ESTIMATING AQUIFER TRANSMISSIVITY FROM GEO-ELECTRICAL SOUNDING

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ABSTRACT

A geophysical survey was 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 the estimation of Transmissivity of the aquifer. Sixty-six Schlumberger Vertical Electrical Soundings (VES) were carried out using a maximum electrode separation of 200m.Data analysis and interpretation of the field curves by computer modeling proposes a distinctive 3-4 geoelectric layer situations. 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/fractured Basement constitutes the main aquifer unit. Aquifer resistivity range from 4.26 ohm-m to 755.3 ohm-m with maximum thickness of 52.25m. A maximum 55.52m depth- to-basement was obtained in the study area. 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. In order to test the reliability of the results, the calculated Transmissivity values were compared with those obtained from pumping test analysis, and a linear regression coefficient of 0.94 was obtained.

Introduction

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 metropolitan water supply scheme for the area is grossly inadequate for the needs of the people especially during the dry season. At this time of the year many rivers and streams in the area dry up and this creates problem of availability of water.

One of the common methods for evaluating aquifer characteristics such as Hydraulic conductivity and 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, 1981; 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, 1991, Singh, 2005)

The objectives of this study were designed to determine different subsurface geoelectric layers, the aquifer units and to estimate aquifer Transmissivity from DC resistivity

measurements in the Kaduna Polytechnic Bye-pass Senior Staff Quarters of Sabo area of Kaduna State of Nigeria.

Geologic and Hydrologic Settings

The study area lies approximately between latitudes $10^o25'N$ and $10^o30'N$ and longitudes $7^o25'E$ and $78^o30'E$ covering an area of about 500,000m^2(Fig.1).

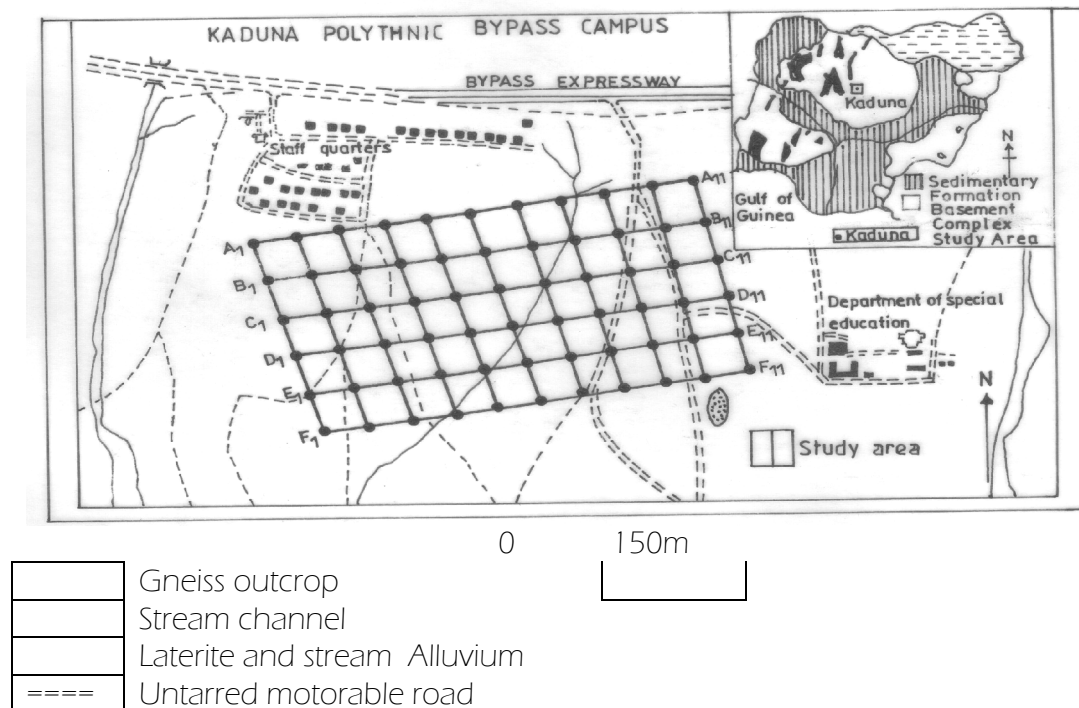|	Gneiss outcrop
	Stream channel
	Laterite and stream Alluvium
====	Untarred motorable road

Fig. 1: Map of the Study Area.

The 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 (32^0C) 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.

