



Mapping of contamination plumes at municipal solid waste disposal sites using geoelectric imaging technique: Case studies in Malaysia

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Abstract Municipal solid waste disposal sites can be sources of groundwater contamination and the contamination problems are more likely to occur in humid areas, where the moisture available exceeds the ability of the waste pile absorb water. In tropical country like Malaysia which is characterized by high rainfall, the subsurface contamination problems are expected to occur. Seriousness of the pollution problem is still unknown and specific detailed study is generally needed. Two dimensional geoelectrical imaging has frequently been used in the subsurface pollution studies. The method maps the distribution of resistivity of subsurface materials. The resistivity image provides general information on subsurface stratification of buried waste and contaminated soil, as well the depth to the bedrock below the lines of traverse. Underground soil or water that has been contaminated by leachate usually has a significantly lower resistivity value. This paper discusses the results of the 2-D resistivity imaging which were conducted to identify and delineate the extent of contaminated soil and leachate plumes, as well as to assess the capability of the 2-D resistivity imaging as a pre-characterization tool for tracing the properties of disposed waste and its severity underneath a capped landfill sites. The imaging method was used in this study to map the contaminated subsurface soil and ground water at three municipal solid waste disposal sites namely Ampar Tenang (AT) open-tipping site, Bukit Kemuning (BK) capped landfill, and Taiping landfill (TL) where a total of twenty two 2-D resistivity lines were surveyed. The surveys were conducted using ABEM SAS1000 resistivity meter and LUND Automatic imaging system and the measured resistivity profiles were interpreted using 2-D resistivity inversion programme (RES2DINV). Generally the results of the measured resistivity values obtained from the three sites define the contaminated leachate plumes as electrically conductive anomalies of relatively low resistivity value less than 10 ohm-m.

Key words: 2-D Resistivity imaging, solid waste, disposal sites, and leachate plume.

Introduction

Solid waste in developing countries is generally disposed of in uncontrolled open dumps. The environmental consequences of such inadequate disposal sites are often quite evident, yet necessary improvements are seldom delt with. These areas are vulnerable to ground and surface water pollution. Seriousness of the problem is still unknown and specific detailed study is generally needed. Solid waste land disposal sites can be sources of groundwater contamination and the contamination problems are more likely to occur in humid areas, where the moisture available exceeds the ability of the waste pile absorb water. In tropical country like Malaysia which is characterized by high rainfall, the contamination problems are expected to occur.

The main environmental problem of waste dumping sites is the potential risk of groundwater pollution and subsequent influence on surface water quality. The total pollutant load to the

environment is dependent on the quantity and quality of the water that percolates through the disposal site and reaches the groundwater (Bengtsson et al., 1994). Waste disposal sites can seriously affect local wells and drilled holes used for public water supply and therefore, their locations must be planned and monitored carefully (Matias et al., 1994).

Presently there are about 230 municipal waste disposal sites still in operation in Malaysia. Most of them are an open dumping sites and seldom the sites have been constructed according to a containment objective, i.e. the bottom layers have not been made impermeable. To be able to adapt a long-term view it is necessary to collect complementary data about the deposits in an effective way. Resistivity method has a good potential, not only to map the extension of closed old landfills, but also to reveal potential pollution plumes and provide a basis for where to place other actions accurately. This technique is non-invasive and can be deployed rapidly and cost effectively. It has the ability to remotely locate significant contamination to determine its distribution and to monitor any change over time.

Landfill-related geophysical surveys are frequently reported in the literature. Stanton and Schrader (2001) investigated a chemical waste landfill using 2-D direct current resistivity survey and electromagnetic conductivity to delineate possible buried zones. Bernstone and Dahlin (1996) conducted a 2-D resistivity survey on old landfills to locate the extension of old landfills and to trace the possible pathways for contaminated leakage. Carpenter et al.(1990) used a resistivity technique to map the internal landfill structure, the leachate level and the thickness of the cover material. Bernstone and Dahlin (1997) used direct current resistivity magnetometry to estimate the location of metals in closed landfill. Geophysical measurements have also been used to identify the condition and function of landfill's final cover, and to identify fractures and erosion degradation (Bergstorm 1997; Carpenter et al 1991).

