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The use of geoelectrical imaging to study groundwater pollution at Gemenceh waste disposal site, Negeri Sembilan

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Abstract: Geoelectrical imaging method is now frequently used for environmental pollution studies. The resistivity imaging surveys carried out in the present study basically measures and maps the resistivity of subsurface materials. It provides the general information on subsurface stratification of the soil and wastes and the depth to the bedrock below the lines of traverse. The survey was conducted using ABEM LUND Automatic imaging system. Groundwater that has been contaminated by leachate frequently has a significantly lower resistivity value.

This paper briefly describes some preliminary results of the electrical resistivity imaging survey to assist in understanding the underground conditions and to study the groundwater pollution at Gemenceh waste disposal site in Negeri Sembilan. The geoelectrical imaging technique was used in this study to help in delineating contaminated groundwater at the disposal site. The quality and contaminated zone of the undergroundwater was determined based on the measured geoelectrical resistivity value of subsurface materials. Two dimensional resistivity profiles and subsurface geological information from both boreholes as well as seismic refraction data were used to interpret the extension and direction of the contaminant flow within the undergroundwater system in the area being studied.

The contaminated zone of the groundwater aquifer gives relatively low resistivity values of less than 10.0 ohm-m compared to that of the uncontaminated groundwater which gives resistivity values ranging from 10 to 100 ohm-m. The geoelectrical resistivity and chemical analysis of the water samples indicate that the undergroundwater aquifer in all boreholes except boreholes SP8 and SP12 have been contaminated by the leachate. In comparison, the groundwater sample from borehole SP4 is highly contaminated. However the groundwater contamination in this area appears to be confined within the vacinity of the dumping ground. The resistivity profiles suggest a flow of contaminant towards north east which follows the regional trend of groundwater flow of the area.

INTRODUCTION

Geoelectrical resistivity methods were developed in the early twentieth century but have been more widely used since the 1970s due primarily to the availability of computers to process and analyse the data (Reynolds, 1997). These techniques are used extensively in the search for suitable groundwater sources and also to monitor types of groundwater pollution, in engineering surveys to detect underground cavities, faults and fissures, mineshafts etc; and in archaeology for mapping out the areal distribution of buried foundations of ancient buildings.

Assessing contaminated land poses many problems and is both difficult and hazardous. Major difficulties include locating the actual contamination and determining its spatial distribution. An accurate measurement of contaminant concentrations in highly heterogeneous soils is extremely difficult. Extensive drilling, probing and direct sampling of contaminated materials poses health and safety hazards and can be costly.

Geophysical techniques are both non-invasive and non-destructive. These techniques can be deployed rapidly and cost effectively, and have the ability to remotely locate significant contamination to determine its distribution and to monitor any change over time. This paper described preliminary results of a resistivity imaging survey conducted to investigate the groundwater contamination at a domestic waste dumping site of Gemenceh, Negeri Sembilan.

GEOLOGY AND HYDROGEOLOGY

The Gemenceh dump site is located about 10 km from Tampin town and it occupies a small plot

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of generally flat land with a total area of about 15 square acres. The open dumping and burning operation started since 1981 with a total volume of 39,780 cubic metres of domestic waste being dumped in the area. Remains of partially buried and burnt old waste is found in the northeast part of the dump site whereas a relatively new waste is being dumped more towards the southwest side and adjacent to the existing pond (Fig. 1).

The subsurface lithology of the area was determined from a total of twelve observation boreholes drilled to a maximum depth of 9 m to 15.0 m below ground level. Figure 2a shows a geological profile along NE-SW section which passes through boreholes SP4, SP5, SP6, SP7 and SP8. The profile indicates that the aquifer layer which is made up of silty sand has variable thicknesses ranging from 5 to more than 10 metres. The water table along this line is relatively shallow with depth ranging from 0.66 m to 2.00 m below ground level. Figure 2b illustrates a geological profile along NW-SE section (i.e from boreholes SP12 to SP10 and SP7) with relatively deeper groundwater level.