Geo-electric Survey 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 maximum half spread (AB/2) of current electrode was 100m with the potential electrode MN changing correspondingly from 0.5-15m. The measurements were made with ABEM 300C Terrameter units. 20mA was used in four staking to collect the data .Transmissivity evaluation based on hydraulic conductivity estimates can be erroneous if the saturated thickness and electrical resistivity of the aquifer are not interpreted accurately. Thus, to minimize aquifer thickness and resistivity interpretation error, field data were interpreted by using fast computer assisted program (INTERPEX,1XID).The VES curves reflect, geo-electrically a three and four-layer curve types, with a maximum fitting error of 7.59% between the observed and computed VES data, Fig 2 shows representative sounding and the inverted model .
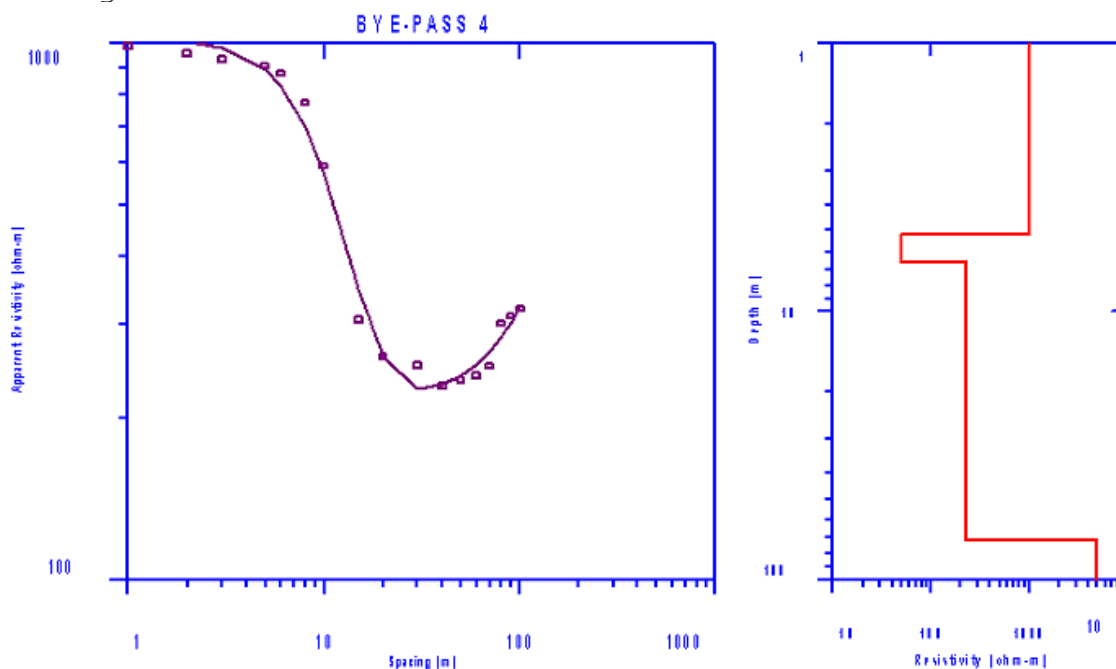

