DOI: 10.1007/s002670010250

# Evaluation of Groundwater and Soil Pollution in a Landfill Area Using Electrical Resistivity Imaging Survey

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ABSTRACT / Landfills are sources of groundwater and soil pollution due to the production of leachate and its migration through refuse. This study was conducted in order to determine the extent of groundwater and soil pollution within and around the landfill of Seri Petaling located in the State of Selangor, Malaysia. The condition of nearby surface water was also determined. An electrical resistivity imaging survey was used to investigate the leachate production within the landfill. Groundwater geochemistry was carried out and chemical analysis of water samples was conducted upstream and downstream of the landfill. Surface water was also analyzed in order to determine its quality.

Soil chemical analysis was performed on soil samples taken from different locations within and around the landfill in the vadose zone (unsaturated zone) and below the water table (in the soil saturated zone). The resistivity image along line $L–L_1$ indicated the presence of large zones of decomposed waste bodies saturated with highly conducting leachate. Analysis of trace elements indicated their presence in very low concentrations and did not reflect any sign of heavy metal pollution of ground and surface water or of soil.

Major ions represented by Na, K, and Cl were found in anomalous concentrations in the groundwater of the downstream bore hole, where they are 99.1%, 99.2%, and 99.4%, respectively, higher compared to the upstream bore hole. Electrical conductivity (EC) was also found in anomalous concentration downstream. Ca and Mg ions represent the water hardness (which is comparatively high downstream). There is a general trend of pollution towards the downstream area. Sulfates ($SO_4$) and nitrates ($NO_3$) are found in the area in low concentrations, even below the WHO standards for drinking water, but are significantly higher in the surface water compared to the groundwater. Phosphate ($PO_4$) and nitrite ($NO_2$), although present in low levels, are significantly higher at the downstream. There is no significant difference in the amount of fluoride (F) in the different locations. In the soil vadose zone, heavy metals were found to be in their typical normal ranges and within the background concentrations. Soil exchangeable bases were significantly higher in the soil saturated zone compared to the vadose zone, and no significant difference was obtained in the levels of inorganic pollutants. With the exception of Cd, the concentration ranges of all trace elements (Cu, Zn, Cr, Pb, and Ni) of Seri Petaling landfill soils were below the upper limits of baseline concentrations published from different sources.

Most waste management in the 1990s consisted of landfilling (Scrudato and Pagano 1994). Leachates that originate due to the disposal of domestic and industrial solid wastes are an aquifer contamination source (Rosa and others 1996). Most studies to date have been conducted on landfills containing an unsaturated zone between the wastes and the groundwater, where the contaminants are attenuated by diverse processes (Matthess 1980, Kjeldsen 1983, Mirecki and Parks 1994).

Electrical resistivity surveys are widely used in geophysical exploration and nowadays electrical methods have been used extensively in environmental geophysics (Stierman 1984, Fitterman and Stewart 1986, Greenhouse and others 1989, 1993). The electrical resistivity method is the most popular geophysical tool used in groundwater exploration, and it is also used for determining the groundwater quality, ie, whether the water is saline, fresh, or contaminated (Zohdy 1974, Stollar and Roux 1975, Rogers and Keen 1980, Urish 1983). Successful monitoring of groundwater contamination has been reported by Rogers and Kean (1980) at a fly-ash disposal site using surface resistivity. One of the new developments in recent years is the use of 2-D electrical imaging surveys to map areas with moderately complex geology (Griffiths and Barker 1993).

KEY WORDS: Groundwater pollution; Soil pollution; Landfill; Resistivity imaging survey; Malaysia

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## Location and Geological Setting

Seri Petaling Landfill is located in Cheras, lying 15 km south of the city center of Kuala Lumpur, Malaysia, between latitudes 3°3.2′ and 3°3.5′ N and longitudes 101°41.73′ and 101°42.6′E, covering an area of 21.1 ha. This waste facility started operation in 1979 and was closed in 1991 with a total of 7.1 million tonnes (received 1500 tonnes/day). The maximum difference in elevation between the top of the landfill and the surrounding area was estimated to be 28.74 m, which is regarded as a high difference and high groundwater head differential, indicating a maximum pressure exerted by the leachate onto the surrounding groundwater and surface water bodies. Figure 1 shows the location and topography of the site, location of the electrical resistivity line L–$L_1$; the three groundwater bore holes AH1 (upstream), AH2 (downstream), and AH3 (bore hole within the landfill body); and location of soil sampling. The climate of the area is tropical equatorial and is characterized by uniform temperature and high rainfall with mean maximum annual temperature varying from 24.2°C to 32.3° and mean annual rainfall varying from 2137.9 to 2667.7 mm.

