ISSN 1996-3343

Asian Journal of Applied Sciences

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Asian Journal of Applied Sciences 7 (7): 518-535, 2014
ISSN 1996-3343 / DOI: 10.3923/ajaps.2014.518.535
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Electrical Resistivity Techniques and Chemical Analysis in the Study of Leachate Migration at Sungai Sedu Landfill

Umar Hamzah, Mark Jeeva and Nur Atikah Mohd Ali
School of Environmental and Natural Resource Science, Faculty of Science and Technology, National University of Malaysia, Bangi, Malaysia

Corresponding Author: Umar Hamzah, School of Environmental and Natural Resource Science, Faculty of Science and Technology, National University of Malaysia, Bangi, Malaysia

ABSTRACT

Monitoring of contaminated water and soil in waste disposal sites is normally carried out by chemical analysis of surface water, leachate and soils as well as by geophysical measurements. Leachate is defined as any contaminated liquid or wastewater generated from rain water percolating through solid waste materials, accumulating contaminants and moving into subsurface and surrounding areas. A study was carried out to detect the leachate movement at Sungai Sedu landfill located on ten square acres near Banting town. Geologically, the study area is underlined by Holocene marine clay of Gula and Beruas Formations sitting on top of metasedimentary rocks of Kenny Hill formation. Geophysical surveys using techniques 2D electrical resistivity imaging, Vertical Resistivity Profiling (VRP) as well as geochemical analysis on soil and water samples were used in this study to investigate the level of leachate migration from the dumping spot into the surrounding areas. This was based on characterizing the measured electrical resistivities and analyzing the heavy metal concentrations. The 2D electrical imaging surveys were carried out on 8 profiles while the VRP surveys were conducted in 6 boreholes. Based on resistivity imaging sections, the leachate was detected to migrate at about 3-5 m depth. Basically the resistivity of leachate is less than 1 Ωm. The concentrations of heavy metals also showed that the leachate has migrated into the nearby river. The concentrations of heavy metals in river bank soil, leachate and surface water samples are high and exceeded the background values especially Ni, Mn, Zn, Cr and As. Conductivity of the river bank soil, leachate, surface water and the surrounding soil samples were approximately around 6600 and 20000-50000 μS cm^{-1}, respectively with pH values of 3-5. The high concentrations of heavy metals and soil conductivities indicate the possibility of leachate migration from the dumping site to contaminate the nearby river, soil and groundwater of the study area.

Key words: Electrical resistivity technique, leachate migration, chemical analysis, Sg. Sedu landfill

INTRODUCTION

Keller (2000) said that the main source of environmental problems is from the increase of residential areas or inhabitants resulting to the increase in the production of domestic waste through daily activities. Solid waste disposal sites frequently cause problems to the nearby residential areas and the environment around the area. Developing countries usually lack efficient system to overcome the solid waste disposal problem, so open dumping is considered as a speedy and cost-effective solution. The open dumping activities will normally cause pollution to the areas

surrounding the waste disposal sites mainly towards the soil, surface water and finally to the groundwater (Martinho and Almeida, 2006). Extensive studies were carried out to measure the pollution extent on the surrounding area of the waste disposal mainly towards the soil, water and the groundwater quality (Dawson *et al*., 2002). For these kinds of studies, laboratory analysis was made on extensive soils and water samples collected around the sites. Water samples were also taken sometimes from the nearby stream and extracted from borehole drilled near the site. These kinds of water were investigated in order to trace the extent of pollutant migration laterally or vertically into the surrounding areas (Al-Khashman and Shawabkeh, 2006). Beside chemical analysis on water and soil samples, additional surveys were also carried out to determine the extent of pollution by selected geophysical methods especially the electrical resistivity techniques (Frid *et al*., 2008) where the current movement is affected by the presence of ions dissolved from the waste that moved around the site (Abdullahi *et al*., 2010). Hence, the effects of pollutants are easily mapped by geophysical characteristics especially in delineating the boundary between contaminated and uncontaminated zones (Porsani *et al*., 2004). Geochemical analysis is normally used in identifying the heavy metals concentration regarded as pollutants and sometimes toxics in the water samples either from surface, boreholes or extracted from soils. The presence of heavy metals exceeding the background values are considered as strong indicator of pollution levels.

The 2D electrical resistivity imaging is one of the geophysical survey techniques used to investigate subsurface soil and groundwater characteristic below the surface traverse line. Basically the technique involves sending the DC current into the earth via a pair of steel electrodes and the resulting potential will be measured by another pair of electrodes. The medium-dependent electrical potential will then be translated into resistivity values. Finally, the resistivity distribution is used in the interpretation of the whole survey line by inverse modeling (Loke *et al*., 2003). Groundwater contamination, especially the pollutant migration below several waste disposal sites were reported by Karlik and Kaya (2001), Hamzah *et al*. (2006, 2007), Meju (2000) and Osazuwa and Abdullahi (2008) using similar techniques. Electrical resistivity imaging or tomography technique is considered (Batayneh and Barjous, 2005) to be a suitable tool for site characterization at disposal site since the presence of leachate pollutant riched in soluble ions will fascilitate the flow of an electrical current hence lowering the resistivity of the medium (Aristodemou and Thomas-Betts, 2000). This technique was widely extended to a 3D measurement for a more detail investigation (Cardarelli and Fischanger, 2006). Hamzah and Chieh (2008) have successfully used Vertical Electrical Sounding (VES) in mapping leachate infiltration into the ground around Ampar Tenang waste disposal site.