Fig. 2. Typical computer interpretation for VES D_4

Interpretation of Geo-electric sections

Geologic sections were constructed using the results of the VES and geologic data obtained from the works of Dan- Hassan, (1999) and Eduvie, (2003). The VES interpretation suggested that the layering in the area varies from 3 to 4. Deductions from borehole log after Dan- Hassan, (1999) and Eduvie, (2003) in the area suggests that the top most layers consists of laterite, river sand and gravel. The resistivity value varies from 250 ohm-m to 3000ohm-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 transition zones, have resistivity values between 14.26 ohm-m to 750 ohm-m. It has a maximum thickness of 55.52m and a minimum thickness of 0.67m. The resistivity of the basement, which either forms the 3rd or 4th layer, ranges from 630 ohm-m to 10000 ohm-m. The relatively low resistivity value (< 1000 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 transition zone/ fractured bedrock form the aquifer units in the study area. Fig 3 shows the interpretated geo-electric sections of VES A_1-A_3.
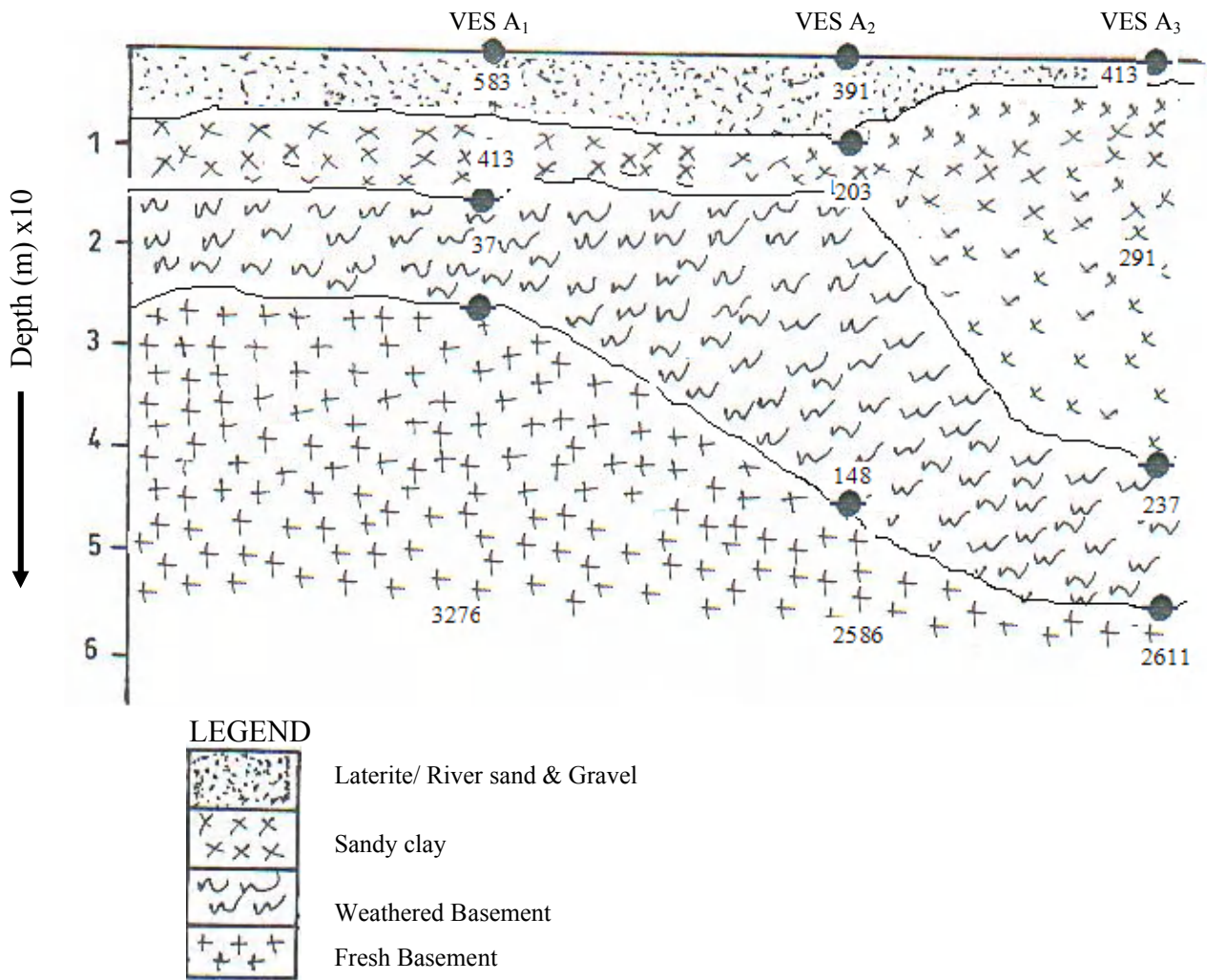
Fig. 3: Interpreted Geologic Section for VES A_1, A_2 &A_3

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

$$T = K\sigma R = KS\rho = Kh \text{————————— (1)}$$

Where T is the Transmissivity, K is the hydraulic conductivity, σ the layer conductivity, R the transverse resistance, S longitudinal layer conductance, ρ layer resistivity and h the thickness of the aquifer respectively. According to Niwas and Singhal (1981) the practical applicability of equation 1, 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 0.61m[1]day[-1] from 60 existing boreholes within Igabi, Kaduna North, Kaduna South and Chikun Local Governments Areas (Dan-Hassan et al, 1999 and Eduvie, 2003), Transmissivity of the aquifer in the study area was calculated using the relation T == KσR Table1 shows the calculated Transmissivity values.

Fig 4 shows the frequency distribution of the Hydraulic conductivity of the 60 existing boreholes considered while Fig 5 shows the corresponding Transmissivity values.
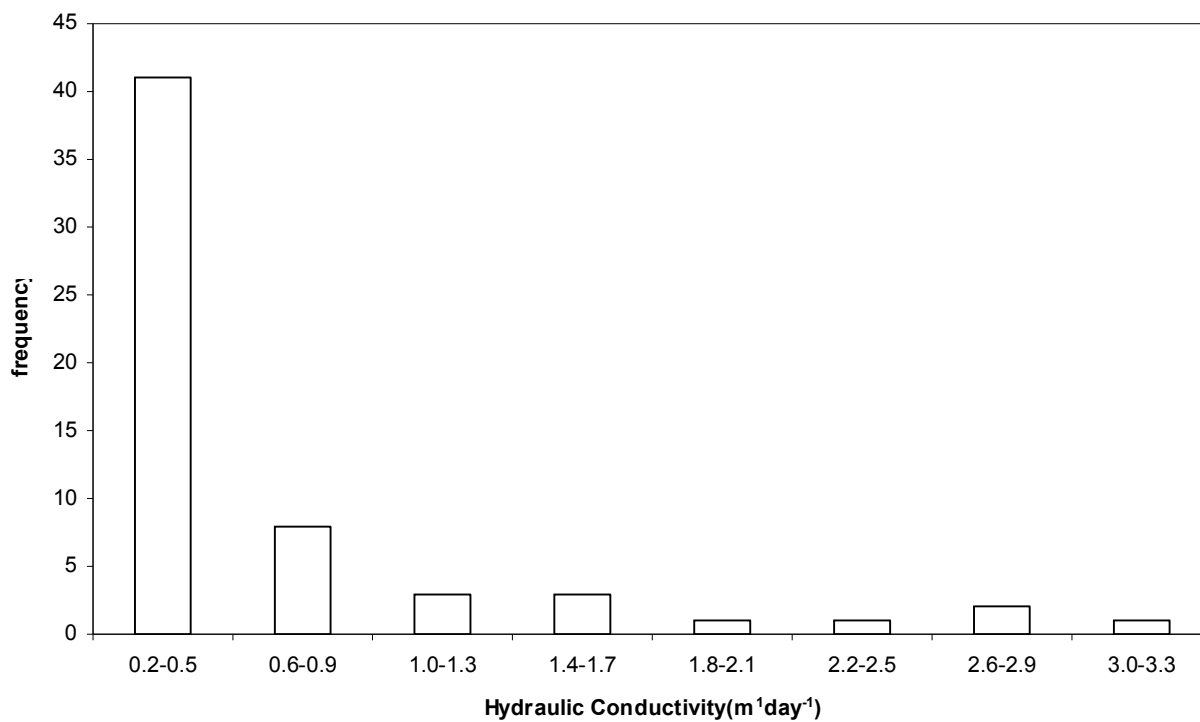