The local groundwater flow pattern within the vicinity of the dumping site has been based on the results of detailed ground and groundwater elevation measurements conducted by MINT. Observation of groundwater table at the boreholes indicated that the static groundwater level ranges from 1.45 m to 2.44 m. The groundwater appears to flow northeast which follows the general trend of surface water flow in the area.

MATERIAL AND METHOD

The resistivity method basically calculates the resistivity distribution of the subsurface materials. Table 1 shows the resistivity and conductivity values of some typical rocks, soils materials, leachate and several chemicals of typical industrial contaminants (Daniels and Alberty, 1966; Keller and Frischknecht, 1966; Shahrin Ibrahim,1999).

Igneous and metamorphic rocks normally have high resistivity values. The resistivity is mainly dependent on the degree of fracturing which commonly filled with groundwater. The greater the degree of fracturing, the lower is the resistivity value of the rock. Sedimentary rocks on the other hand, generally have higher porosities than igneous and metamorphic rocks, so they usually have lower resistivity values especially when saturated with groundwater.

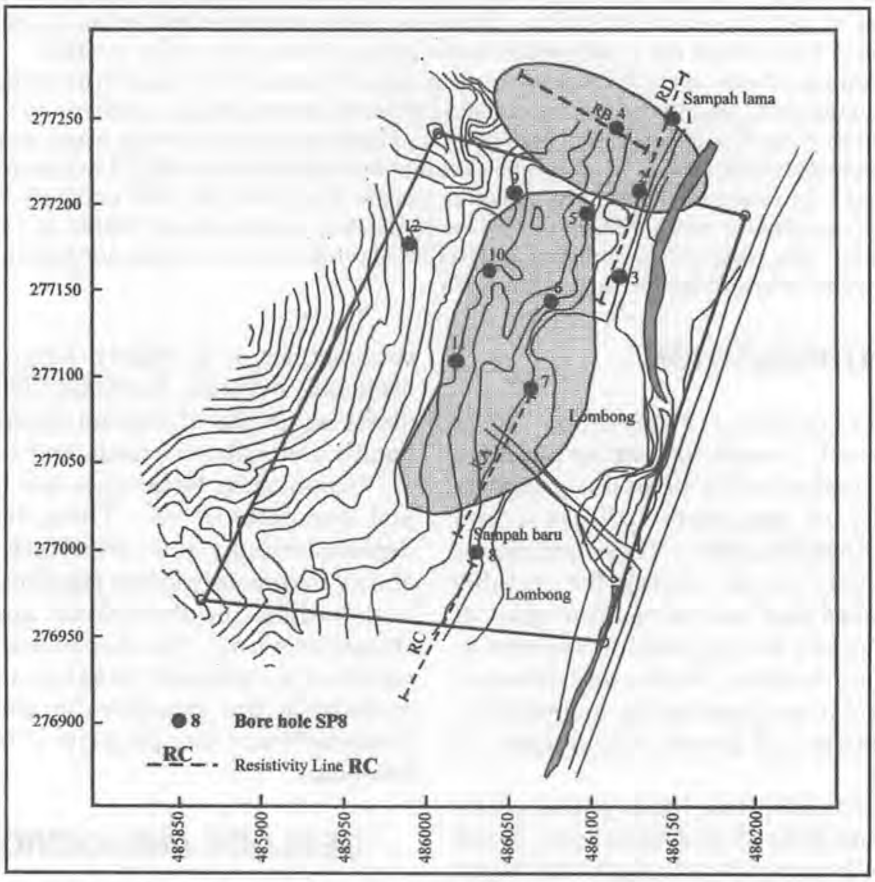

Figure 1. Map showing location of new and old dump sites, monitoring boreholes and resistivity imaging lines.