Geologically the landfill area lies entirely within the Kenny Hill Formation, which was informally investigated by Yin (1961), and is believed to have been deposited during the Upper Palaeozoic. Lithologically, it consists of interbedded sandstones, shales, and mudstones, which are thought to have been deposited in a moderately deep marine environment situated near a large supply of reworked sediments (Yeap 1969). This formation was estimated to be the bedrock, and fracturing and foliation characterize it, facilitating the movement of the groundwater flow. The landfill is located on a tin tailing area, and fresh sandstone and phyllite of the Kenny Hill Formation outcrops to the northwest of the northern boarder of the landfill. The present study has been carried out to investigate the status of ground- and surface water contamination in the landfill area and the possible impact on soil quality.

## Materials and Methods

A resistivity survey line L–$L_1$ was conducted on the top of the landfill (in the central part) with a northwest–southeast direction. The method used for obtaining a two-dimensional (2-D) electrical resistivity image involves measuring the resistance of the ground by using an OYO McOhm resistivity meter. A 250-multicore cable at 5 m takeout interval was laid in the ground and 50 electrodes (or less depending on the situation in the field) were connected to the 5-m-interval takeouts. The electrodes were connected to the central switching system. The current and potential poles of the resistivity meter were connected to the central switching system. Four electrodes were chosen at any one time for resistance measurement. Current was injected into the ground via two current electrodes located exterior to the potential electrodes. The potential differences between the potential electrodes were measured and the resistance of the ground was calculated automatically by the meter. The measured resistances were recorded into a previously prepared data entry sheet. The electrode configuration used in the present survey is a Wenner Array (Figure 2). Resistance values were converted into apparent resistivity values $\rho_a$ using the equation:

$$\rho_a = 2\pi aR$$

where $a$ is the spacing used in the measurement and $R$ is the resistance of the ground recorded by the resistivity meter. The $x$ position of measurement along the resistivity traverse, the electrode spacing, and the calculated apparent resistivity values were entered into the data files, which were subsequently used by RES2DINV (2-dimensional resistivity imaging interpretation software) (Loke and Barker 1996). The interpretation program essentially calculates the true resistivity and true depth of the ground from the inputted data file using Jacobian matrix calculation and forward modeling procedures. The results of the interpretation are displayed as the 2-D electrical resistivity image of the subsurface along the line of traverse.

The groundwater elevations from the three bore holes at the landfill (Figure 1), were determined to be 30.72, 41.58, and 24.04 m for AH1, AH3, and AH2, respectively. These bore holes were drilled to the bedrock (Kenny Hill Formation). Following Todd's procedure (1980) the groundwater flow direction was estimated to be towards the downstream bore hole.

The ground- and surface water chemistry was determined by sampling the bore holes located in the upstream and downstream areas of the landfill and the river of Sungai Kuyoh bordering the landfill at its southern end. The sampling was carried out over a period of six months (August 1998 to January 1999) using an electric pump. Groundwater samples were collected from the bore holes and stored in 1-liter polyethylene plastic bottle containers. The collected samples were then kept in an icebox and sent to the laboratory for preservation and chemical analysis. The samples were preserved at 4°C and acidified with concentrated hydrochloric acid to pH $< 2.0$ to minimize precipitation and adsorption on the walls of the container (APHA-AWWA-WEF 1995).