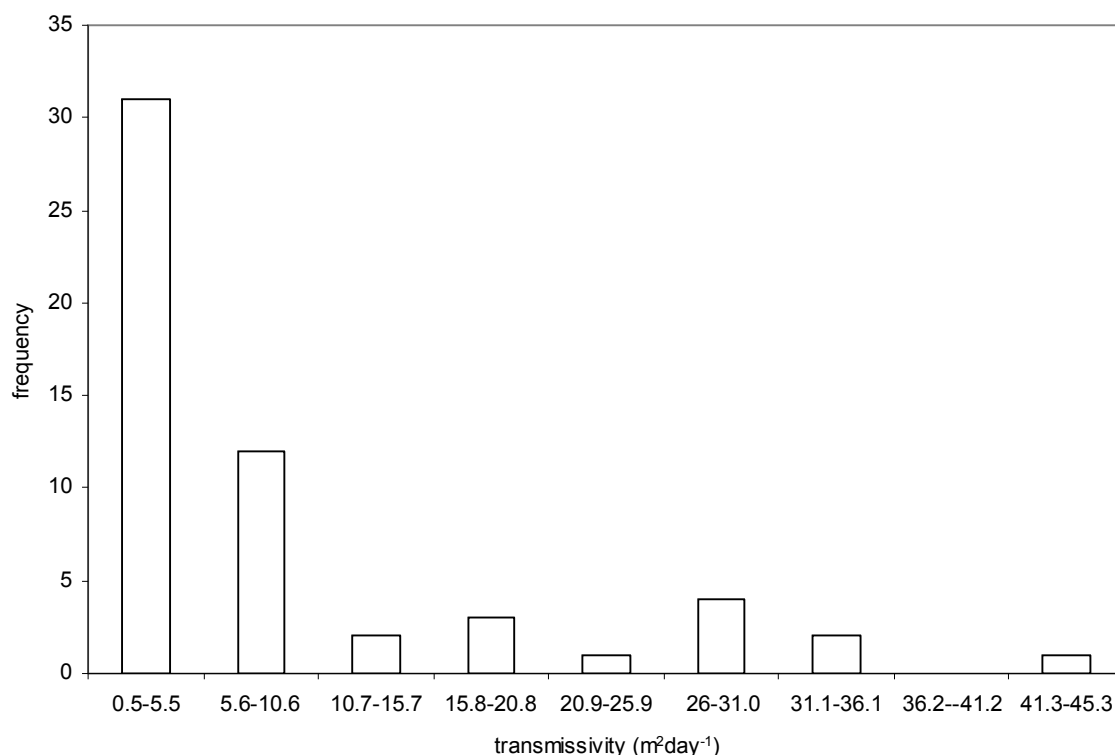**Fig 4 frequency distribution of hydraulic conductivity of existing boreholes**

FIG 5 frequency distribution of Transmissivity from pumping test

Results and Discussion

Fig 6 shows the isopach map of the aquiferous layer (Weathered basement). The map plotted with Surfer (version 8.01) shows that the aquifer is highly variable in thickness, being thinnest in the vicinity of VES E_7 with thickness value of 0.64m while VES D_{10} with a value of 55.52m forms the thickest point in the survey area. This result 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 North-Eastern and South-Eastern parts of the survey area, the survey area appears thick enough for drilling productive boreholes over the entire area with values ranging from 15 –56m.

