Delineating The Subsurface Structures Using Electrical Resistivity Sounding In Some Part Of Willeton, Perth, Western Australia

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Abstract: Geophysical survey using electrical resistivity methods has been carried out within the industrial area of Willeton, Perth, Western Australia with the view to delineate the geoelectric characteristics of the basement complex and evaluate the groundwater potential in the area. Vertical electrical sounding with ABEM SAS 3000 Terrameter and Schlumberger electrode configuration were employed for data acquisition. Apparent resistivity values obtained from the field measurements were plotted against half current electrodes spacing on a log-log graph while a model was suggested to fit the resistivity distribution presented in the sounding. The results from the modelling were finally iterated to the lowest Root Mean Square (RMS) percentage error using computer software, "A 7 point filter" derived by Guptasarma to calculate a forward model. Analysis of the results showed that the study area has fairly homogenous subsurface stratification with four distinct subsurface layers above the depth of 37m. The four subsurface layers comprises: top soil mainly of unconsolidated and sand containing organic matter, unsaturated sand layer with consolidated and highly resistive, water saturated sand layer with highly water saturated soil, and the sub-stratum layer consisting of clay material. The aquifer performance is best at about 32m hence it is suggested that boreholes for sustainable water supply in this area should be drilled to about 32 m to hit prolific aquifer.

Key Words: Aquifer*, subsurface structure, electrical resistivity, geo-electric*

1 INTRODUCTION

Water is commonly used by many people for both industrial and domestic purposes hence it is regarded as the foundation of opportunity (Deming., 1975, Rybkina, 1978). Ideally, Rivers and lakes are the easiest and most convenient way to meet the public demand for water but this source of water is less than 0.01 percent of the world's total water and less than two percent of the world's fresh water. Further, they are spatially distributed and in most cases are highly polluted. Groundwater, on the other hand accounts for about ninety-eight percent of the world's reasonably constant supply, which is not likely to dry up under natural conditions in crust to the surface sources. Though groundwater is significantly protected from surface pollutants, however, the need to ensure that true extent of the aquifer is understood and delineated is highly desirable. Generally, geological structures such as faults, fractures and lithologic contacts plays significant role in the movement of groundwater. Groundwater in the study area occurs in three major aquifers which are (in order of increasing depth) namely: Superficial aquifer which is unconfined, Leederville aquifer which is said to be confined and Yarragadee aquifer regarded also as confined. Groundwater in the study area is variable as high nutrient levels are frequently experienced in some areas and in some other areas high levels of Lead, Zinc and other contaminants have been observed especially within the industrial areas. This study is therefore aimed at determining the number of geoelectric/geologic layers beneath the depth sounding stations and the layer parameters (resistivity and thickness), identify the aquifer units and determine their thicknesses, evaluate the groundwater potential and determine the feasibility of groundwater development of the survey areas

2. Location and Geology of the Study Area

Willetton, the study area is located about 15 kilometres south of the centre of Perth. It is built on a section of flat sandy coastal plain which was originally covered with open Banksia woodland and stands of Paperbark trees marking the edges of shallow seasonal swamps(DLS, 2006). Willetton is bounded by Karel Avenue to the west, Leach Highway and High Road to the north, Willeri Drive to the east, South Street and Roe Highway to the south while Vahland Avenue runs north-south through the suburb. The area is dominated by Bassendean sands with deposits of limestone, granite, pegmatite, shiest, gneiss and peaty clay to the north of the river which are Precambrian in nature. Weathering and other denudational activities have made parts of the under laying rock mass to be slightly thicker in some areas than others. The area has a fairly plain topography with sparsely distributed medium size hills and highlands that may have been formed by outcropping basement rocks. The study area is characterized by long dry season and short wet season and has high rainfall of about 200mm and peak rainfall between July and August. Figure 1 is the location map showing the study area.