Geoelectrical resistivity surveys are commonly used for geotechnical investigations, and environmental surveys (Loke, 1999). Due to its efficiency and effectiveness in producing images of the subsurface, the resistivity-imaging method has now become more popular in electrical exploration (Dahlin and Zhou, 2002). The 2-D geoelectrical resistivity imaging actually measures the apparent resistivity of the subsurface, which can be inverted to develop a model of the subsurface structure and stratigraphy in terms of its electrical properties (Loke, 2003). The resistivity of the subsurface is affected by porosity, amount of water in the subsurface, ionic concentration of the pore fluid and composition of the subsurface materials. However, the resistivity data can be used to identify, delineate and map subsurface features such as electrically conductive contamination plumes, the vadose zone and electrically conductive lithologic units such as clay (Dawson et al., 2002). Table 1 shows the resistivity and conductivity values of some typical rocks and soil materials (Keller and Frischknecht, 1996). Igneous and metamorphic rocks typically have high resistivity values. Clay has a significantly lower resistivity than sand.

Table 1: Resistivity of some common rocks and soil materials

Material	Resistivity (ohm-m)
Alluvium	10 – 100
Sand	60 - 1000
Clay	1 - 100
Groundwater (fresh)	10 - 1000
Granite	5000 – 1,000,000

In this study, three different municipal solid waste disposal sites have been surveyed. These include Ampar Tenang (AT) open-tipping site and Bukit Kemuning (BK) covered landfill which are located in Selangor State. The third site, Taiping landfill (TL) is situated in the area of Matang,, some 7 kilometers southwest of Taiping city, in Perak State (Fig. 1).

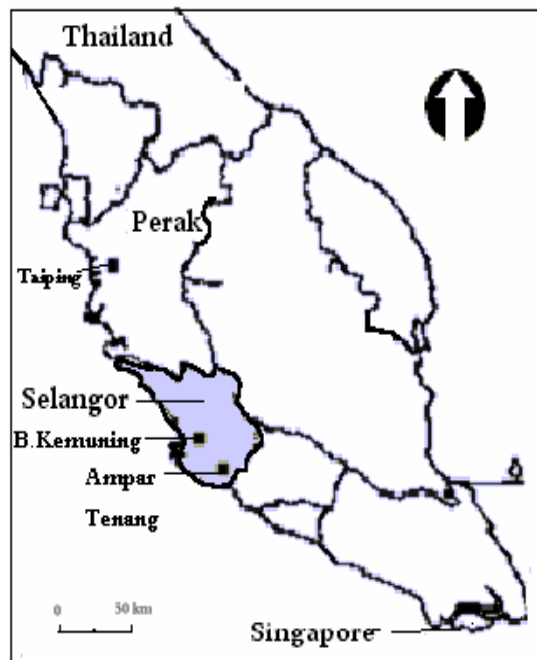


Fig. 1: Location map of the study area

The main goals of this study were to identify and delineate the extent of contaminated leachate plumes below surface as well as testing the efficiency of the 2-D resistivity method as a pre-characterization tool for tracing the properties of the disposed waste and its severity underneath a capped landfill sites.

Methodology

The resistivity data acquisition used a two-dimensional resistivity imaging technique (Fig. 2). Both the SAS1000 resistivity meter and ABEM LUND automatic electrode selector system were used in these studies. The meters were connected to a total of 61 steel electrodes, which were laid out on a straight line with a constant spacing via a multicore cable. The Wenner equal spacing

electrode array was used for this survey. The Lund system automatically selects the four active electrodes used for each measurement (Griffith and Barker, 1993).

The measured resistivity data were interpreted using the RES2DINV inversion software. Details about the survey and interpretation method can be found in published papers by (Keller and Frischknecht, (1966), Griffiths *et al.*, (1990), Griffiths and Barker, (1993), and Loke and Barker (1996). To interpret the 2-D resistivity data, a 2-D model for the subsurface consisting of a large number of rectangular blocks was used. The inversion software was used to determine the resistivity of the block so that the calculated apparent resistivity values agree with the measured apparent resistivity values from the field survey. The program RES2DINV will automatically subdivide the subsurface into a number of blocks, and then it uses a least-squares inversion scheme to determine the appropriate resistivity values for each block.