The main objective of electrical resistivity survey and geochemical analysis conducted at Sungai Sedu landfill site was to investigate the migration pattern of leachate pollutant in soil and groundwater below the dumping area (Fig. 1). The pollutant flow direction and the degree of toxicity in the water were determined by chemical analysis of the soil, surface water and groundwater samples extracted from the drilled boreholes. The landfill is situated at a small village of Sungai Sedu in Telok Datok and can be accessible via a junction at 20 km along the Klang-Banting main road. The 10-acres landfill is very near to a river flowing in the direction of SW-NE and historically, it started to be in used since 1989 until now. It is overlying a Quaternary alluvial layer consisting of marine silty clay. Geologically, these alluvial deposits are of Gula and Beruas formations deposited on Carboniferous Kenny Hill formation as the meta-sedimentary bedrock consisting mainly of shale, phyllite, schist, argillite and sandstone.

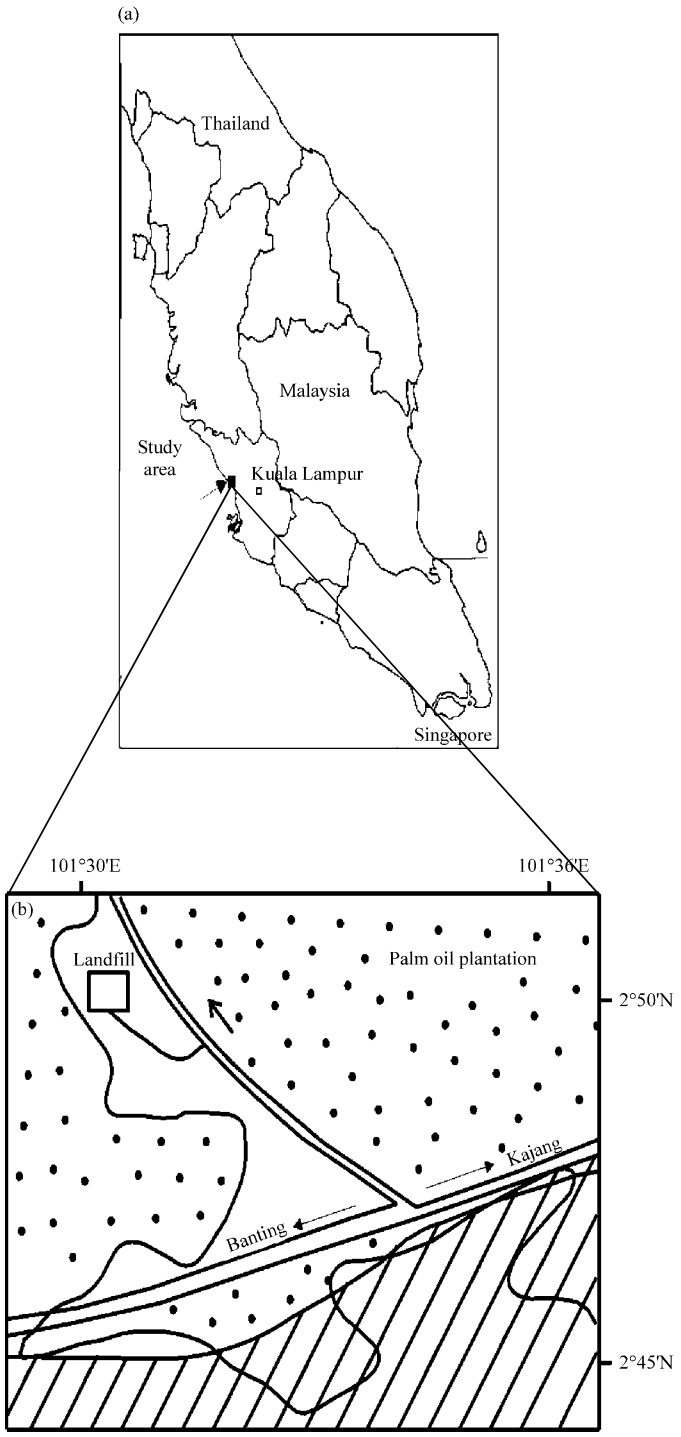

Fig. 1(a-b): (a) Map of the study area in Malaysia and (b) Exact location of the landfill study area

METHODOLOGY

Electrical resistivity method is specially chosen in this research because the constituent of inorganic pollutants increases the number of ions in leachate and hence fascilitate the current

movement in the medium. In this method, the measured subsurface potentials due to the passage of direct current are used in calculating the apparent resistivity and subsequently utilized as inputs in inverse modeling to build a subsurface true resistivity model (Loke *et al*., 2003). Inverse modeling involves a few steps beginning with dividing the area below the profile into similar sized cubes by means of finite elements technique. These small cubes are then assigned with resistivity readings that are estimated by forward modeling and compared with the observed field resistivity values. Resistivity values calculated by the computer modeling will be adjusted to match the observed ones until these two types of reading are almost similar or close to each other (Dahlin and Zhou, 2002). The difference in both readings are determined by the root means square error, where its value of not more than 10% will be acceptable as the best model representing subsurface geology below the profile.