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- *where is the constant of proportionality, known as the resistivity of the medium through which the current is passing.*

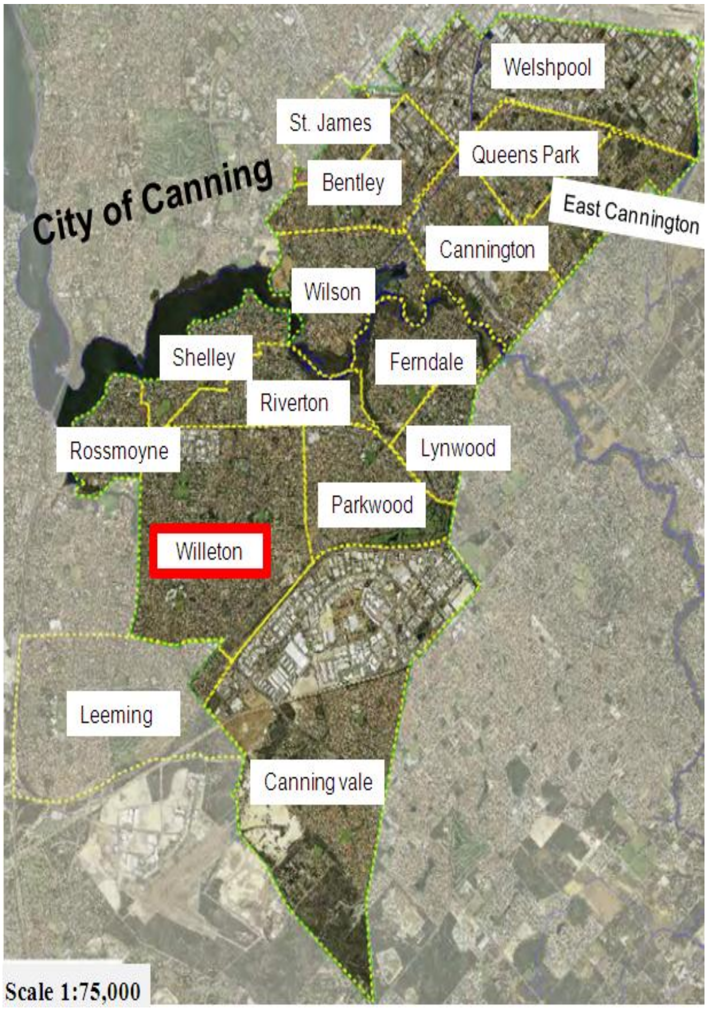

Figure 1: *The location map showing the study area.*

3. Materials and Methods

Electrical Resistivity (ER) surveying is a geophysical prospecting method which produces ER cross sections of shallow earth structure in the order of 10s of meters of depth. This method has been used since the 1920s in hydrogeological, mining, and environmental investigations (Telford et al., 1990). Among its many applications, it has been used to characterize aquifers, which are underground layers of permeable rock from which drinking water can be extracted. It has also been used in the monitoring of groundwater pollution and in the investigation of the Earth upper crust as well as in the delineation of the structural setting of volcanic areas (Osella, and Sánches, 2001, Park and Wernicke, 2003, David and Ofrey, 1989; Osemeikhian and Asokhia, 1994; Mallam and Ajayi, 2000, Palacky, 1998). The method is very unique because of its ability to detect increases in pore water conductivity (Adepelumi et al 2008, Khalil, 2006). In all electrical resistivity surveying methods, a known electrical current is injected into the ground through two electrodes which form a complete circuit. In homogenous ground, current distributes itself uniformly across a hemispherical shell cantered on the source. As current paths cross an interface separating different resistivities, they refract much as seismic waves encountering an interface (Figure 2). However, unlike the case of seismic waves, current paths refract towards the normal when crossing into rock with higher resistivity, and away from the normal in rock with lower resistivity (Telford et al., 1990).