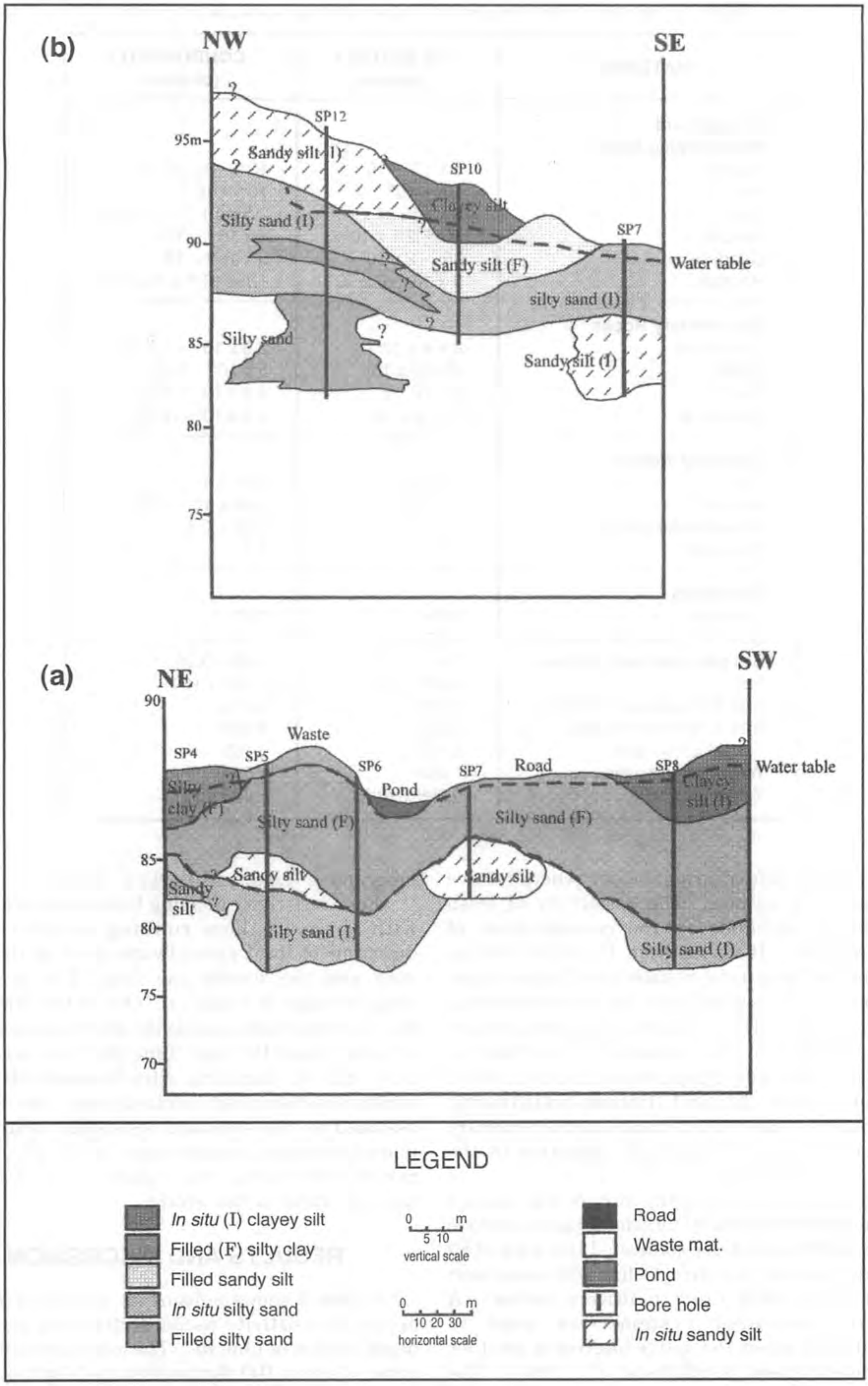

Figure 2. Subsurface geological profiles along (a) NE-SW and (b) NW-SE section of the study sites.

