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Groundwater investigation using electrical resistivity imaging technique at Sg. Udang, Melaka, Malaysia

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Abstract: Electrical resistivity imaging surveys have been conducted in order to locate, delineate subsurface water resource and estimate its reserve. The resistivity imaging surveys carried out basically measures and maps the resistivity of subsurface materials. Electrical imaging is an appropriate survey technique for areas with complex geology where the use of resistivity sounding and other techniques are unsuitable to provide detailed subsurface information. The purpose of electrical surveys is to determine the subsurface resistivity distribution by making measurements on the ground surface. The resistivity imaging measurement employing Wenner electrode configuration was carried out using an ABEM SAS 1000 terrameter and electrode selector system ES464. In this survey, electrodes were arranged in a straight line with constant spacing and connected to a multicore cable. A 2-D geoelectrical resistivity technique was used. The field survey was conducted along four profiles which provide a continuous coverage of the resistivity imaging below surface. Colour-modulated sections of resistivity versus depth were ploted for all lines, giving an approximate image of the subsurface structure. The surface soil material is mainly clayey silt. The results showed that the layers associated with the low resistivities (Ω.m) are located at depth ranging from 2 to 28 m. This low resistivity values are associated with zone of water saturated weathered layer and fractures. The results showed that the thickness of residual soil is about 0.5-2.55 m. Borehole data indicated that the depth of bedrock is about 10m and the groundwater level is ranging from 8.73 m to 8.54 m.

Keywords: 2-D resistivity imaging, electrical imaging, groundwater, Melaka

INTRODUCTION

The increased interest in recent years in underground sources of water has led to a need for more intensive studies of the geometry and properties of aquifers. Geophysics has played a useful part in such investigations for many years and improvements in instruments and the development of better methods is resulting in a widening of its applications. A geophysical model created can be used to support other studies which involve, primarily one-, two-, and three- dimensional modelling. Resistivity imaging is one of the geophysical surveys which have been used to map groundwater contamination and it is widely used for environmental surveys (Griffiths & Barker, 1993; Hamzah *et al*., 2006; Samsudin *et al*., 2000, 2001). This technique has been used to determine the subsurface resistivity anomalies and recently it has become popular for the investigation of water movement in vadose zone. A groundwater characteristic study using electrical resistivity imaging was conducted at a proposed landfill site in Sungai Udang area of Melaka. The results of this study were used for developing groundwater model and guidance in designing groundwater monitoring network as part of environmental surveillance program for the proposed landfill site. The area is located about 15 km from Melaka city centre and about 3 km from Sg. Udang town in adjacent to Sg. Udang Centralized Sludge Treatment Plant owned by Jabatan Perkhidmatan Pembetungan (JPP)/Indah Water Konsortium Sdn Bhd (IWK). It is located about 1km from the existing Ayer Keroh to Alor Gajah/Sg. Udang Road (M136). The existing site is currently surrounded by oil palm and rubber estate. The area is bounded by latitudes N2° 18.55’and N2° 18.78’, longitudes E102° 9.359’ and E102° 9.448’ (Figure 1).

The main objective of this study is to determine the subsurface resistivity and depth of bedrock and compare these information to borehole data (BH_1 and BH_7), as well as to evaluate of the occurrence of groundwater in fractured bedrock in the study area.

SETTING OF THE AREA

The area is characterised by undulating topography. Field study indicated that slope angles of the ground surface are generally less than 20°. The surface soil material is mainly clayey silt. This material is derived from the *in-situ* weathering of the schist, which form the bedrock of the study area. Examination of a moderately to highly weathered cut slope along the road at the entrance to the site showed that the schist is highly fractured. Quartz lenses are present within the interbedded rocks. Generally, silty soil materials are characterised by moderate to high erodability. However, as the slope angles are relatively low and the slope lengths are also low to moderate, soil erosion under conditions of complete removal of vegetation is expected to be moderate.

The climate of Melaka is generally characterized as humid tropical. Humidity and temperature show very little variation. Nevertheless, the climate does have a seasonal rhythm which is controlled largely by the synoptic wind system. In this study, base line data used to describe the climate was obtained at Batu Berendam Airport (102° 15’E; 2° 16’N). The climatological station located approximately three km onshore and is about 12 km east of the study area.

