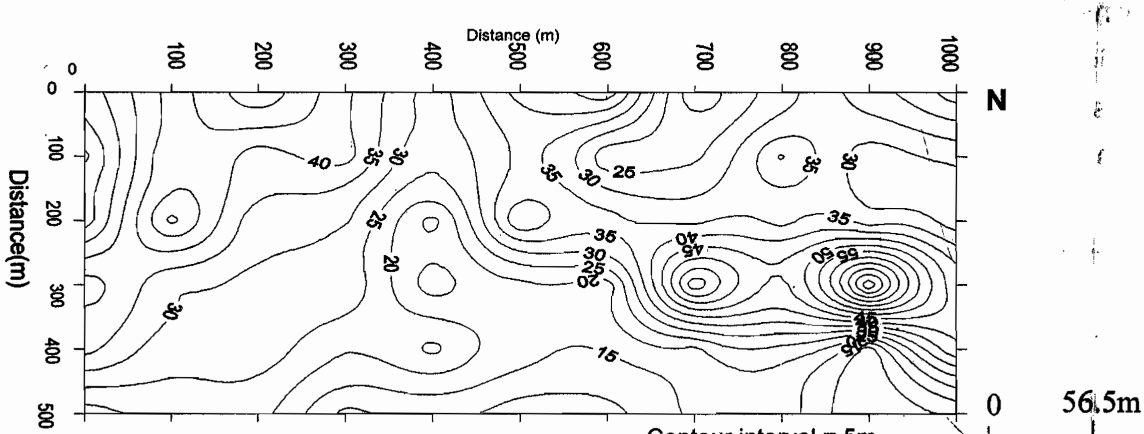


Fig. 9: Depth-to-Basement map

The basement resistivity contour map produced using a contour interval of 2000 ohm-m is shown in Fig. 11. The map of the basement resistivity was produced to indicate the nature, strength or competence and degree of weathering of the basement of the study area, since the resistivity of the basement is a function of their degree of weathering and hence its strength (Aboh and Osazuwa, 2000). The values of the basement resistivity range from 2000 ohm-m to 32,000 ohm-m. The high resistivity ends > 6000 ohm-m is located along profiles E F that are approximately 100m away from where the basement rock outcropped. These are the southeast and southwest sections of the study area. The rocks here are thought to be competent. Areas with low basement resistivity values <2000 ohm-m is also shown in the map. These are areas near the stream flow lines.

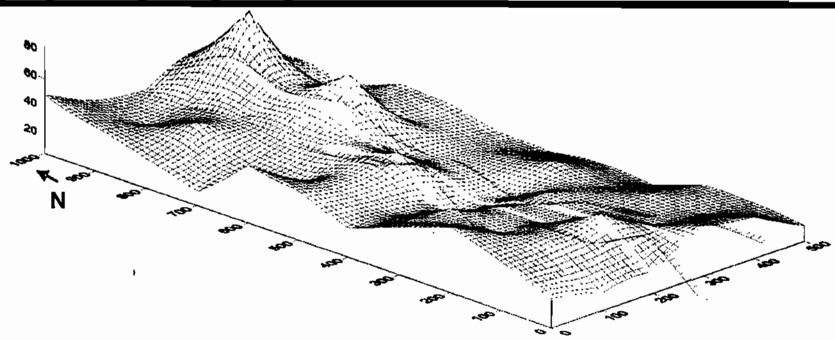


Fig. 10: Orthographic map of depth-to- basement

The rocks here have low resistivity values because of the likely weathering effect due to the chemical effect of the stream fluid. The rocks at these sections of the study area are less competent probably because they are fractured, faulted or heavily weathered (Aboh, 2002).

The topsoil resistivity map was produced to show spatial variation of the resistivity of the topmost layer, which could be used to compare with surface features such as stream and exposed outcrop. Fig.12 shows the topsoil resistivity map with contour interval of 100 ohm-m. Areas of low resistivity < 600 ohm-m have been identified. These are the northwest, southwest, lower southeast and center corresponding to stream channel. Higher resistivity values are located at upper southeast, lower southwest and northeast. The high resistivity values at these locations are due to an outcrop of gneiss rock and dry lateritic cover. The resistivities at these sections of the study area are generally greater than 800 ohm-m. Areas that consist of consolidated thick lateritic cover, which dominate the survey area may be good for Engineering and construction purposes.