Electrical imaging surveys were conducted along 15 profiles in the site using ABEM SAS 1000 resistance meter, 2 sets of multi-core cables, 41 steel 1 m long electrodes and ES464 model automatic electrode selector. The electrodes are connected along the cable at 5 m spacing. The electrode selector will choose 4 active electrodes following Schlumberger configuration for each resistance measurement. In this configuration, 2 outer electrodes were used to penetrate the electrical current into the ground and another inner pair of electrodes will be used to measure the current potential resulting from the current flow in the ground. The measured resistances are stored in the memory and will be retrieved for inverse modeling purposes.

Beside the electrical surveys, 33 soils and 9 water samples from the Langat river and boreholes were also sampled for chemical analysis. Soil sampling was carried out by following the USEPA (2000) procedures. Soil samples were taken randomly within the waste disposal site and also in the deep and shallow boreholes close to the electrical resistivity survey lines. Soil samples were also taken in areas surrounding the dumping site such as in the palm oil and banana plantation. Soil sample was taken at every 30 cm depth sampling interval in each shallow borehole until 1.2 m depth using hand auger technique. All soil samples were kept in plastic bags, properly closed and labelled. The soil samples were then analyzed in the laboratory for pH, organic content and soil conductivity determinations. Mixed solution was prepared following ISO 10390, 1994 for pH determination using glass electrode pH meter. Organic content in the soil was determined by mixing 2 g of dry soil with 5 mL of hydrogen proxide which was kept for about 24 h. One hundred fifty milliliter distilled water was then added to the solution and stirred and was kept for another night. All liquid was then extracted out and the remaining soil was dried in the oven and the weight was measured for the content of organic matter calculation. As for the soil conductivity measurement, 20 g of dried soil was mixed with 250 mL of Calcium Sulphate solution and stirred. The sample conductivity was then measured by a conductivity meter which was dipped into the filtered solution. Titration and Atomic Absorption Spectrometer (AAS) analysis were carried out in determining the Cationic Exchange Capacity (CEC) of Hydrogen, Aluminium, Sodium, Potassium, Magnesium and Calcium following ASTM (1984). Solution obtained by mixing a 20 g of soil sample with Sodium Hydroxide was used in the titration process for determining the H^+ and Al^{3+} concentrations. As for the Na, K, Mg and Ca determination, a 4 g soil sample was mixed with a 33 mL of ammonium acetate solution and stirred for about one hour. This solution was then transferred into tubes and centrifuged. The clear solution obtained from the centrifuge process was transferred into bottles for AAS analysis using Perkin Elmer 3300.

Procedures as reported by Lamothe *et al.* (1986) were adopted in this study to determine the heavy metal concentrations in soil. Soil sample was sieved and 1 g sample of 1.25 μm size was chosen and filled into a 250 mL plastic bottle. A mixture of 40% HCl and 60% HNO_3 was mixed with the soil sample in the bottle and heated to 100°C for about 65 min in the oven. This solution was cooled in the room temperature for a while and analysed for the heavy metal concentrations such as Pb, Zn, Cu, Ni and Co using ICP-Mass Spectroscopy Perkin Elmer Elan 6000. The anions concentrations including sulphate and nitrate were also determined by the same HACH kit instrument.

Monitoring the water quality as part of the analysis to determine the level of contamination was also carried out by in-situ measurement of some physical properties of surface water and leachate. The parameters measured were pH using pH meter Hanna HI 9025, temperature and Electrical Conductivity (EC) using conductivity meter HACH 44600 and Dissolved Oxygen (DO) by using YSI 57. For laboratory measurements, the surface water and leachate were also sampled and kept in 0.5 L pre-cleaned polyethylene bottles. These bottles were cleaned with acid washed by soaking overnight in nitric acid before rinsing with distilled water. This procedure is very important in removing any contaminant originating from cleaning reagent. Leachate was sampled at 4 locations around the waste disposal randomly and a few drops of nitric acid were mixed into the leachate to maintain the pH level at 5. These bottles were then safely kept in ice box during the field sampling and later stored in the laboratory refrigerator before chemical analysis.

Altogether 6 deep boreholes were drilled in the waste disposal site for soil, water and vertical resistivity analysis. These boreholes were dug by using YBM2WS rotary drilling machine. Washed boring method was used throughout the drilling processes. Geological logging was carried out simultaneously during the boring to identify the soil and rock types along the boreholes. Water sampling at several depths along the borehole was carried out using liquid sampler SEBA Hydrometrie model of 2 inches length and 0.5 L volume. Before the water sampling, about 3 volumes of borehole water was drawn out from the borehole so that the water sample is represented only by water originating from the aquifer coming through the pores along the borehole wall. Borehole water was extracted using OLEO-MAC SA 18 pump.