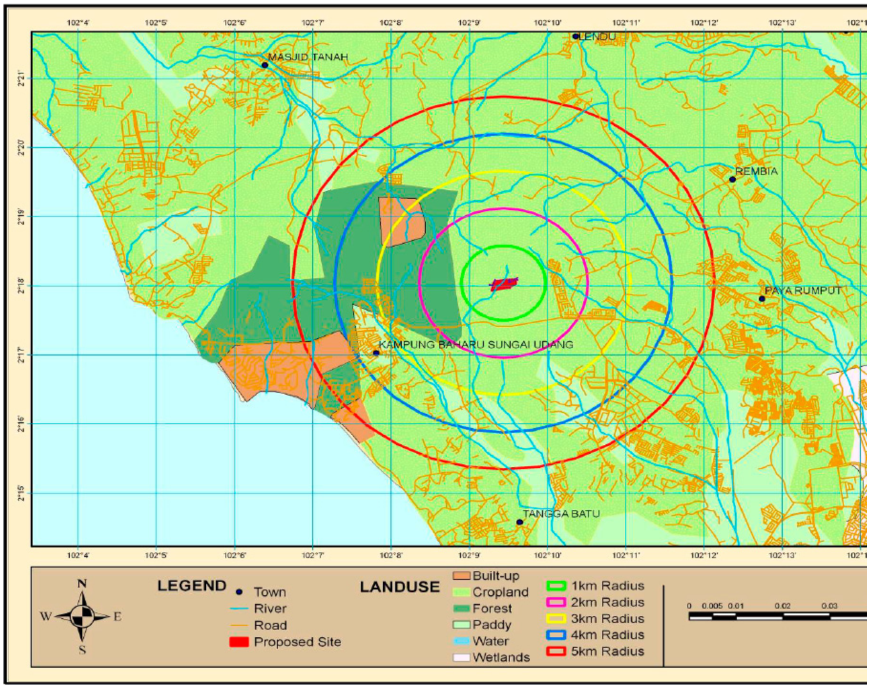

Figure 1: Location map of study area (landfill site).

A peak in the rainfall amount begins around September and ends abruptly around November. In March the rainfall amount rises again as the northbound Inter-tropical Convergence Zone (ITCZ) moves over Peninsular Malaysia after its sojourn south of the equator. A smaller peak occurs in April. From April until September the rainfall amount remains virtually constant. Over 20 years (1985-2008), the mean maximum rainfall was recorded in November (284.3 mm) while the minimum, 101.4mm was recorded in February. Maximum temperature as accumulated from 1985-2008 fluctuates between 33.1°C in March to 30.1°C in September. The mean minimum varies between 23.4°C in March to 22.3°C in November. The diurnal range varies between 8°C during the Southwest Monsoon to 10°C during February and March, the end of the dry Northeast Monsoon. The high moisture content is instrumental in reducing the diurnal range as the water vapour absorbs incoming solar radiation during the day and arrests terrestrial radiation during the night.

MATERIAL AND METHOD

Electrical resistivity imaging was used in this study to investigate the subsurface geological characteristics and groundwater condition in the study area. The resistivity method has its origin in the 1920's due to the work of the Schlumberger brothers. In the next 60 years, for quantitative interpretation, conventional sounding survey was normally used. In this method, the centre point of the electrode array remains fixed, but the spacing between the electrodes is increased to obtain more information on the deeper sections of the subsurface. The resistivity method is the most popular of all the geophysical methods as far as groundwater explorations is concerned. However the method as such has not developed much in the last two decades (Barker, 1981). Electrical resistivity is a fundamental physical property of any material. It is the impedance of electrical current flow through that material. Electrical resistivity of sediments or rock is a function of porosity, saturation, resistivity of the pore fluids and the solid phase, and the material texture. Because tills, fluvial and lacustrine sediments, bedrock, and structural features such as faults, are expected to exhibit large contrasts in such properties, electrical resistivity should be well suited to resolving structural features and intruded bedrock in unconsolidated sediments. Resistivity methods can be used to investigate the boundary between crystalline and sedimentary rocks, compact quartzite rocks with schist or phyllite, etc. where resistivity differentiation of rocks can be anticipated in the horizontal direction, i.e. in the maximum resistivity changes occur in the vertical direction, i.e. in areas with approximately horizontally deposited layers and vertical electric sounding is used (Telford *et al*., 1976). Electrical resistivity surveys have been used for many decades in hydrogeological, mining and geotechnical investigations. More recently, it has been used for environmental surveys (Loke, 1997). Many geophysical methods (i.e. magnetic, gravity, seismic and electrical methods) have been used to locate and delineate subsurface water resources (Telford *et al*., 1976). The resistivity measurements are normally carried out with four electrodes set equidistant along a line. The arrangement of the four electrodes, known as an array, will affect the depth of investigation, sensitivity, resolution and the incorporation of noise into each apparent resistivity measurement (Smith, 2006; Loke, 2001). The sensitivity plot for the Wenner array has almost horizontal contours beneath the centre of the array. The Wenner array is relatively sensitive to vertical changes in the subsurface resistivity below the centre of the array. However, it is less sensitive to horizontal changes in the subsurface resistivity. In general, the Wenner is good in resolving vertical changes (i.e. horizontal structures), but relatively poor in detecting horizontal changes (i.e. narrow vertical structures) (Loke, 2004). The Wenner array has the strongest signal strength. This can be an important factor if the survey is carried out in areas with high background noise (Loke, 1997). The Wenner electrode array has one current electrode, followed by two potential electrodes and ends with the second current electrode. The four electrodes are spaced an equal distance apart (*a*). The geometric factor *(k)* for the Wenner array equals $2\pi a$. The Wenner array is robust in the presence of measurement noise and is well suited to resolving horizontal structures because it is more sensitive to vertical changes in resistivity than to horizontal changes (Smith, 2006; Loke, 2001).