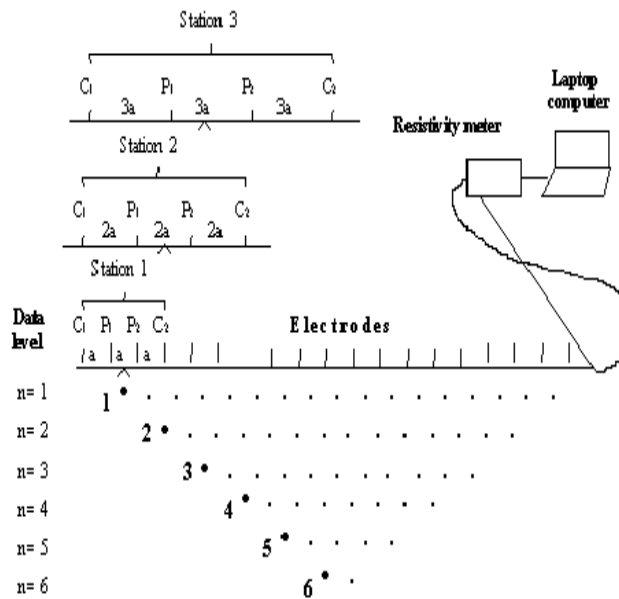


Fig. 2: The arrangement of electrodes for a 2-D geoelectrical imaging survey and the sequence of measurement used to build up a pseudosection

Results and Discussion

Case Study I: Ampar Tenang Open-Tipping Site

A total of nine lines of 2-D resistivity images were established, four were located on the waste pile and the other four lines were located upstream and downstream of the landfill site. The final line was constructed at the eastern edge of the site which partially covered the disposed waste. Fig. 3 shows the inversed resistivity models of three resistivity lines (Profiles 5, 6 & 7) measured on the top of the waste pile. The electrically conductive anomaly on the dumping site was interpreted as leachate plumes, which appear to have seeped through the underground soil at depth as far as 20m below surface (Profile5). The 2-D image of the subsurface resistivity shows that the thickness of the decomposing waste is slightly more than 10 meters (Profile 6) and this agrees well with the actual thickness of the waste pile observed in the field. Past re-excavation and re-

filling operations of the waste have created some isolated low resistivity zones which were interpreted as to be related to fringing of contaminated leachate water mixed with existing decomposed wastes (Profile 7 in Fig. 3).