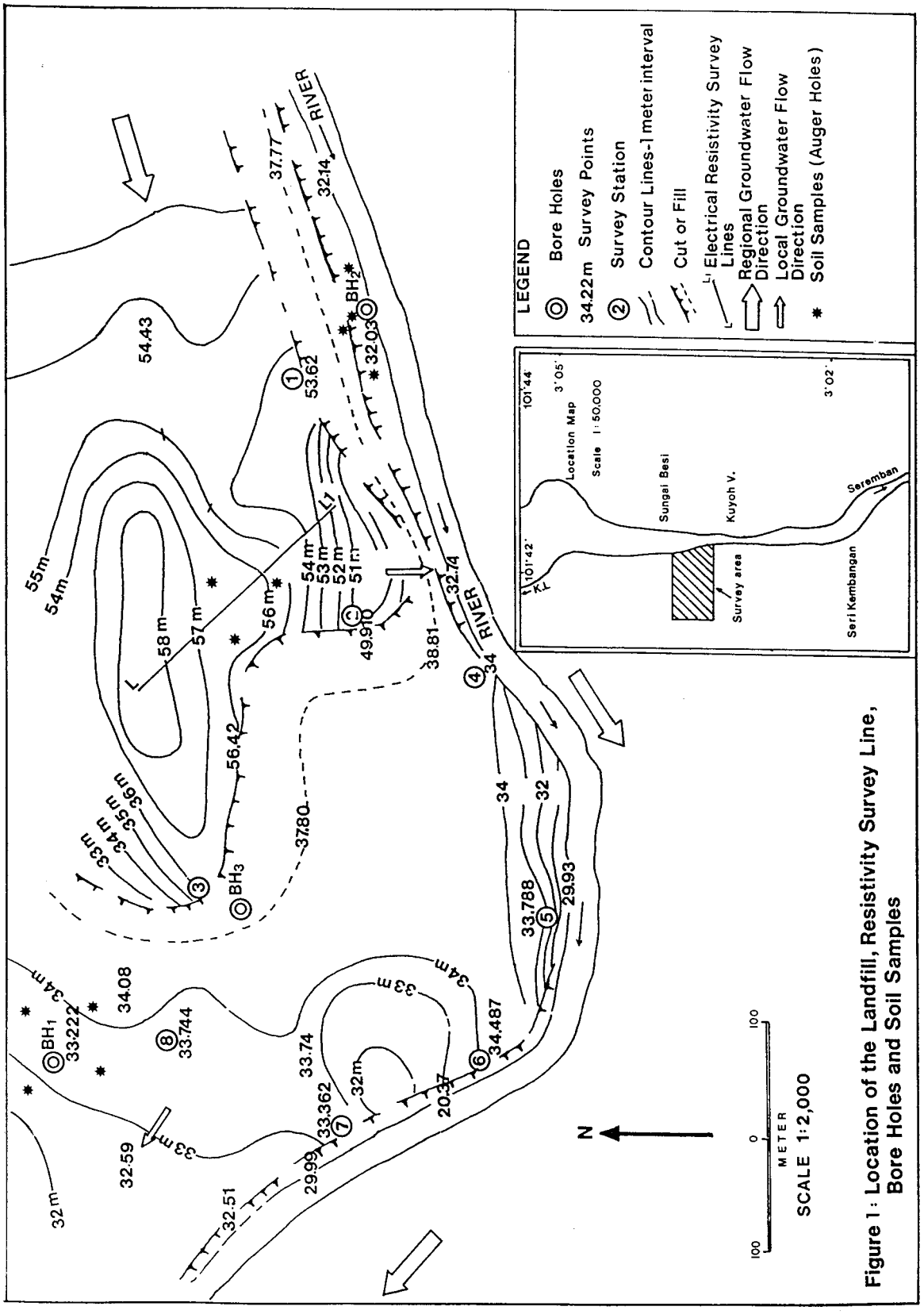


Figure 1: Location of the Landfill, Resistivity Survey Line, Bore Holes and Soil Samples

**Figure 1.** Location of the landfill, resistivity survey line, bore holes and soil samples.

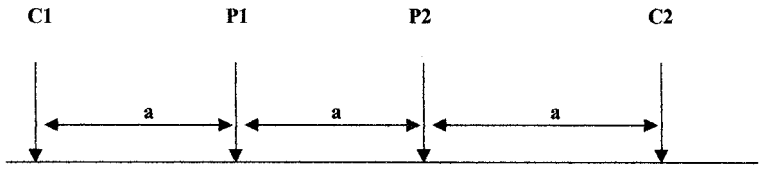


**Figure 2.** Electrode configuration (Wenner array): "a" is the electrode spacing, C1 and C2 are current electrodes, and P1 and P2 are potential electrodes.