The Vertical Resistivity Profiling (VRP) survey was conducted in each of the deep boreholes mainly for measuring the resistivity variations along the vertical soil profiles. The sensor used for this measurement consists of a 5 cm diameter PVC pipe with 4 copper electrodes fixed at 2.5 cm spacing along the PVC wall. The electrode diameter and length are 2.5 mm and 3 cm, respectively. The resistivity values measured are plotted against the borehole depth for interpretation. In conducting the VRP survey, the soil sample retrieved from depth of 0.5 m until maximum depth of about 20 m with an interval of 0.5 m was attached to the sensor for measuring the resistance due to the current movement into it. Two outer electrodes were used for sending current through the soil and another pair of electrodes were used for potential measurement. The resistance was then used for resistivity calculation. The vertical resistivity variation was ploted along the borehole for interpretation.

RESULTS AND DISCUSSION

A total of 15 resistivity traverse lines were modeled using inversion software RES2DINV. Locations of all survey lines are shown in Fig. 2. The lines are randomly positioned in the study area occupying the middle part of the active landfill as well as around the inactive dumping ground. Interpretation of inverse resistivity models are based basically on the resistivity values

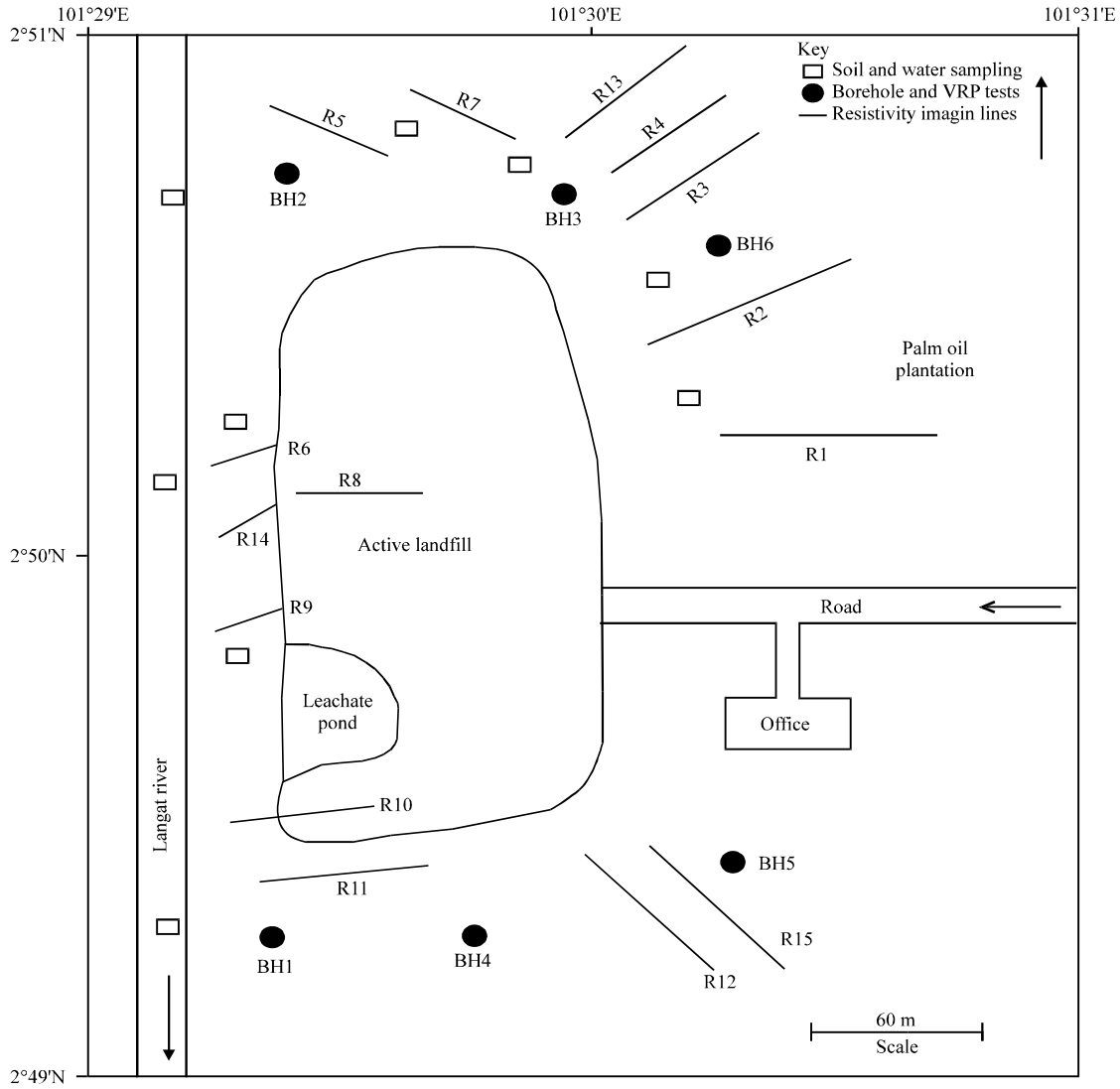

Fig. 2: Locality of resistivity lines, borehole, soil and water sampling

experimentally measured by mixing leachate with clay, sandy clay and clayey sand in a small scale laboratory studies (Bahaa, 2005). In general, the range of resistivity values observed in all inverse models vary from 0.5 Ωm to about 200 Ωm representing either the uncontaminated or contaminated soil and groundwater within the surface to a maximum depth of about 20 m in the ground. These resistivity models were also compared with the vertical resistivity probe curves measured in boreholes together with the soil layering observed during the drilling.