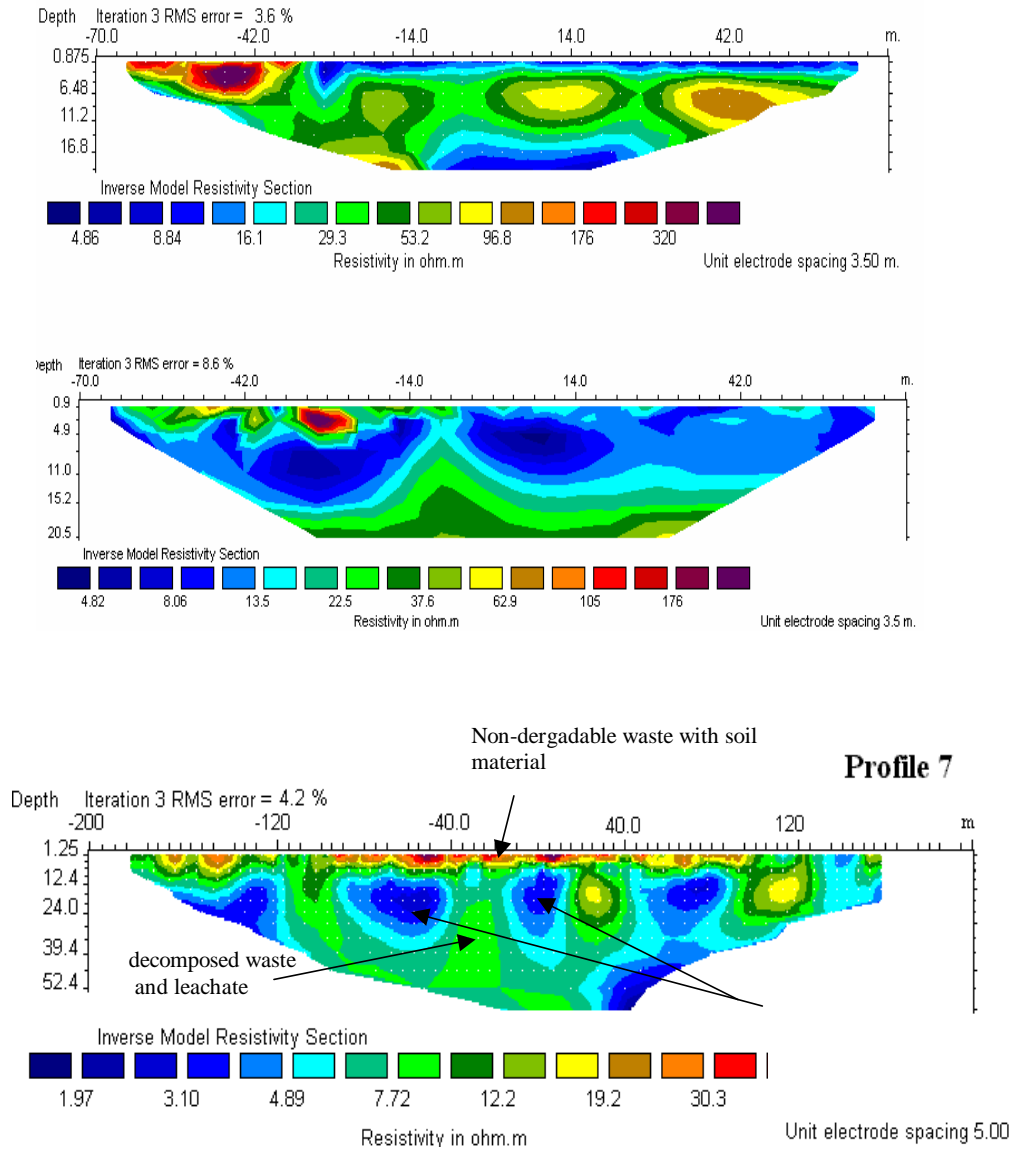


Figure 3: Resistivity sections conducted on top of the wastes at Ampar Tenang (AT) landfill site

Case II: Bukit Kemuning Capped Landfill

At this landfill site, the resistivity imaging sections clearly outline a large variation in the properties of disposed wastes (Fig. 4). In profile 1, the dark reddish to yellowish high resistivity zones near the surface are associated with non-degradable wastes material as shown in site photograph in Fig. 5. However, the dark blue zone of low resistivity (< 10 ohm m) at depth of 6 to 13 meters below ground surface has been interpreted as decomposed wastes mixed with leachate in both the unsaturated and saturated soil layers. The sharp variation in resistivity distribution between upper and lower parts of the profile 1 (Fig. 4) is strongly attributed to the degree of waste decomposition, which in turn, reflects the type of wastes (i.e. non-degradable and degradable (leachate)). The resistivity layers in profile 1 correlates well with the actual profile of the excavated part of the site in terms of the thickness of cap, disposed waste, and clay liner (Fig. 5).