The ground- and surface water investigation and analysis were carried out for in-situ parameters examined in the field and laboratory chemical analysis. In-situ parameters include pH, temperature, dissolved oxygen, and electrical conductivity. These parameters were determined using a pH-meter with a glass electrode, a thermister probe (YSI 58), a dissolved oxygen meter, and a digital Temperature Level Conductivity (TLC) meter, respectively. The parameters examined in the laboratory include the major cations (Na, K, Ca, and Mg), heavy metals (Fe, Pb, Zn, Cu, and Cr), and the analytical technique used for their determination was atomic optical emission spectroscopy using an induced couple plasma (ICP-2000) spectrometer. Major anions (Cl, $SO_4$, $NO_3$, $NO_2$, F, and $PO_4$) were determined using an ion chromatographic technique, and chromatography was performed with an Alltech Chromatograph. Six heavy metals in soil vadose zone (Cu, Cd, Zn, Cr, Pb, and Ni) were determined by sampling auger holes drilled upstream (site A), within the landfill itself (site B), and downstream (site C). Soil sampling was conducted at four soil depths (0–30, 30–70, 70–110, and 110–150 cm). Soil samples were also taken from below the water table (soil saturated zone) from the upstream and downstream auger holes for analysis of heavy metals (Cu, Pb, Ni, Cr, and Cd). Another soil sampling and analysis was performed for investigation of soil reaction, exchangeable bases (CEC, Na, K, Ca, and Mg) and heavy metals (Cu, Pb, Ni, Cr, and Cd). The latter sampling was conducted downstream for the soil vadose and saturated zones.

## Statistical Analysis

Analysis of variance (ANOVA) of the ground- and surface water data was performed using the SAS Statistical Package MSTAT (MSTAT-C, Michigan State University). The comparison of means was determined by using Duncan's new multiple range test (DMRT) at the 5% level of significance.

ANOVA of the soil data was performed using a randomized complete block design (RCBD) and the same statistical package. The comparison of means was determined using Duncan's DMRT at the 5% level of significance; *t* tests were also performed for soil analysis.

## Results and Discussion

The electrical resistivity model section of line $L–L_1$ will be discussed and compared to the resistivity values obtained from the laboratory measurements for the landfill material and other earth materials at certain localities in Malaysia (Lukut, Tioman) as shown in Table 1.

### Line $L–L_1$

This line is located on the top of the landfill in the central part with a total length of 250 m and total number of datum points 392. The most prominent feature that can be distinguished from the resistivity image of this line (Figure 3), is the presence of three low resistivity zones of decomposed waste saturated with highly conductive leachate. The large zone is found at a distance of 145–175 m from the base point (first electrode position) on the right part of the model section and is situated at a depth of about 10–25 m from the surface with a thickness of about 15 m. The leachate is near the ground surface at about 170 m from the base point along the survey line. The other two small zones are found on the left side of the model section situated at about the same depth and at about 90 m from the base point. The decomposition of the waste materials decreases with distance around these zones. There are relatively higher resistivity materials, reaching up to 20 Ωm and probably composed of soil and sand saturated with leachate beside fresh waste materials (plant materials, strands of rubber and sand) saturated with leachate and rainwater. The bedrock is represented by the high resistivity materials greater than 100 Ωm on the bottom of the section at a depth of about 38 m from the top of the landfill. There is a narrow thin layer of high resistivity on the surface and interpreted as a dry layer of weathered materials and hard rocks with sand materials brought in for beautification of the landfill for the Commonwealth Games held at Bukit Jalil in September 1998.

### Groundwater Pollution

Table 2 shows the ground- and surface water hydrochemistry at the landfill. Among the in-situ parameters, pH is significantly ($P \leq 0.05$) higher downstream com-

Table 1. Electrical resistivity of earth materials

| Sampled materials | Resistivity (Ωm) |
|---|---|
| Leachate only | 2.994 |
| Sand saturated with leachate | 4.97–5.04 |
| Fresh waste (plant materials, rubber strands, sand) saturated with leachate | 6.03–7.16 |
| Soil saturated with leachate | 3.51–4.00 |
| Rainwater only | 73.88 |
| Sand saturated with rainwater | 14.36–17.50 |
| Fresh waste (plant materials, rubber strands, sand) saturated with rainwater | 19.71–22.50 |
| Soil saturated with rainwater | 9.30–10.57 |
| Clay saturated with brackish water (Pulau Burung, Nibong Tebal, Southern Seberang Perai) | 0.12–0.20 |
| Clay saturated with brackish water (Lukut) | 0.05–0.26 |
| Clean sand saturated with sea water (Tioman) | 1.5–3.5 |