In general, the resistivity distributions can be grouped into 3 different major zones corresponding to firstly the top high resistivity values (50-100 Ωm) of waste pile or the decomposed waste covered with soil at depth of 0-2 m. In areas away from the landfill especially in the palm oil plantation, the high resistivity top layer can be associated to the dry soil located above the water table. Secondly, a much lower resistivity zone (1-10 Ωm) observed at depth of 2-4 m below the surface corresponds to clay and sandy clay soils based on nearby boreholes. Large amount of leachate solution originated mainly from the dissolved waste is believed to be accumulated in this

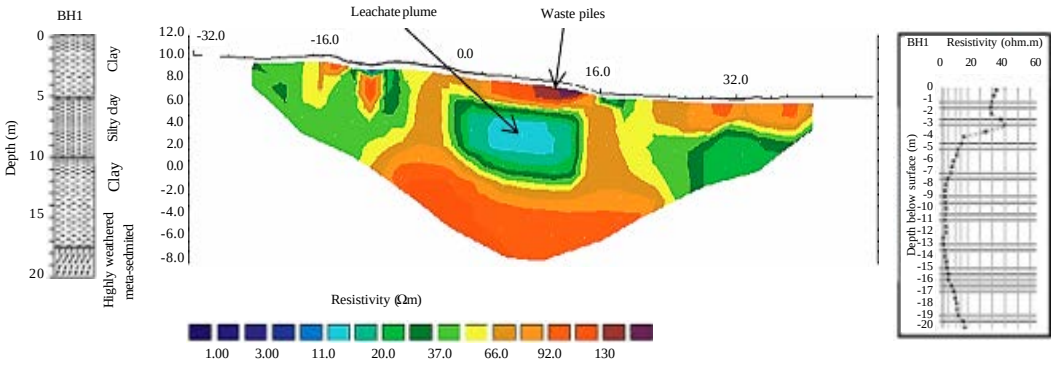

Fig. 3: Inverse model of line R10 measured in the active landfill area

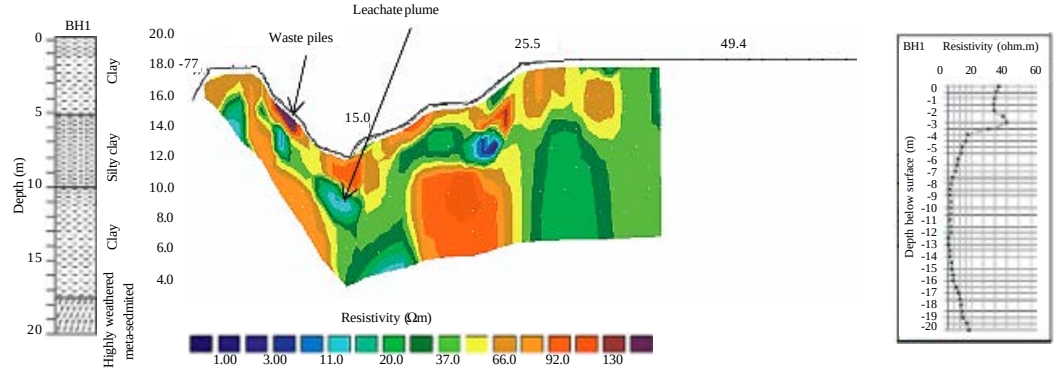

Fig. 4: Inverse model of line R8 measured in northern part of the active landfill area

zone. With high leachate content, this ions rich and conductive zone is always represented by a much lower resistivity value as observed in the field and during the laboratory studies. Nevertheless, the leachate plume or the highly leachate concentrated zone could hardly be detected in the inverse model from survey lines conducted in clay or clayey dominated areas since both clay and leachate have quite similar resistivity values.

The presence of leachate with resistivity values around 5-9 Ωm is observed in resistivity models of profiles R8 (Fig. 3) and R10 (Fig. 4) measured across the active landfill towards the western border of the oil palm plantation along east-west direction. The low resistivity leachate zones are located immediately below the waste piles in both survey lines as indicated in both figures. The waste piles show much higher resistivity values of approximately 100-200 Ωm overlying the leachate plumes with resistivity less than 10 Ωm. The lengths of leachate plumes shown in the inverse models are also similar to the lengths of waste piles in both survey lines indicating vertical movement of leachate into the soil is strictly only in the area of the dumping. The leachate migration is not widely distributed either horizontally or vertically due to the low porosity characteristic of clayey soil below the disposal area as indicated by the soil strata in borehole 1.