Table 1 Calculated Transmissivity Values

VES NO	Transmissivity (m^2day^{-1})	VES NO	Transmissivity (m^2day^{-1})	VES NO	Transmissivity (m^2day^{-1})
A_1	8.97	B_{10}	11.36	D_8	21.89
A_2	9.74	B_{11}	12.99	D_9	12.93
A_3	33.11	C_1	2.65	D_{10}	52.16
A_4	0.07	C_2	29.11	D_{11}	12.81
A_5	5.79	C_3	8.52	E_1	11.69
A_6	20.49	C_4	10.97	E_2	7.97
A_7	26.03	C_5	13.20	E_3	12.49
A_8	7.30	C_6	20.03	E_4	8.28
A_9	3.40	C_7	21.24	E_5	5.77
A_{10}	22.10	C_8	12.63	E_6	5.89
A_{11}	22.65	C_9	14.16	E_7	1.11
B_1	2.23	C_{10}	14.35	E_8	8.68
B_2	22.67	C_{11}	11.28	E_9	6.40
B_3	15.21	D_1	18.84	E_{10}	1.37
B_4	38.08	D_2	10.54	E_{11}	23.00
B_5	10.70	D_3	7.59	F_1	4.60
B_6	15.44	D_4	16.20	F_2	9.54
B_7	7.85	D_5	2.25	F_3	4.54
B_8	7.43	D_6	6.64	F_4	3.91
B_9	19.88	D_7	8.36	F_5	2.44
F_6	2.38	F_8	5.35	F_{10}	1.57
F_7	3.03	F_9	9.97	F_{11}	6.50

The corresponding resistivity map of the aquiferous layer (Weathered Basement) (Fig 7) shows that the resistivity value ranges from 100–300 ohm-m in the Northwestern and Southwestern zones and 300-900 ohm-meter in the Northeastern and Southeastern parts 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. . However, according to Mbonu et, al (1991), isoresistivity map is a qualitative interpretation tool which shows possible variations in resistivity at a given electrode spacing and does not give the true resistivities of a definite geoelectric layer. The high resistivity values (> 400 ohm-m) recorded in profiles E and F is due to basement (Young Granite) intrusion. Profiles E and F are 102 and 2m away from where the basement rock outcropped respectively.
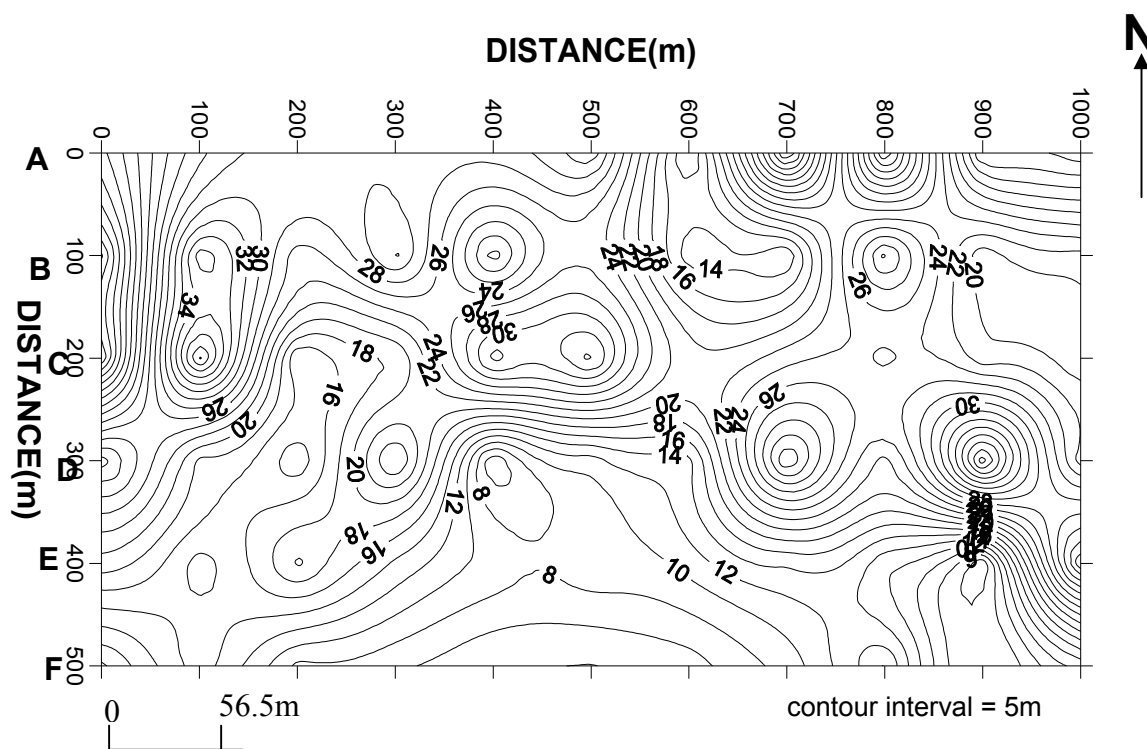