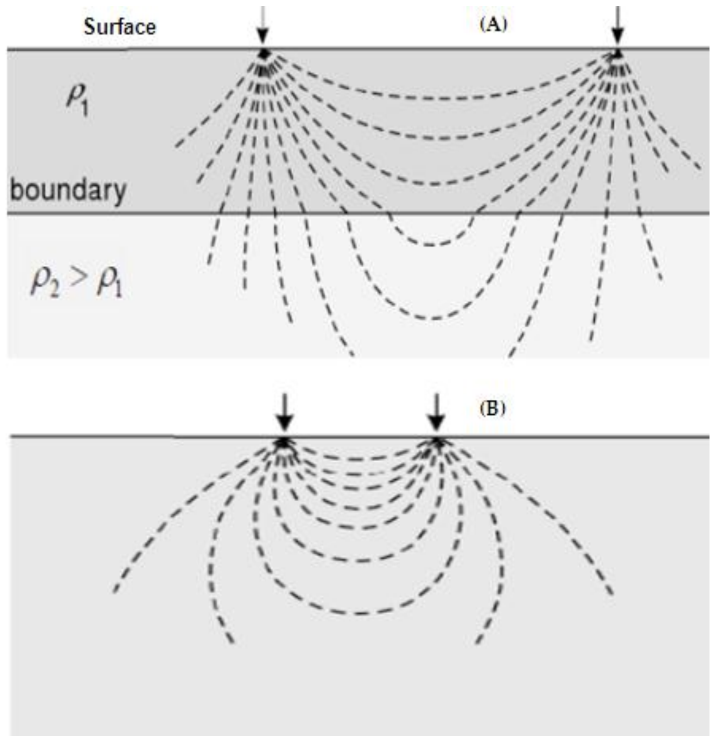

Figure 2: *Qualitative distribution of current flow lines, (a) Homogenous subsurface, (b) Layered subsurface. When material with greater resistivity is located beneath the horizontal interface, the current flow lines refract away from the normal and are more closely spaced than in (a)*

In this study, Vertical Electrical Sounding was carried out using ABEM SAS 3000 Terrameter. Other equipment includes current and potential electrodes, long conductors with crocodile clips, hammers, field survey tapes and mobile phones for communication. The survey was carried out using a Schlumberger electrode configuration array Figure (3) where the two pairs of current and potential electrodes were positioned symmetrically on a line and the set up was mirrored around the centre. The pair of potential electrodes was kept close to the centre, while the pair of current electrodes was gradually moved out ward and symmetrically away from the centre so that the current probe deeper into the earth. The distance between the current electrodes was exponentially increased in logarithmic steps until the scheduled maximum length of current arm was attained.

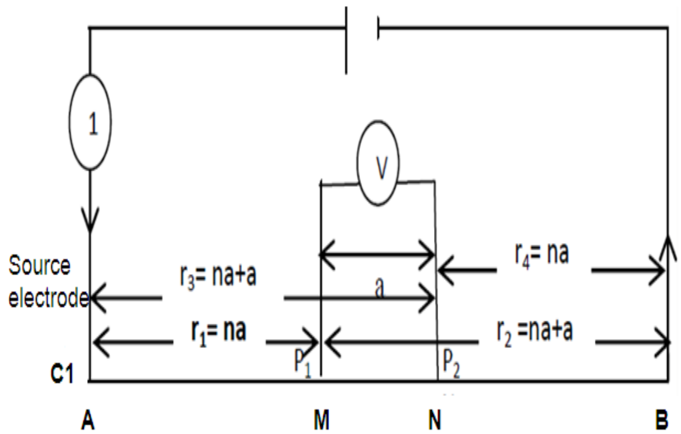

Figure 3: *Schlumberger electrode configuration array used to collect data*

Since the earth is not homogeneous, the expectation is a kind of averaging of the resistivity of the earth below the measuring site within this depth; this average resistivity is usually referred to as apparent resistivity. Where the relationship for apparent resistivity for Schlumberger array is derived from:

$$dV = (V_c - V_d) = \frac{1}{2\pi}\left\{\left(\frac{1}{r_1} - \frac{1}{r_2}\right) - \left(\frac{1}{r_3} - \frac{1}{r_4}\right)\right\} \quad (1)$$