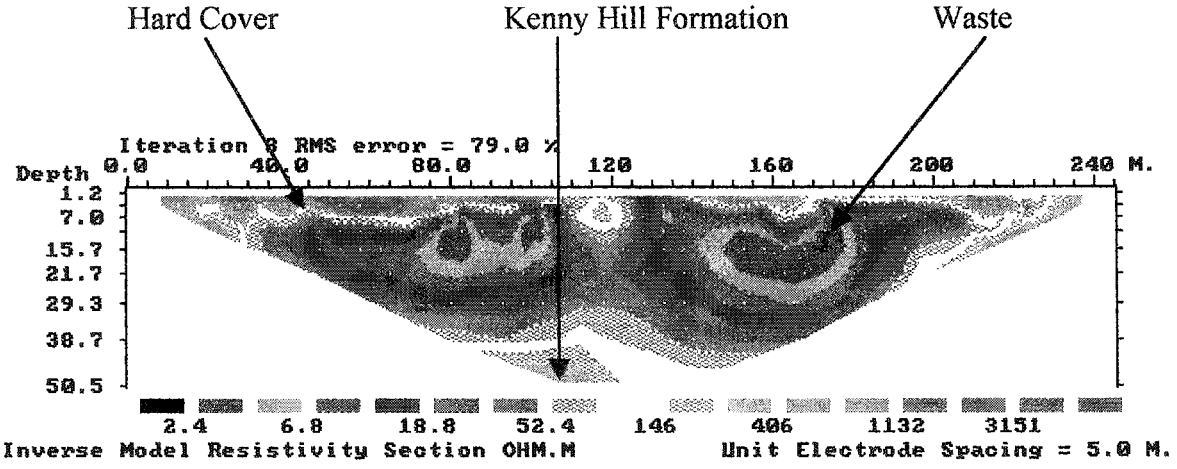


**Figure 3.** Resistivity image along line L–$L_1$.

pared to upstream and to river water. The pH at the downstream borehole is slightly higher than neutral, which indicates the slightly alkaline nature of the groundwater at this location. Electrical conductivity (EC) is significantly higher downstream compared to upstream and to river water. The EC downstream, 7160 μS/cm, is far higher than the WHO (1984) value of 1400 μS/cm set for drinking water. The higher EC downstream can be attributed to the presence of anomalous concentrations of Cl, Na, and K ions at this location (Revel and others 1999). Cl, Na, and K were significantly ($P \leq 0.05$) higher and found in anomalous concentrations downstream (Table 2), confirming pollution at this location (Ramesh and others 1995). Cl, Na, and K levels downstream were 438.51, 983.12, and 383.45 mg/liter, respectively, compared to 3.97, 6.06, and 3.20 mg/liter, respectively, upstream and 13.02, 15.68, and 6.52 mg/liter, respectively in river water (Table 2). The Na concentration of 438.51 mg/liter downstream is far higher than the WHO (1984) guidelines of 200 mg/liter and higher than US EPA (1976) standards for drinking water. Cl at 983.12 mg/liter downstream supports leachate migration and hence groundwater contamination at this location. It is known that Cl is the best indicator for detecting the presence of leachate in groundwater (Bouwer 1978), and it is among the pollutants frequently found in leachate generated from landfills (Todd 1980). Most probably the leachate after its production within the landfill, moved downwards, and mixed with the groundwater system. Then leachate migrated towards downstream, facilitated by the high topographic difference between the landfill and the surrounding ground- and surface water. The local groundwater flow towards downstream also facilitated leachate movement in this direction. Mg and Ca represent the water hardness, and they are present at low levels in the ground- and surface water. Mg is significantly higher downstream, while Ca, although it is significantly higher downstream compared to the upstream, did not differ significantly from the