Table 1. Resistivity and conductivity values of rocks, soils and chemicals.

MATERIAL	RESISTIVITY (ohm-m)	CONDUCTIVITY $(\text{ohm-m})^{-1}$
Igneous and Metamorphic Rocks		
Granite	$5 \times 10^3 - 10^6$	$10^{-6} - 2 \times 10^{-4}$
Basalt	$10^3 - 10^6$	$10^{-6} - 10^{-3}$
Slate	$6 \times 10^2 - 4 \times 10^7$	$2.5 \times 10^{-8} - 1.7 \times 10^{-3}$
Marble	$10^2 - 2.5 \times 10^8$	$4 \times 10^{-9} - 10^{-2}$
Quartzite	$10^2 - 2 \times 10^8$	$5 \times 10^{-9} - 10^{-2}$
Hornfels	$8 \times 10^3 - 6 \times 10^7$	$1.7 \times 10^{-8} - 1.3 \times 10^{-4}$
Sedimentary Rocks		
Sandstone	$8 - 4 \times 10^3$	$2.5 \times 10^{-4} - 0.125$
Shale	$20 - 2 \times 10^3$	$5 \times 10^{-4} - 0.05$
Marls	3 – 70	$1.4 \times 10^{-2} - 0.3$
Limestone	$50 - 4 \times 10^2$	$2.5 \times 10^{-3} - 0.02$
Soils and Waters		
Clay	1 – 100	0.01 – 1
Alluvium	10 – 800	$1.25 \times 10^{-3} - 0.1$
Groundwater (fresh)	10 – 100	0.01 – 0.1
Sea water	0.15	6.7
Chemicals		
Leachate	2.994	0.33
Sand saturated with leachate	4.97 – 5.04	0.19 – 0.2
Soil saturated with leachate	3.51 – 4.00	0.25 – 0.28
Iron	9.074×10^{-8}	1.102×10^7
0.01 M Potassium chloride	0.708	1.413
0.01 M Sodium chloride	0.843	1.185
0.01 M acetic acid	6.13	0.163
Water with dissolved air	1,000	1.0×10^{-3}
Xylene	6.998×10^{16}	1.429×10^{-17}

Wet soils and fresh groundwater generally have low resistivity values. The resistivity of fresh groundwater depends on the concentration of dissolved salts. It varies from 10 to 100 ohm-m which is well above the resistivity of saline water whose resistivity is very low (< 1 ohm-m) due to the high salt content. The resistivity of the groundwater is also effected by the presence of leachate or chemicals. This effect depends on the electrolytic behaviour of the chemical (Daniels and Alberty, 1966). A higher chemical concentration is necessary in order to cause a significant reduction in the resistivity of the water.

The geoelectrical imaging survey was carried out using ABEM SAS300C terrameter and electrode selector ES464 which are connected to a total of 80 electrodes laid out in a straight line with a constant spacing via ABEM Lund multicore cables. A computer-controlled system was used to automatically select the active electrodes used for each measurement (Griffiths *et al.*, 1990). The data collected was interpreted using 2D inversion programme (Loke and Barker, 1995).

Four resistivity imaging lines were established with three of them running parallel to the direction of local groundwater flow of the study area and the fourth one (Line RB) is almost perpendicular to it (Fig. 1). One of the lines (Line RC) is located well outside the waste dumping area whereas 'Line RA' and 'Line RD' run across the new and old dumping sites respectively. The subsurface resistivity obtained from 'Line RC' was assumed as the standard resistivity value of the uncontaminated groundwater in the area. This resistivity value was used as a basis of interpretation in this study.