A total of 7 resistivity imaging lines were carried out outside of the dumping area. Lines R1 and R2 are located in the palm oil plantation about 20 m towards the eastern part of the landfill. While

survey lines R3, R4, R5, R7 and R13 are located in the northern part of the landfill. The landfill is separated from the surrounding area by a 2 m width and 3 m depth trench purposely made by the landfill authority to avoid leachate migration from the landfill into the palm oil plantation as well as into the river. Inverse models representing all of these resistivity survey lines generally show almost similar pattern of three distinct resistivity zones interpreted as representing the top, middle and bottom of soil layers below the survey profiles. These patterns are clearly indicated in lines R1, R2 and R7 as shown in Fig. 5-7. Generally, inverse model of all lines show top high resistivity thin (1-2 m) layer corresponding to a very dry clay layer located above the water table with resistivity values ranging from 66-200 Ωm. The nearest borehole vertical resistivity curve is also attached beside the model for comparison. Resistivity values representing the top layer from borehole survey BH6 (5-10 Ωm) are much lower compared to the model resistivity values. Resistivity values representing the top layer measured in BH2 (100-150 Ωm) is much comparable in this case. A much thicker layer of about 4-6 m with lower resistivity values ranging from 11-40 Ωm is observed below the top layer from depths of 1-5 m. Based on borehole 6, this layer corresponds to clay and silty clay below the water table at 1 m. This layer might correspond to a water saturated zone with little indication of any contamination from the landfill. Resistivity values from borehole vertical measurement representing this layer is about 5-10 Ωm. The lowest zone observed in these