Table 2. Chemical composition of groundwater and surface water[a]

| Parameter | Upstream BH | Downstream BH | River water |
|---|---|---|---|
| Temp (°C) | 29.92b | 31.88ab | 33.82a |
| pH | 5.58c | 8.05a | 7.37b |
| EC (mS/cm) | 0.11b | 7.16a | 0.41b |
| DO | 4.77a | 5.08a | 2.78b |
| Na | 3.97b | 438.51a | 13.02b |
| K | 3.20b | 383.45a | 6.52b |
| Ca | 9.52b | 31.32a | 31.07a |
| Mg | 1.62c | 8.53a | 2.67b |
| Cl | 6.06b | 983.12a | 15.68b |
| $SO_4$ | 8.37b | 3.57c | 21.05a |
| $NO_3$ | 1.67b | 1.38b | 7.56a |
| $NO_2$ | 0.02c | 0.70a | 0.20b |
| F | 0.30a | 0.00a | 0.33a |
| $PO_4$ | 0.35b | 2.38a | 1.07b |
| Fe | 0.27a | 0.47a | 0.31a |
| Pb | 0.001b | 0.00005b | 0.005a |
| Zn | 0.014a | 0.015a | 0.01a |
| Cu | 0.003b | 0.012a | 0.005b |
| Cr | 0.002b | 0.01a | 0.01a |

[a]Means with the same letter in each row are not significantly different at 5% level of significance by DMRT. All values in mg/liter except as specified. BH = bore hole.

surface water. Sulfates ($SO_4$) and nitrates ($NO_3$) are found in the area in low concentrations, even below the WHO standards for drinking water, but are significantly higher in the surface water compared to the groundwater. Phosphate ($PO_4$) and nitrite ($NO_2$), although present at low levels, are significantly higher downstream. No significant difference was obtained in the amount of fluoride (F) in the different locations. Iron (Fe) concentrations in the different locations were not significantly different, but in the downstream bore hole (0.47 mg/liter) and surface water (0.31 mg/liter), its levels were higher than the allowable concentrations of the WHO (1984) value of 0.3 mg/liter set for drinking water. The levels of heavy metals in the ground- and surface water at the landfill are very low, even below the permissible limits set by the WHO (1984) guidelines and US EPA (1976) for drinking water, and their levels did not reflect any sign of heavy-metal pollution. The anomalous concentrations of EC, Cl, Na, and K and the high concentrations of different ions in the downstream area are most probably due to release of contaminants during the acidic phase of the landfill development (Arneth and others 1989). The slightly basic pH downstream (8.05) indicates that the landfill is in its methane-producing phase, because during the acidogenic stage the pH values are quite low, while during the methanogenic stage the pH appeared to be neutral to alkaline (Fatta and others 1998). The release of

Table 3. Distribution of heavy metals in soil vadose zone at Seri Petaling landfill[a]

| Parameter (mg/kg soil) | Site A | Site B | Site C |
|---|---|---|---|
| Cu | 1.83b | 5.52a | 6.49a |
| Cd | 0.92b | 1.07a | 1.01a |
| Zn | 3.97c | 8.02b | 20.44a |
| Cr | 12.61a | 9.92b | 5.71c |
| Pb | 5.79ab | 3.42b | 7.67a |
| Ni | 2.89a | 2.2b | 2.38ab |

[a]Means with the same letter(s) in each row are not significantly different at 5% level of significance by Duncan's multiple range test.

Table 4. Probable background levels and typical concentrations of some heavy metals in soil[a]

| Element | Background concentration (mg/kg) | Typical normal range (mg/kg) |
|---|---|---|
| Cd | 0.01–0.2 | 0.01–2.4 |
| Cr | 80–200 | 5–1500 |
| Cu | 6–60 | 2–250 |
| Ni | 1–100 | 2–1000 |
| Pb | 12–20 | 2–300 |
| Zn | 17–125 | 10–300 |

[a]Data from Bowen (1979), Balsberg-Pahlsson and others (1982), Kabata-Pendias and Pendias (1984), Fergusson (1990), and Alloway (1990).

contaminants from the waste is due to the effect of leachate migration from the landfill (where its production was indicated by the resistivity image of line L–$L_1$), in the downstream direction.