RESULTS AND DISCUSSION

Figure 3 shows subsurface measured Wenner apparent resistivity pseudosection and resistivity depth section of Line RC. The minimum resistivity value of about 100 ohm.m obtained for the aquifer layer suggests that the groundwater underneath

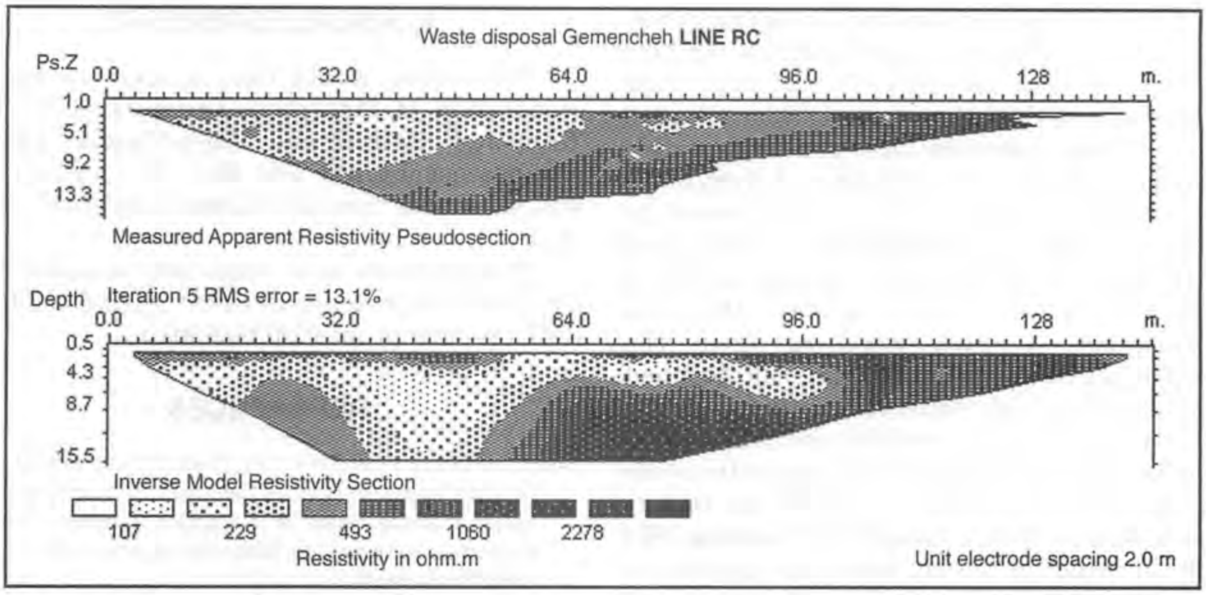

Figure 3. Measured Wenner apparent resistivity pseudosection and resistivity true depth section of resistivity Line RC.