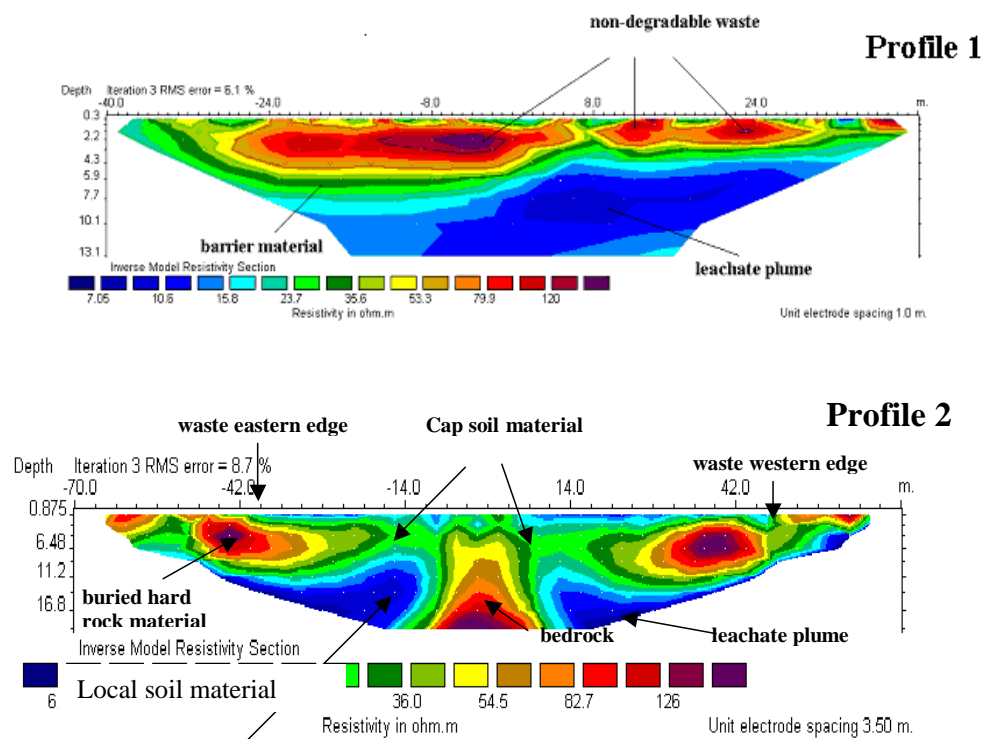


Fig. 4: DC-resistivity imaging profiles at BK landfill site



Fig. 5: Photograph showing the excavated part of BK landfill

The resistivity line of Profile 2, which is perpendicular to Profile 1, was surveyed a few months after the landfill site had been rehabilitated. The resistivity section indicates the presence of several isolated zones of low and high resistivity values, which are interpreted as the results of landscape activities that involved excavation and removing of disposed wastes. Due to these activities, some decomposed wastes had been exposed on the surface, which in turn produces thin low resistivity surface layer in the 2-D resistivity image. Two isolated low resistivity zones (< 5 ohm.m, bluish colour) which are interpreted as leachate plumes are observed at depth of between 6 and 16 meters below ground surface. The leachate plumes appear to move in two opposite directions. The plume shown on the left side of Profile 2 is the same leachate plume traced in Profile 1.

Case study III: Taiping Landfill

For Taiping landfill site a total of nine resistivity lines were established with two of them located within the landfill site and seven others are situated outside and around the perimeter of the landfill. Fig. 6 shows the 2-D resistivity section of profiles 4, 5 & 7. Profile 5, located within the landfill site, shows a distinct subsurface boundary of the new and old waste as well as leachate migration within the site. The leachate which is associated with zone of low resistivity (< 10 ohm-m,) appears to flow in southwest direction. A wide distribution of low resistivity zone suggests that the leachate has contaminated both subsurface soil material and groundwater within the landfill area and there is a possibility the leachate has moved outside the landfill site. On the other hand, the resistivity high is associated with dry soil and gravel materials used to cover the wastes. Profile 7, located well outside the landfill site, shows relatively high near surface resistivity (>40 ohm-m). This value was assigned as the standard resistivity for the soil cover in the area. The resistivity value of less than 10 ohm-m recorded for the deeper subsurface layer suggests that the soil materials in this area could have been affected by leachate contamination. The resistivity section obtained for profile 4 supports this interpretation. This profile clearly shows vertical zone of low resistivity anomaly (blue colour), which can be interpreted to be associated with downward

movement of leachate. The results of the resistivity survey also indicate that there is an eastward subsurface movement of the leachate.

Summary

The geoelectrical imaging method was used to map the contaminated subsurface soil and ground water at three selected municipal solid waste disposal sites in Malaysia. The sites include Ampar Tenang open-tipping site, Bukit Kemuning (BK) capped landfill, and Taiping landfill (TL) where a total of twenty two 2-D resistivity lines were surveyed. The measured resistivity were interpreted using 2-D resistivity inversion programme (RES2DINV).

The migration of leachate plume at Ampar Tenang site was traced in form of low resistivity zones (with resistivity less than 2.0 ohm.m) of decomposing waste bodies saturated with highly conductive leachate. At the Bukit Kemuning landfill site, two plumes of a reasonably high conductive leachate have been traced. The resistivity images indicate that the subsurface soil and groundwater within Taiping Landfill area has been contaminated by leachate, which appears to have migrated outside the landfill site.

Conclusion

The 2-D direct current resistivity imaging technique has been successfully used in this study to map the contamination plume and to characterize the landfill sites in terms of subsurface resistivity distribution of the waste material and soil underneath the vicinity of each landfill site. The interpreted resistivity section which correlates well with the actual profile of the excavated part of the site (Bukit Kemuning), suggests the potentiality of 2D resistivity imaging technique as pre-characterization tool for mapping subsurface contamination in the vicinity of waste disposal sites. However 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.