Fig. 6. Acquifer Isopatch Map

Fig 7 Weathered Basement Iso-resistivity Map

Contour interval= 50 ohm- m

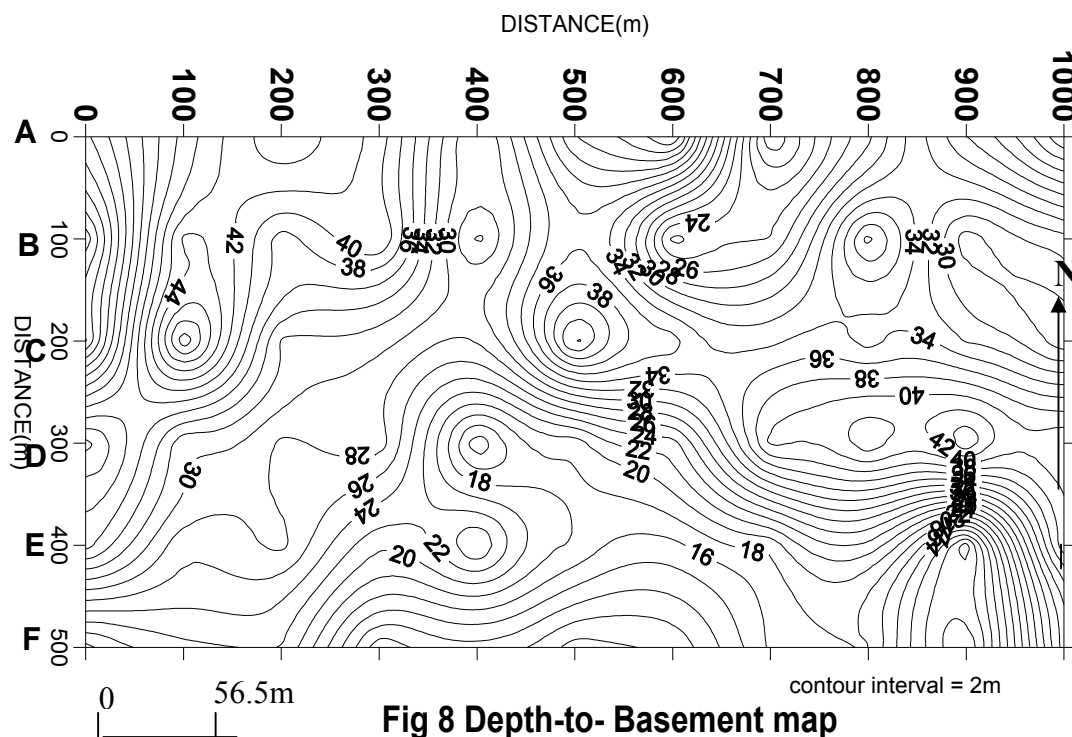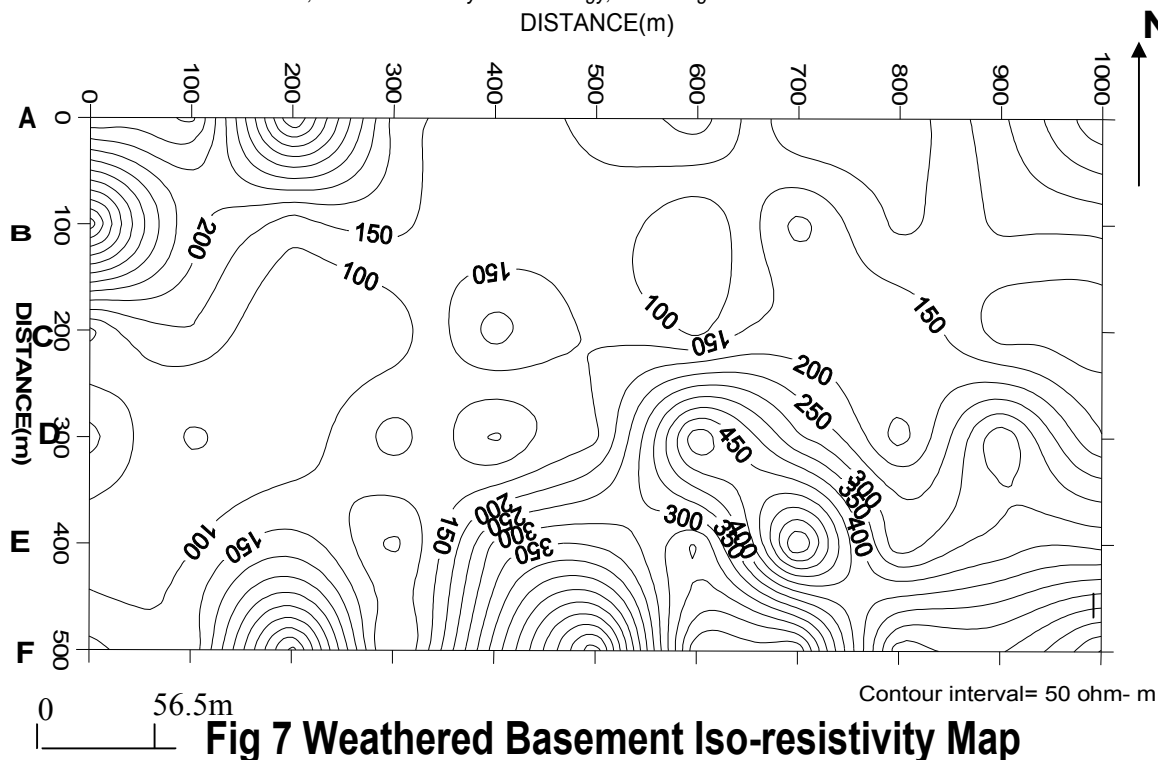**Fig 8 Depth-to- Basement map**