The electrical resistivity imaging was conducted using ABEM SAS 1000 Terrameter and Lund electrode selector system ES464. For data collection, 41 electrodes were arranged in a straight line with constant spacing and connected to a multicore cable. The electrode selector system will automatically select the relevant four active electrodes for each measurement of resistivity data. The data were processed by using inversion software RES2DINV (Geotomo software 2006; Loke & Barker, 1995). Basically, the data from these surveys are commonly arranged and contoured in the form of a pseudosection which gives an appropriate picture of the subsurface resistivity (Loke *et al*., 2003). Two lines of 2-D electrical resistivity imaging were performed along profiles with its center located at borehole $BH_1$and BH_7. A Wenner electrode configuration was used during the resistivity measurements with electrode spacing of 2m and 5m. The two outer current electrodes (C1 and C2) supply the constant electric current (I). The inner electrodes (P1 and P2) measure the voltage difference (V).

The apparent resistivity of the subsurface can be computed using the following formula: $\rho = 2\pi aR$, where a=electrode spacing and R=resistance

As a result of the developments of multielectrode resistivity equipment and data acquisition technique, the electrical resistivity imaging has become a standard tool in near-surface geophysical surveys (Griffiths & Barker, 1993).

Electrical resistivity is measured in Ω.m (ohm·m) and represented by ρ. This physical property represents how difficult it is to pass an electric current through a volume of material with a given length and cross sectional area (Smith, 2006; Loke, 2001). The resistivity of a volume of material (ρ) can be calculated by multiplying the electrical resistance (R) with the cross sectional area (A) and divided by the length (L). This is given by the equation, $\rho = R\,(A / L)$

After the field survey, the resistance measurements are reduced to apparent resistivity values. Practically all-commercial multi electrode systems come with computer software to carry out this conversion. To interpret the data from a 2-D imaging survey, a 2-D model for the subsurface consisting of a large number of rectangular blocks is usually used. A computer program is then used to determine the resistivity of the blocks so that the calculated apparent resistivity values agree with the measured values from the field survey. Here the computer program RES2DINV.EXE provided will automatically subdivide the subsurface into a number of blocks, and then it uses an inversion scheme to determine the appropriate values that must be entered into a text file which can be read by the RES2DINV program (Geotomo software, 2006; Loke & Barker, 1995). The electronic manual, MAN2DINV.EXE, gives a detailed description of the data format used. The use of the RES2DINV essentially involves the reading of the field data, inversion of the data using least square inversion procedure to get the true resistivity and the true depth of the field resistivity image. Topographic corrections to account for variations in the surface elevation are also included in RES2DINV. Basically, the data from these surveys are commonly arranged and contoured in the form of a pseudosection which gives an appropriate picture of the subsurface resistivity (Loke *et al*., 2003).

RESULTS AND DISCUSSION

The subsurface resistivity distribution of the area at BH_1 is shown in Figures 2 and 3. The resistivity image for 2 m electrode spacing (Figure 2) shows that the unsaturated top soil layer has medium to high resistivity (1100-2600Ω.m) with thickness about 4 m. The large variations of the resistivity values suggest that the soil materials are not homogenous. At depth below 4 m, the saturated zone shows medium resistivity (750-1100 Ω.m). Figure 4 shows the resistivity image for the survey with 5m electrode spacing which gives image with 28 m depth of penetration. The unsaturated top soil layer comprises of clay and silt. While at depth from 20 m to 28 m, it is a water saturated zone which was indicated by a zone of low resistivity. A high resistivity zones (>1723 Ω.m) observed in the image is interpreted as weathered schist (Figure 3). The large variation of resistivity for the unsaturated layer shows that the top soil is not homogenous. Ground water level measured for BH_1 is at depth of 8.73 m below ground level.