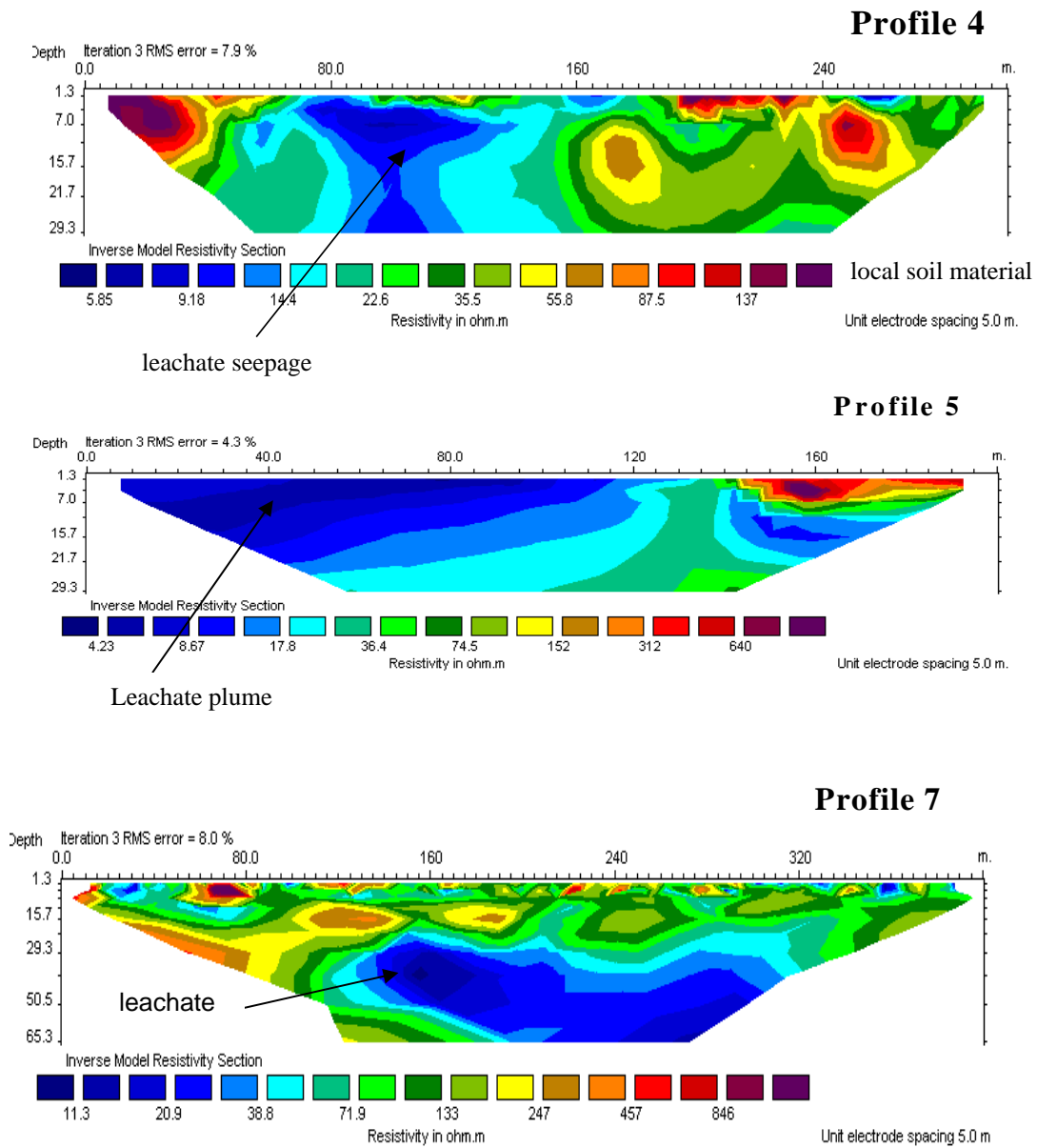


Figure 5: 2D resistivity imaging of profiles 4, 5 & 7 at Taiping Landfill site

Acknowledgements

The authors wish to acknowledge Ministry of Science and Technology of Malaysia for financial support through an IRPA Grant No. 08-02-02-0008- EA178 and Malaysian Institute of Nuclear Technology (MINT) for resistivity data acquisition. Thanks are also due to School of Environment and Natural Resource Sciences of National University of Malaysia (UKM) for providing excellent research facilities.

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