contour interval = 2m

Figure 8 shows the depth –to-basement map. The map was produced by summing topsoil, clayey sand layer and the weathered/fractured basement layer. It varies between 5.98m at F_{10} , which correspond to basement highs(F_{10} is 2m where the basement outcropped) to 55.52m at D_{10}, the deepest point in the study area which correspond to basement depression. This agrees with the results of 4.3 – 64m depth reported by Dan-Hassan and Olorunfemi (1999).The overburden is deep in the Northcentral, Northwest and extreme Eastern 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. Figure 9 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 and Southwestern parts of the survey area with values between $8 – 52 \ m^2 \ day^{-1}$ .These are the zones where aquifer resistivity values ranged between 100-150 ohm-m and therefore the groundwater condition in these zones are potentially high..
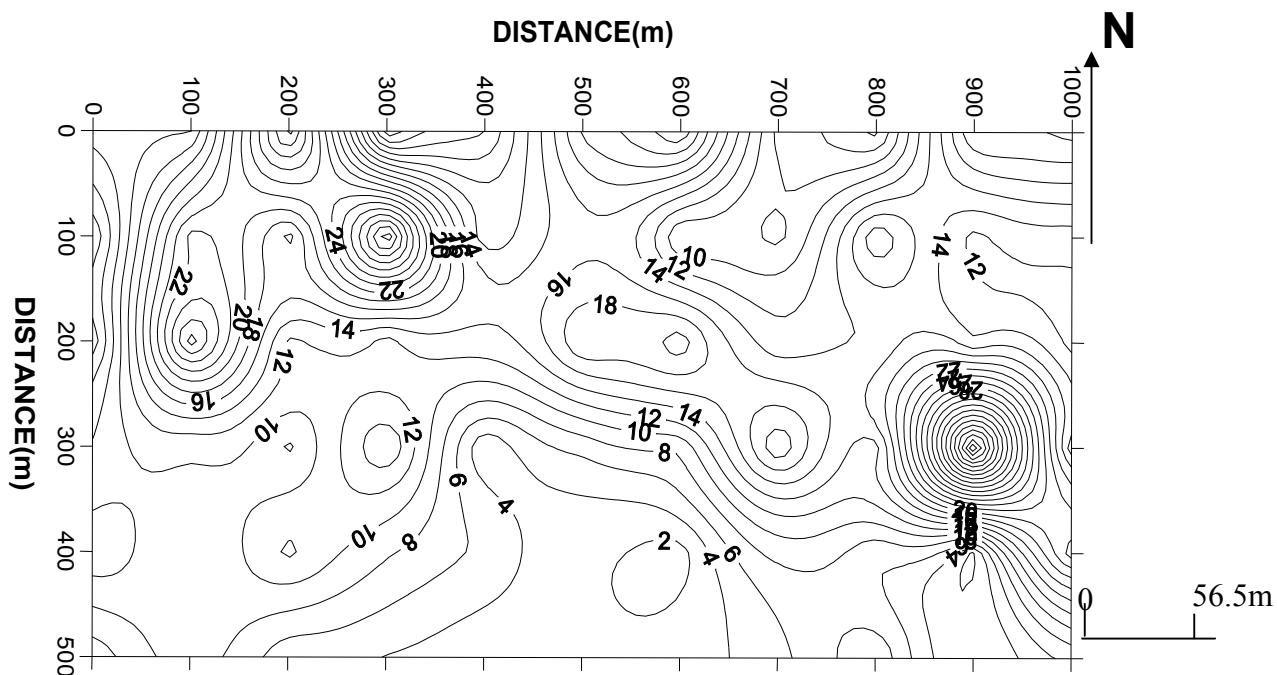