No	Electrode Spacing (m)	Voltage Electrode Spacing (m)	Current (A)	Forward Voltage (V)	Revise Voltage (V)	Average Voltage (V)	Apparent Resistivity (ohms)
1	1	0.3	0.1	10.3	-10.4	10.5	493.1515068
2	1.5	0.3	0.1	5.5	-5.5	5.5	622.0353454
3	2	0.3	0.1	3.78	-3.78	3.78	773.8685184
4	4	0.3	0.1	1.6	-1.6	1.6	1332.873043
5	8	0.3	0.1	0.44	-0.45	0.445	1489.1123
6	10	0.3	0.1	0.255	-0.257	0.256	1339.206494
7	30	0.3	0.2	0.017	-0.04	0.0405	190.3746243
8	20	0.3	0.2	0.074	-0.33	0.33	687.2626629
9	15	0.3	0.2	0.008	-0.76	0.763	889.899316
10	40	1.5	0.2	0.041	-0.019	0.018	148.49294
11	50	1.5	0.2	0.33	-0.037	0.0355	104.6255073
12	60	1.5	0.2	0.766	-0.009	0.008	94.18887475

Table 1 *observed data and the calculated apparent resistivity.*

$$\rho = \frac{2\pi\Delta v}{1}\left\{\frac{1}{\left(\frac{1}{r_1} - \frac{1}{r_2}\right) - \left(\frac{1}{r_3} - \frac{1}{r_4}\right)}\right\} \quad (2)$$

Re-arranging equation 2 by assuming that $r_1 = r_4 = na$ and $r_2 = r_3 = na+a$ we have that

$$\rho = \frac{2\pi R}{1}\left\{\frac{1}{\left(\frac{1}{na} - \frac{1}{na+a}\right) - \left(\frac{1}{na+a} - \frac{1}{na}\right)}\right\} \quad (3)$$

$$\rho = 2\pi R\left[\frac{na(na+a)}{2a}\right] \quad (4)$$

$$\rho_a = 2\pi R(n+1)a \quad (5)$$

But the geometric factor K is given as $K = \pi n(n+1)a$

This K demand that AB = 2(n+1)a with n > 2 to ensure that B/2 > 5MN/2 at all times Where r1 = r4 = na and r2 = r3 = na+a. The apparent resistivity values obtained from the field measurements (Table 1) using equation 5 above were plotted against half current electrodes spacing on a log-log graph(Figure 4) while a model was suggested to fit the resistivity distribution presented in the sounding. The forward algorithm simulates the response of the earth to the measuring equipment by calculating the response of the model to be compared to the actual data. A continued interpretation of the model was made until a satisfactory agreement was reached in terms of the value of the acceptable misfit (Table 2).

L	Data	Calc		Meas Err %	Misfit
1	493.1515	486.7118		5	0.068208
1.5	622.0353	643.9878		5	0.49819
2	773.8685	798.4391		5	0.403234
4	1332.873	1236.984		6	1.437663
8	1489.112	1453.959		5	0.222916
10	1339.206	1369.887		5	0.209942
15	889.8993	985.7959		14	0.592473
20	687.2627	632.3415		8	0.997823
30	190.3746	258.8582		15	5.751385
40	148.4929	139.5542		5	1.44943
50	104.6255	105.0774		5	0.007461
60	94.18887	95.08979		5	0.036596
				Total Misfit	11.68

Table 2: *Modified model to contain the observed data*

Apparent resistivity curve produce from the modified model in table is shown in (Figure 5). The results from the modified model containing the observed data were finally iterated to the lowest Root Mean Square (RMS) percentage error using computer software "A 7 point filter" derived by Guptasarma to calculate a forward model. This filter approximates the apparent resistivity measured by a Schlumberger array with L= AB/2 over a layered earth with a digital filter to determine the smoothed resistivities and thicknesses of other layers (Table 3). From this information, the subsurface lithologies are obtained and the geoelectric sections of the study area were drawn.