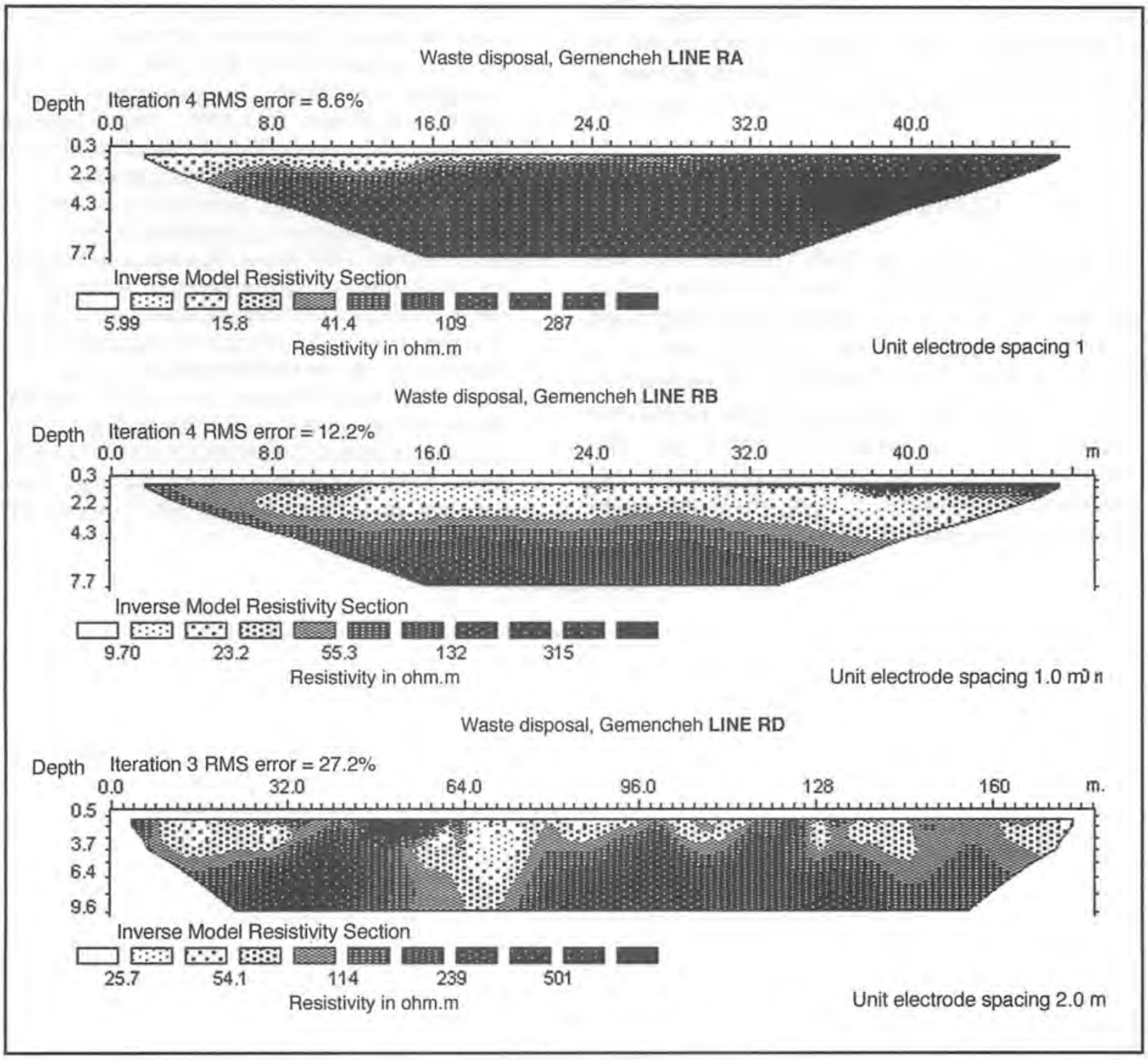

Figure 4. Inverse model resistivity sections for resistivity Line RA, Line RB and Line RD.

Line RC is relatively fresh and uncontaminated. Whereas the resistivity inverse sections for Line RA, Line RB and Line RD (Fig. 4) have their minimum resistivity values ranging from 3.5 to 9.0 ohm.m. These reasonably low resistivity values are interpreted to be related to the resistivity of the groundwater which has been contaminated by leachate produced by the disposed waste. The above interpretation is substantiated by the results of chemical analysis which indicate that the groundwater samples obtained from the corresponding boreholes have high chemical content (Tan, 1999; Bashillah Baharuddin, 1999).

The resistivity and borehole results show that the contamination of the groundwater in the study area appears to be confined only within the vicinity of the dump site. Water sample from borehole SP4 which is located in the old dump site appears to have high concentration of chemical content and the mechanism by which the contamination arrived at that site was unclear. This will require further investigation and long term monitoring. The resistivity profiles also suggest a movement of contaminants towards northeast which follows a local trend of the groundwater flow in the area being studied.

CONCLUSIONS

Results of the present study indicate that the resistivity imaging technique, borehole information and hydrochemical analysis can be successfully used for pollution mapping of the groundwater at a contaminated site. The complexity of subsurface conditions beneath contaminated lands requires a multidisciplinary approach combining the systematic and careful application of hydrogeological, chemical and environmental geophysical techniques.

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