Fig 9 Calculated Transmissivity Map

Fig 10 is the distribution of the calculated Transmissivity with highest value of $52.16 \ m^2 \ day^{-1}$ and lowest value of $1.11 \ m^2 \ day^{-1}$. The calculated Transmissivity values are generally higher than those obtained from pumping test (Fig 5) because they were calculated for the whole saturated thickness of the aquifer while those from pumping test analysis were obtained from the screened section of the aquiferous zones. A correlation analysis between the calculated Transmissivity from VES data and fifty (50) from pumping test analysis, (Fig 11), suggested that they are linearly related with a correlation coefficient of 0.94.
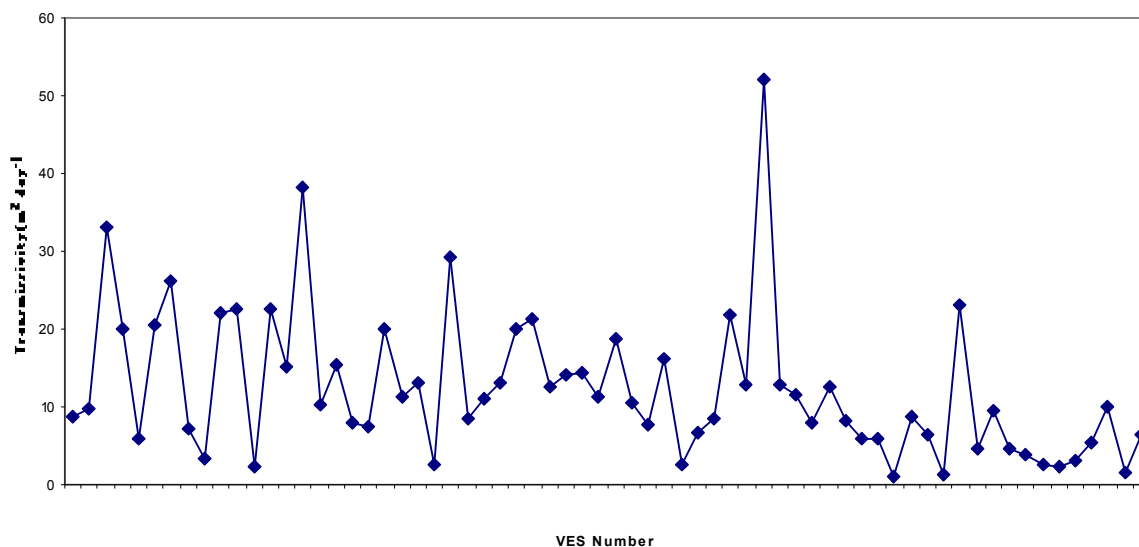
Fig 10 Distribution of Calculated Transmissivity

CAL_TRAN vs. P_TRANS (Casewise MD deletion)
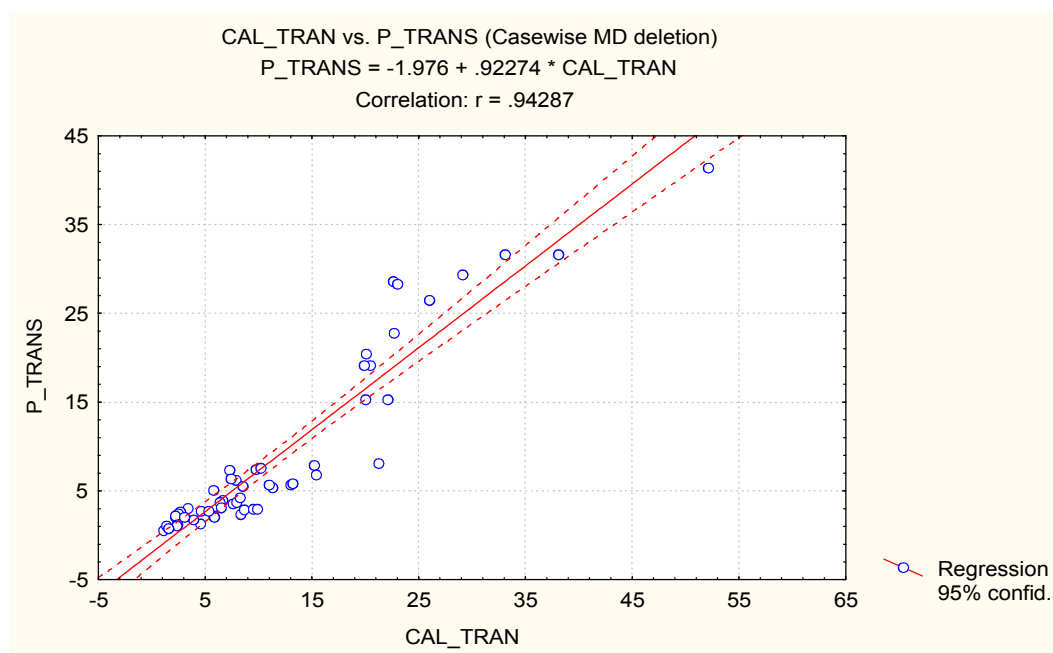P_TRANS = -1.976 + .92274 * CAL_TRAN
Correlation: r = .94287

Fig 11 Linear regression correlation of Transmissivity from pumping test(P-TRANS) and calculated Transmissivity from VES data (CAL-TRAN) .

The dashed lines represent least-square's fit while the solid lines represents the regression correlation.

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 transition zone/ fractured layer and the fresh basement. 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 0.64m to 55.52m while the

corresponding aquifer resistivity ranges from 14.26 –755.3 Ωm. The depth-to-basement varies between 5.17 – 55.52m. 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 $1.11m^2 \, day^{-1}$ to $52.16 \, m^2 \, day^{-1}$ for the entire saturated thickness of the aquifer. Higher values of the calculated Transmissivity correspond with areas underline by relatively thick aquifer materials.

The present study has revealed that aquifer electrical properties can be converted into Transmissivity and human error and computation time in the interpretation of the VES data can be minimized by using fast inversion computer packages 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. A correlation coefficient of 0.94 obtained between the calculated Transmissivity and those obtained from pumping test analysis suggest close agreement between the two values.

Acknowledgements

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