### Soil Pollution

Heavy metals in the soil vadose zone were analyzed and the results are shown in Table 3. The different locations of soil sampling were represented by site A (upstream), site B (landfill body itself), and site C (downstream). The samples were taken from the vadose zone (unsaturated zone). From Tables 3 and 4, it is clear that the levels of heavy metals in all sites are within their typical normal ranges as can be seen from Table 4. There was no significant difference ($P \leq 0.05$) in the amounts of Cu and Cd at sites B and C, which were significantly higher than at site A. Zn is significantly higher at site C (20.44 mg/kg soil) compared to site A (3.97 mg/kg soil) and site B (8.02 mg/kg soil). Cr is significantly higher at site A (12.61 mg/kg soil) compared to site B (9.92 mg/kg soil) and site C (5.71 mg/kg soil). Although the amounts of Pb were statistically similar at site A (5.79 mg/kg soil) and

Table 5. Soil analysis results in the soil saturated zone[a]

| Parameter | Upstream auger hole (site A) | Downstream auger hole (site C) |
|---|---|---|
| Cu | 14.4 ± 1.9 | 40.7 ± 14.9 |
| Pb | 13.9 ± 2.0 | 28.0 ± 3.0 |
| Ni | 10.0 ± 1.9 | 0.00 |
| Cr | 16.03 ± 1.8 | 8.1 ± 1.13 |
| Cd | 1.97 ± 1.35 | 2.20 ± 1.81 |

[a]Values are mean mg/kg soil ± standard deviation.

C (7.67 mg/kg soil), higher values were obtained in site C (7.67 mg/kg), and sites A and B were statistically similar. The amounts of Ni were also statistically the same in site A (2.89 mg/kg) and C (2.38 mg/kg), but higher amounts were obtained in site A, sites B and C were statistically the same. The concentrations of Cu, Zn, and Ni as shown in Table 3 are within the range of background levels in different soil series as reported by Lee and others (1992), while the concentrations of Pb and Cd as shown in Table 3 were below the levels in Kuala Lumpur soils and street dust (895 and 2466 mg/kg soil for lead and 2.38 and 2.96 mg/kg soil for cadmium, respectively) as reported by Ramlan and Badri (1989).

Other soil samples were taken for analysis of heavy metals from auger holes drilled and sampled from the saturated zone (below the groundwater table) upstream (site A) and downstream (site C) (Table 5). The results were compared using the $t$ test. As shown by Table 5, amounts of Cd and Cu were not significantly different ($P \leq 0.05$) at the two sites. Ni concentration is significantly ($P \leq 0.05$) higher upstream (10.0 mg/kg soil) compared downstream (0.0 mg/kg soil). The level of Cr is significantly higher ($P \leq 0.01$) upstream (16.03 mg/kg soil) compared downstream (8.1 mg/kg soil). The amount of Pb is significantly higher ($P \leq 0.01$) downstream (28.0 mg/kg soil) compared upstream (13.9 mg/kg soil). From the above it is clear that, among the inorganic pollutants, only Pb is present in significantly higher amounts at the downstream site. With the exception of Cd, all these heavy metals (Ni, Cr, Cu, and Pb) are within their background concentrations and their typical normal ranges as can be seen from Table 4. Cd is within the typical normal range, but higher than the background concentration as shown by Table 4.

A comparative study of pH, exchangeable bases, and heavy metals in the vadose and saturated zones was conducted downstream (Table 6). A $t$ test was performed, and the result of analysis revealed no significant difference ($P \leq 0.05$) in the amount of pH-$H_2O$ for both zones. With the exception of Mg all the exchangeable bases (CEC, Na, K, and Ca) were significantly higher in the soil saturated zone. Moreover, the amounts of Na, K, and Ca were significantly higher ($P \leq 0.01$) in the saturated zone compared to the vadose zone. This suggests the downward leaching of these exchangeable bases to the groundwater zone. Cu and Pb were significantly ($P \leq 0.01$) higher in the saturated zone. They were 40.73 and 28.0 mg/kg soil in the saturated zone compared to 5.47 and 13.17 mg/kg soil in the vadose zone, respectively. Ni was significantly ($P \leq 0.01$) higher in the vadose zone. Cr and Cd were significantly higher ($P \leq 0.05$) in the saturated zone.