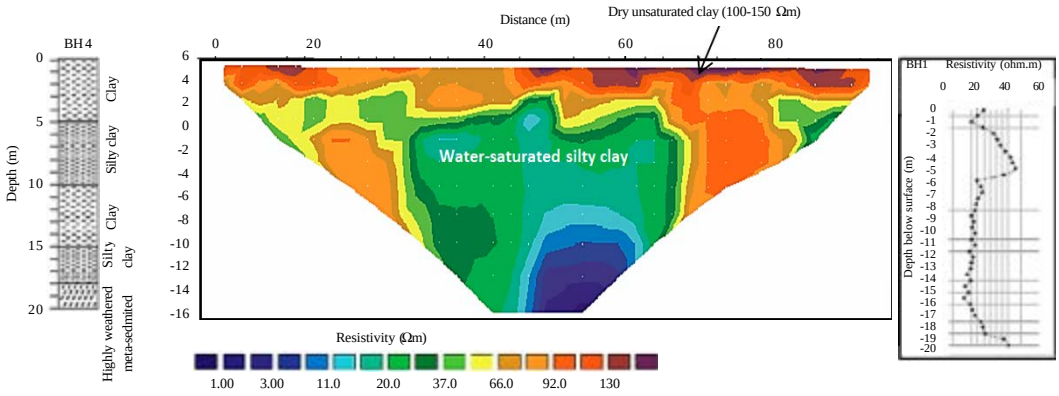

Fig. 5: Inverse model of line R1

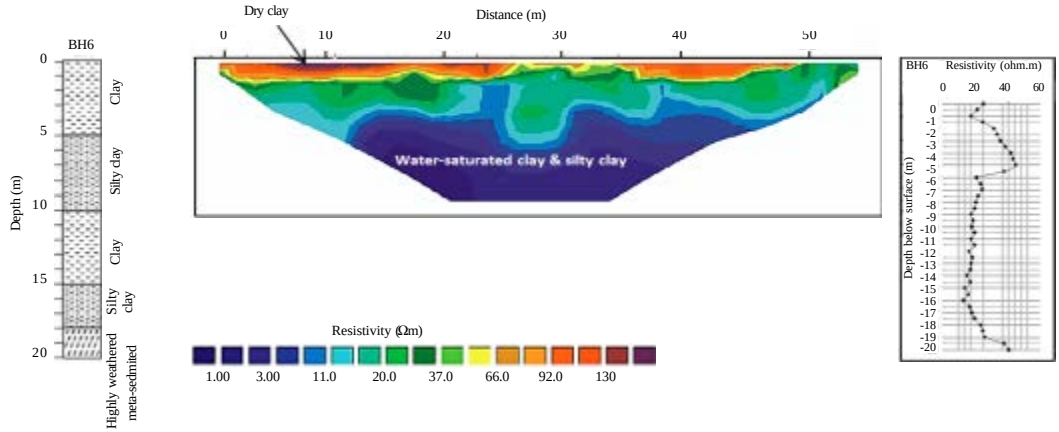

Fig. 6: Inverse model of line R2

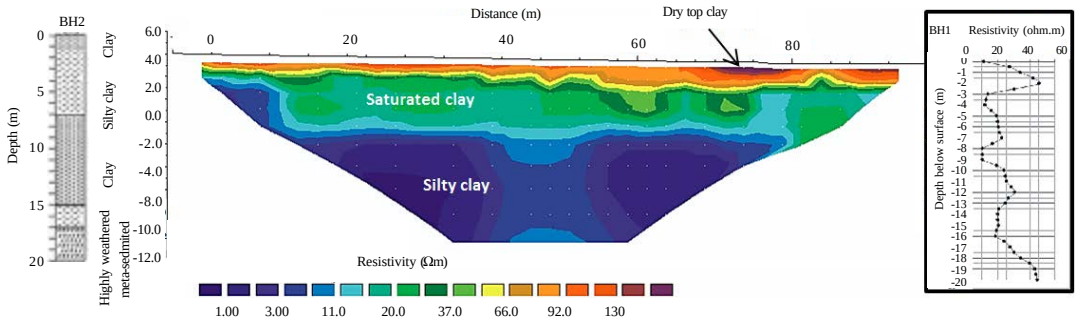

Fig. 7: Inverse model of line R7

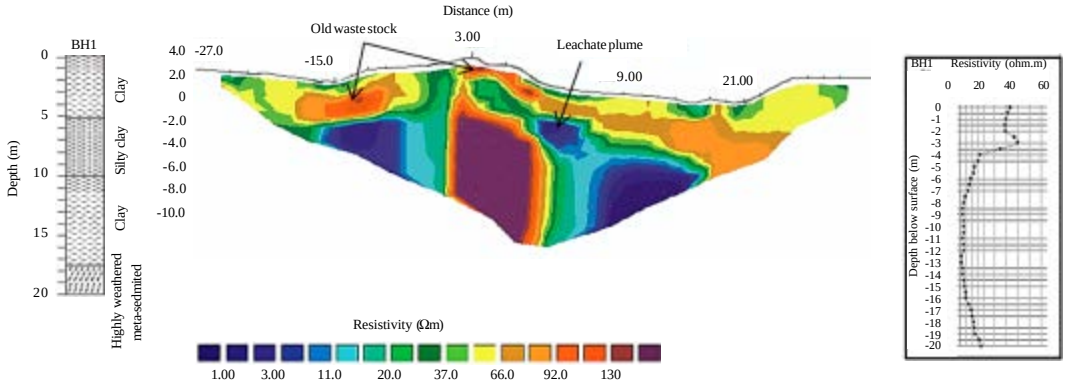

Fig. 8: Inverse model of resistivity line R11

three profiles consists of very low resistivity materials of 1-11 Ωm representing most likely the marine clay. Similar values are obtained from the borehole resistivity data.

Three resistivity lines namely R11, R12 and R15 (Fig. 8-10) were traversed in the southern part of the active landfill. These lines were laid on the abandoned inactive landfill covered by soil and located very near to boreholes 1 and 4. The inverse models show patches of high resistivity zones (100-200 Ωm) which are clearly observed in the top of the models corresponding to old waste materials below the soil covered layer on the surface. Resistivity values measured in boreholes 1 and 4 are much lower (30-40 Ωm) compared to values obtained from resistivity imaging survey. Zones of low resistivity values (1-10 Ωm) interpreted as representing leachate solution in silty clay at depth of about 2 m are observed immediately underlying the much higher old waste. This highly contaminated layer is overlying a much higher resistivity zone (100-200 Ωm) of perhaps uncontaminated clay and silty clay materials at depth of about 5 m as shown in Fig. 8 and 9. The trend of high resistivity value representing top old waste overlying the much lower resistivity of the contaminated zones is basically similar to the trend observed in the vertical resistivity profiles measured in the borehole close to the resistivity survey lines (Fig. 8-10). Even though the trend are