The subsurface resistivity distribution of unsaturated and saturated layers at borehole BH_7 are shown in Figures 4 and 5 respectively. For the electrode spacing 2 m (Figure 4), the high resistivity value is associated with unsaturated dry soil layer. At depth between 2.0 m and 10.0 m, the resistivity is variably low and this is related to weathered layer of the bedrock. Several isolated zones of low resistivity could probably be associated with saturated fractured zone of the weathered layer. The resistivity image for the 5m electrode spacing (Figure 5) shows similar pattern of resistivity distribution with that of the resistivity image of the 2m electrode spacing (Figure 4) but with deeper penetration. The unsaturated layer shows high resistivity whereas the saturated layer at depth from 5.0 m to 12.4 m shows relatively low resistivity. At depth from 12.4 m to 28.7 m, the bedrock has been moderately to slightly weathered with high range of resistivity values. The groundwater level at BH_7 was measured at depth of 8.54 m below ground level and slightly shallower than ground water level at BH_1. The

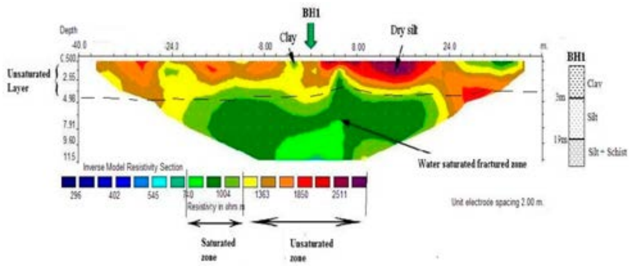

Figure 2: Resistivity image at BH1 (electrode spacing 2 m).

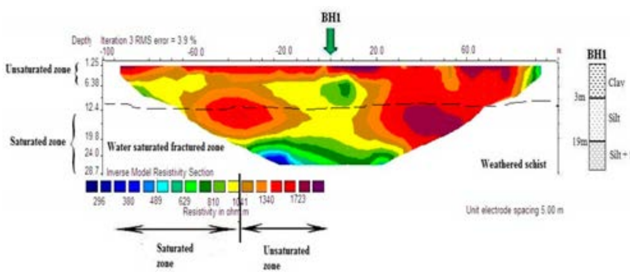

Figure 3: Resistivity image at BH1 (electrode spacing 5 m).

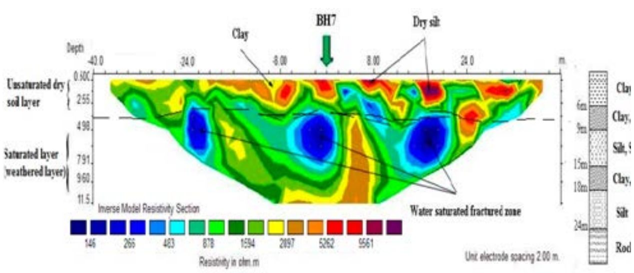

Figure 4: Resistivity image at BH7 (electrode spacing 2 m).

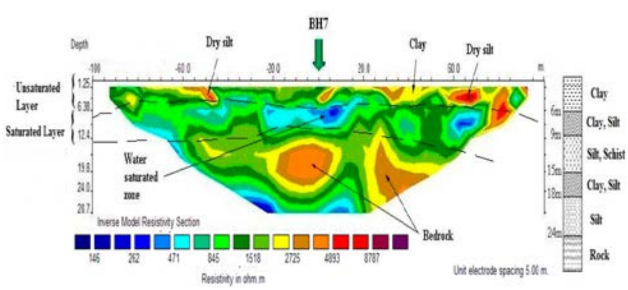

Figure 5: Resistivity image at BH7 (electrode spacing 5 m).

results show that the saturated aquifer layer around borehole BH_1 is relatively thicker than that around BH_7. This is due to difference in topography between the two boreholes. The topographic elevation at borehole BH_7 is higher than that of borehole BH_1; because the borehole BH_7 is located in hilly area. The surface topography between borehole BH_1 and borehole BH_7 is undulating with an elevation increasing towards borehole BH_7. So the ground water flow direction is from the borehole BH_7 to borehole BH_1.

CONCLUSION

The electrical resistivity imaging in this study has been successfully used to determine the subsurface unsaturated and saturated layers in the study area. In conjunction with borehole data, the resistivity image can be used to determine the weathered and fractured zones of the bedrock underneath the study area. A direct correlation between the resistivity and its associated lithology can be made qualitatively. The unsaturated layer is normally characterized by high resistivity values whereas the water saturated layer shows zone of low resistivity. However these layers are not clearly divided partly because of the inhomogeneous properties of the soil material. The groundwater levels at BH1 and BH7were measured at 8.73 m and 8.54 m depths respectively.

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