Table 6. Soil analysis result in vadose and saturated zones of downstream area

| Parameter | Soil vadose zone | Soil saturated zone |
|---|---|---|
| pH | 7.45 ± 0.21 | 7.53 ± 0.04 |
| CEC (cmol/kg) | 11.9 ± 0.74 | 14.58 ± 0.28 |
| Na | 5.36 ± 0.45 | 136.13 ± 1.9 |
| K | 24.3 ± 0.7 | 410.1 ± 1.95 |
| Ca | 1151 ± 40.95 | 2735.1 ± 5.1 |
| Mg | 53.16 ± 6.1 | 51.6 ± 2.31 |
| Cu | 5.47 ± 2.8 | 40.73 ± 14.99 |
| Pb | 13.17 ± 3.59 | 28 ± 3.0 |
| Ni | 2.2 ± 0.92 | — |
| Cr | 5.37 ± 0.93 | 8.1 ± 1.9 |
| Cd | 0.94 ± 0.06 | 2.2 ± 1.81 |

Note: All values are mg/kg soil or as specified.

Soil contamination may be considered when concentrations of an element in soils are two to three times greater than the mean background levels (Logan and Miller, 1983). The upper baseline concentration limits of Cd, Cr, Cu, Ni, and Zn for California, USA; China; and Poland soils as reported in Table 7, were used by Dudka and others (1995) to assess possible metal contamination in Ontario soils. These baseline concentration limits were used to describe the trace element situation in the different sites of Seri Petaling landfill.

With the exception of Cd, the concentration ranges of all trace elements (Cu, Zn, Cr, Pb, and Ni) of Seri Petaling landfill soils were below the upper limits of baseline concentrations as published from different sources (Table 7). The concentration ranges of Cd at site C were higher than the upper limits of baseline concentration except for Poland soils.

## Conclusion

From the above discussion it can be concluded that there are three zones of decomposed waste saturated with highly conductive leachate, and this can be seen

Table 7. Concentrations of Seri Petaling landfill soils compared with published baseline concentrations in soils from different sources (mg/kg)

| Element | Seri Petaling soils | | | California soils[a] | USA soils[b] | China soils[c] | Poland soils[d] |
|---|---|---|---|---|---|---|---|
| | Site A | Site B | Site C | | | | |
| Cu | 1.0–3.3 | 3.6–9.7 | 2.8–8.4 | 7.41–77.8 | 2.86–101 | 7.3–55 | 2.0–18 |
| Cd | 0.73–1.1 | 0.89–1.3 | 0.7–1.4 | 0.05–1.34 | NA | 0.02–0.3 | 0.1–1.7 |
| Zn | 2.9–5.0 | 3.0–16.5 | 13.7–26.7 | NA | 12.6–183 | 28.5–161 | 10.5–154 |
| Cr | 10.4–15.2 | 5.5–14.3 | 2.7–9.7 | 14.8–392 | 6.59–208 | 19.3–150 | 3.7–75.3 |
| Pb | 3.3–11.6 | 0.2–10.7 | 2.9–18.3 | 9.64–48.8 | 4.62–55.4 | 9.95–56.0 | NA |
| Ni | 1.5–4.0 | 0.8–4.0 | 1.1–3.3 | 6.25–207 | 2.44–69.4 | 7.73–70.9 | 2.0–27.0 |

[a]Calculation based on data reported by Bradford and others (1996); $N = 50$.

[b]Calculation based on data reported by Shacklette and Boerngen (1984); $N = 1218$.

[c]Calculation based on data reported by Wei and others (1990); $N = 4095$.

[d]Data reported by Dudka (1992, 1993); $N = 127$.

from the resistivity image of line $L–L_1$ conducted in the central area on the top of the landfill. This indicates the leachate production within the hilly waste body (the landfill). The leachate has migrated downwards, reached the water table, mixed with the groundwater system, and followed the groundwater flow towards the downstream area. Leachate migration was facilitated by the difference in topography between the landfill and the surrounding groundwater and surface waterbodies. The anomalous concentrations of EC, Cl, Na, and K ions in the groundwater of the downstream bore hole confirm the pollution at this location. Soil exchangeable bases were significantly higher in the soil saturated zone compared to the vadose zone in the downstream, and no significant difference was obtained in the levels of inorganic pollutants. With the exception of Cd, the concentration ranges of all trace elements (Cu, Zn, Cr, Pb, and Ni) of Seri Petaling landfill soils were below the upper limits of baseline concentrations as published from different sources. Although there is no sign of heavy metals pollution in the groundwater and soil samples, but there is a general trend towards pollution in the downstream area.

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