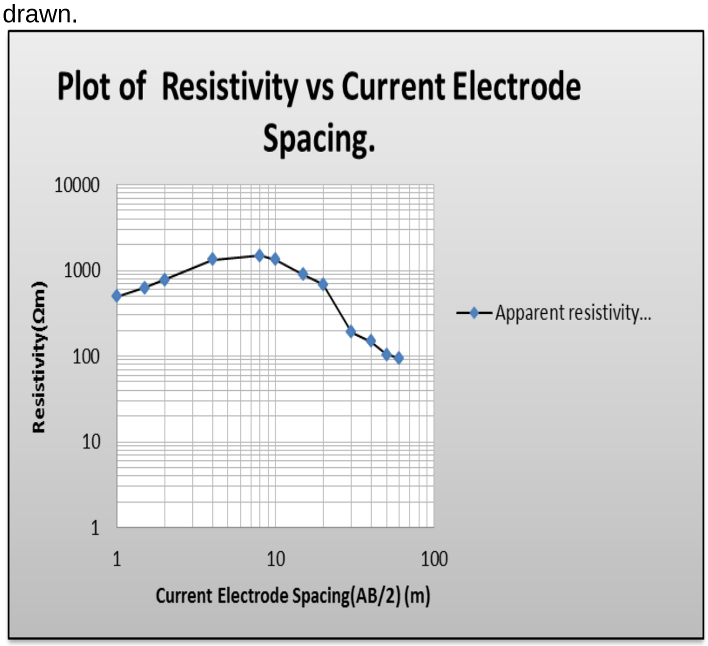

Figure 4: *Plot of Apparent Resistivity VS Current Electrode spacing*

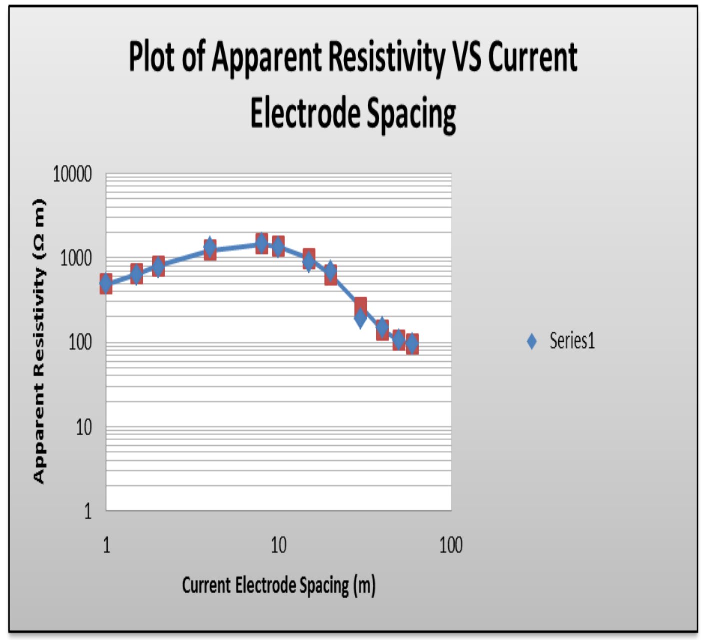

Figure 5: *The curve produced by the model which represents the apparent resistivity*

4 Results and Discussion

Analysis of the results showed that the study area has fairly homogenous subsurface stratification with four distinct subsurface layers to depth above 37 m (Figure 6). The first layer which is the near surface layer (top soil) has resistivity values ranging from 335 – 432 Ωm and thickness of 0.7 m - 1.84 m. This layer consists mainly of unconsolidated and sand containing organic matter and deposits in relatively non decomposed sate. The second layer consist of Subsurface dry sand made of consolidated and highly resistive layer with material and organic matter with resistivity values of 3564 - 3638 Ωm and thickness of 3.42-4.17 m. The third layer consists of highly water saturated soil sand formations with resistivity ranging from 147 Ωm to 239 Ωm with thickness from 14.2-22.67m. This layer is slightly resistive and approaching unto the water table. The last subsurface layer consists of clay materials with thickness of about 28.1m to 37.52m and resistivity ranges from 89 Ωm to 104 Ωm. This layer has the sub-stratum, which is probably a clay material with a very low resistivity. This is the prolific aquifer in this area as it contains appreciable quantity groundwater. Further interpretation of the strata reveal that false aquifers exist at about 17.2 m to 23.5m. Although water seems to be everywhere for most parts of the year in the area, prolific aquifer is within 28.1 – 37.52 metres with appreciable loose sand deposits beneath which implies that the superficial aquifer is unconfined in this area.