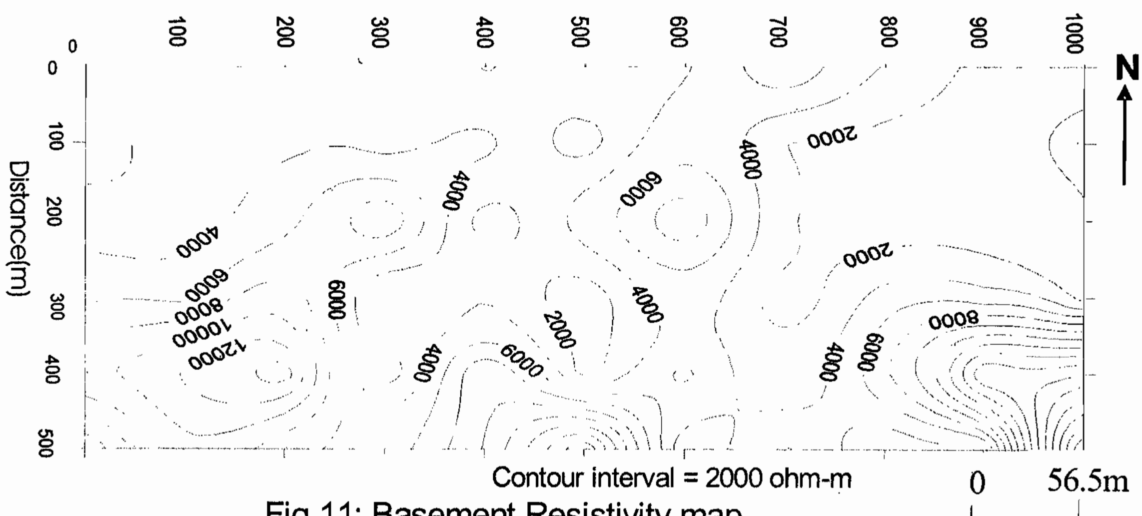
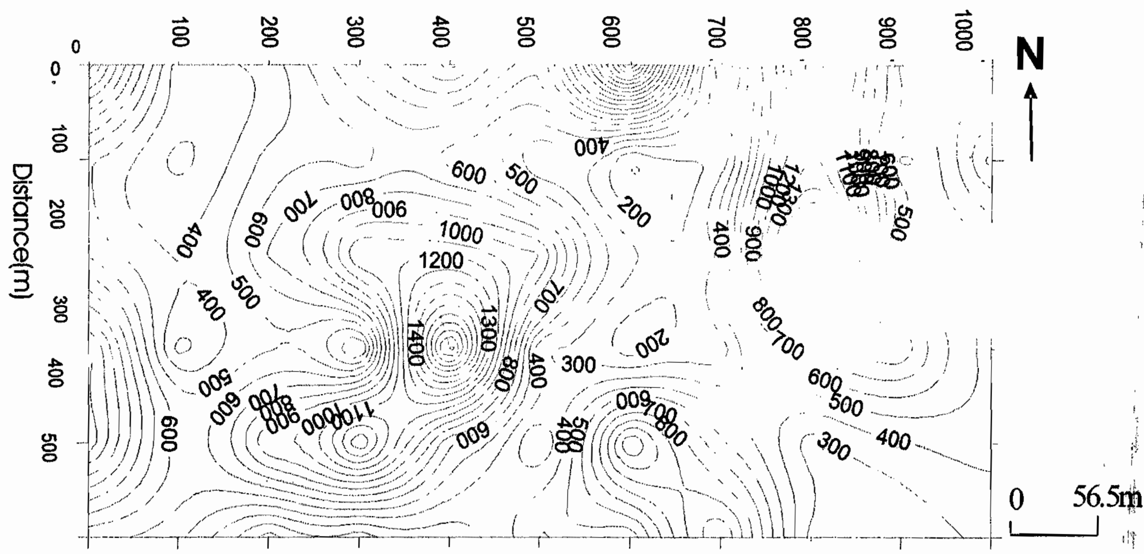


Fig.11: Basement Resistivity map



Contour interval = 100m

Fig.12: Topsoil resistivity map

Conclusion

A total of sixty-six (66) VES stations were established. These were located on six profiles with Azimuth in the East-West direction. The interpretation of the VES data has enabled the derivation of four geologic units. The uppermost layer consists of laterite, river sand and gravel. This formation is followed in succession by clayey sand, weathered basement, fractured/fresh basement. The nature of the overburden and the topography of the bedrock for the study area have been determined. The weathered transition zone/fractured basement constitutes the main aquifer unit in the study area. The isopach map of the weathered basement aquifer in the study area varies from 0.6m to 84.2m while the corresponding aquifer resistivity ranges from 15650 m. The depth-to-basement varies between 5.284.6m. Areas with thick overburden (>30m) correspond to basement depression while the zones with relatively thin overburden correspond to basement highs. Transmissivity values calculated vary from 1.11 m^2 day^{-1} to 52 m^2 day^{-1} for the entire saturated thickness of the aquifer. Higher values of the calculated Transmissivity correspond with areas underline by relatively thick aquifer materials.

The identified high resistive basement

rock zones contain very competent materials, hence are probably good zones for siting high-rise buildings, roads and bridges. Where the basement lies very deep are best recommended for siting disposal wastes and sewage. The materials of the rocks where fracturing and severe weathering occurred (northwest and southwest) are not competent. Such areas are weak zones and hence can serve as good aquifers. The present study has revealed that aquifer electrical properties can be converted into transmissivity. This transformation can be used as valuable information in finding suitable sites for the exploitation of groundwater and construction of safe civil engineering structures in the study area.

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