Model	Resistivity (ohms)	Thickness (h)	Lithology
Layer 1	335 - 432	0.7-1.84	Near surface soil
Layer 2	3564-3638	3.42-4.17	Unsaturated sand
Layer 3	147-239	14.2-22.67	Water saturated sand
Substratum	108-164	28.1-37.52	Clay materials

Table 3: *Filtered four layer model from the filtering*

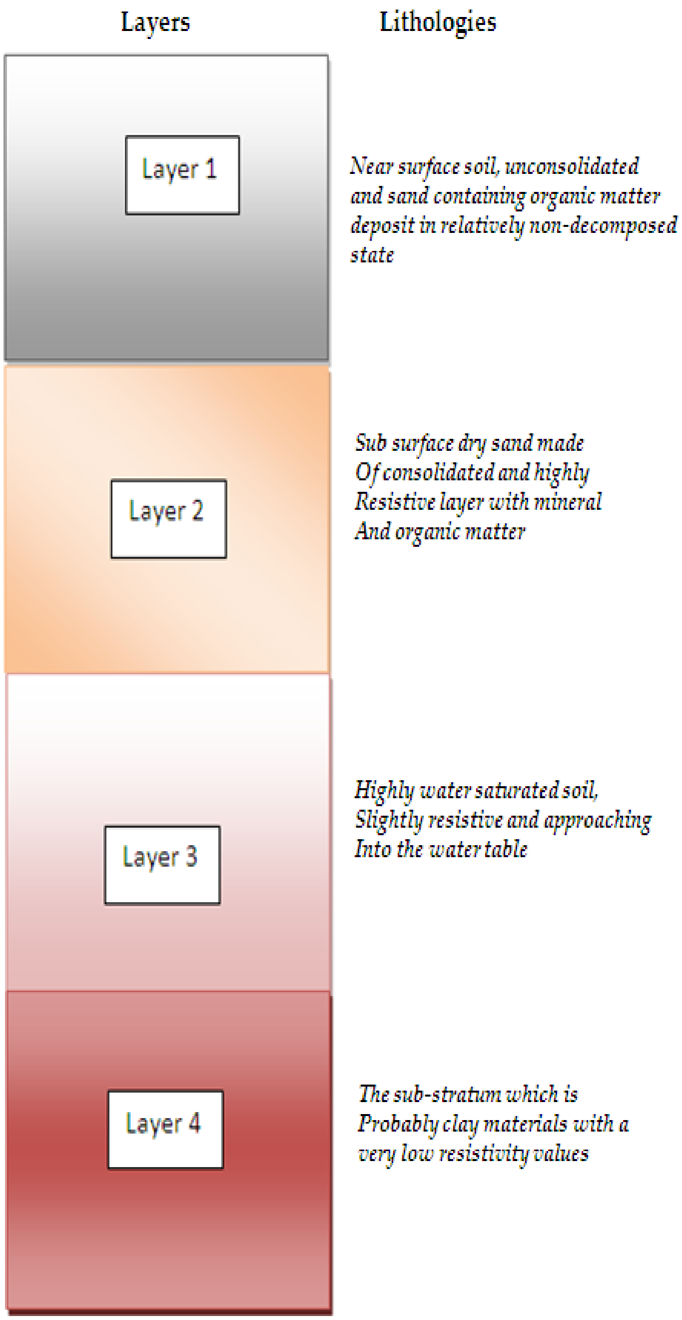

Figure 6: *Geo-electric layers interpreted from the model*

5. Conclusion

This study has been able to demonstrate the importance of resistivity method in evaluating the lithology of an area. The geophysical investigation carried out delineates the presence of four subsurface layers which comprises; top soil mainly of unconsolidated and sand containing organic matter and deposits in relatively non decomposed sate, unsaturated sand layer made of consolidated and highly resistive layer with material and organic matter, water saturated sand layer with highly water saturated soil sand formations and slightly resistive and the sub-stratum layer consisting of clay material with a very low resistivity values. The aquifer performance is best at about 32 m. It is therefore recommended that boreholes for sustainable water supply in this area should be drilled up to 32 m in order to hit prolific aquifer. For economic purpose, we also recommended the use of other geophysical exploration methods such as seismic refraction and self-potential methods for further investigation.

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