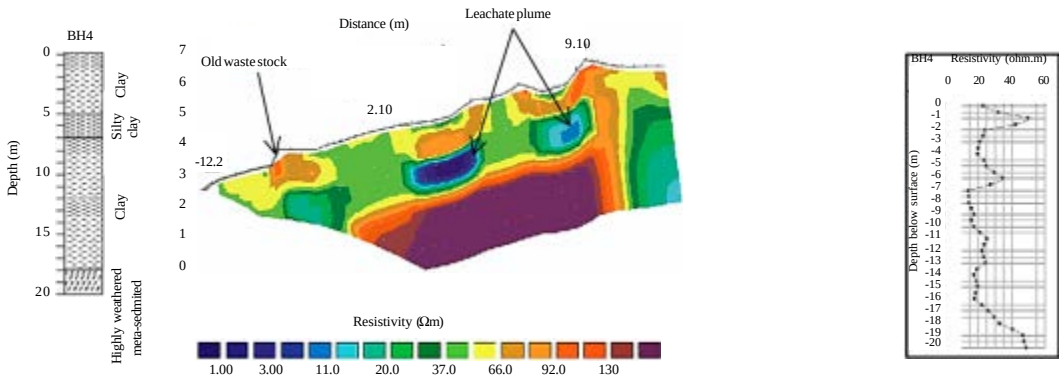

Fig. 9: Inverse model of resistivity line R12

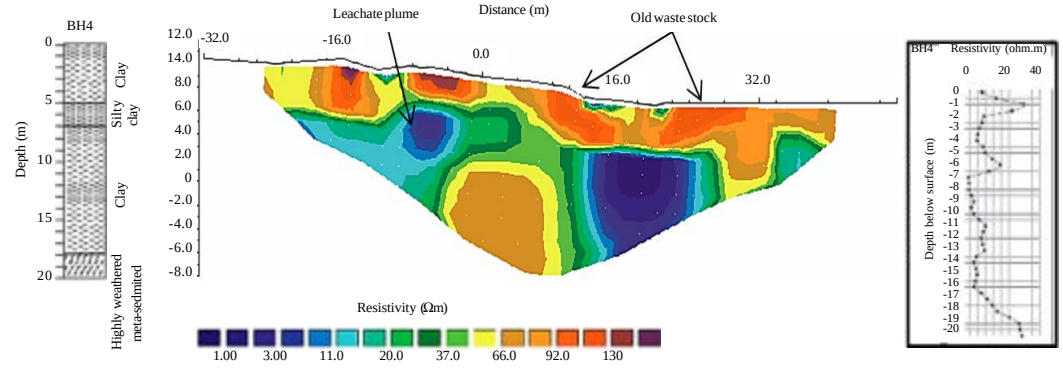

Fig. 10: Inverse model of resistivity line R15

quite similar, the resistivity values measured in boreholes for top waste are much lower (30-40 Ωm) compared to the one obtained by resistivity models (100-200 Ωm). Resistivity values of contaminated zone and clay are quite similar for both types of measurement which is about 1-10 Ωm.

Figure 11-13 show inverse resistivity models for lines R6, R9 and R14 measured just along the western boarder of the active landfill site. These lines are purposely run to capture any possible leachate migration into the soil and groundwater in the western stretch beside the landfill as well as into the river flowing in the north-south direction. Figure 11 shows the inverse model of R6 with no indication of leachate migration from the top layer based on high resistivity values (50-200 Ωm) observed in the top zone. The high resistivity corresponds to top dry clay material above water table. Much lower resistivity values (1-11 Ωm) below the top layer can be interpreted as either due to fresh saturated clay layer or contaminated clay and groundwater. Similar pattern of high and low resistivity values is shown in the vertical resistivity curve of borehole 1 (Fig. 11). A slightly different resistivity distribution pattern is shown in inverse model of line R9, where a possible leachate plume with resistivity values between 1-10 Ωm appeared near the border of the landfill and the plume head is towards the river (Fig. 12). Inverse model of line R14 shows slightly different

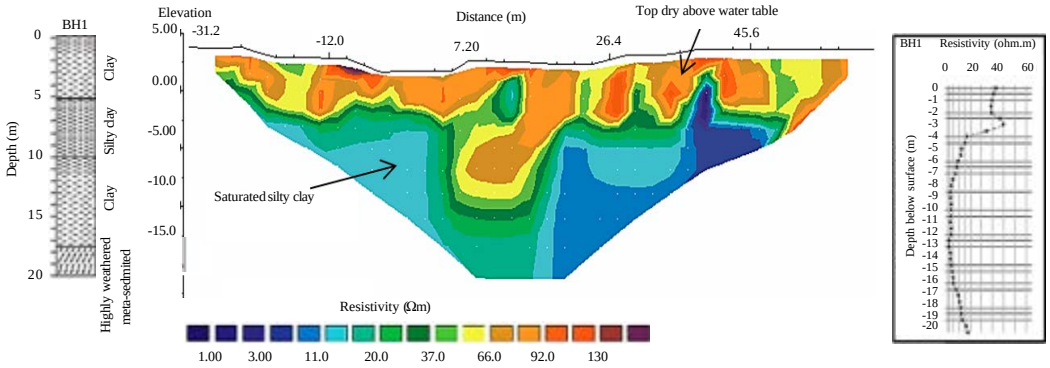

Fig. 11: Inverse model of resistivity line R6

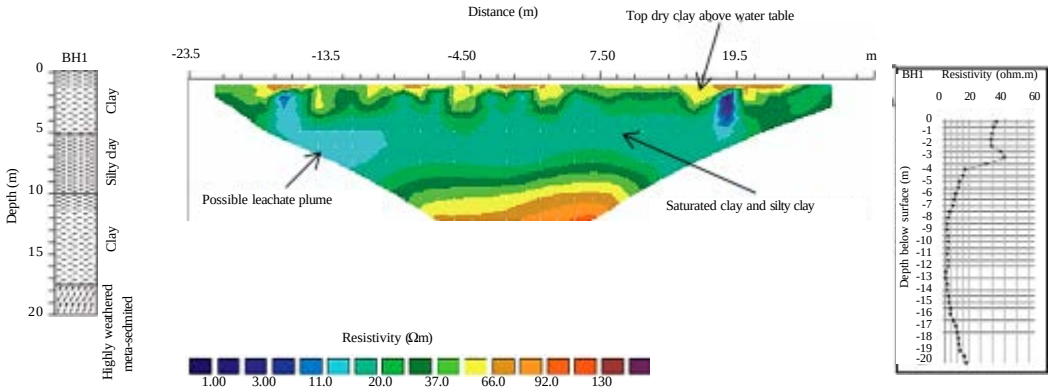

Fig. 12: Inverse model of resistivity line R9

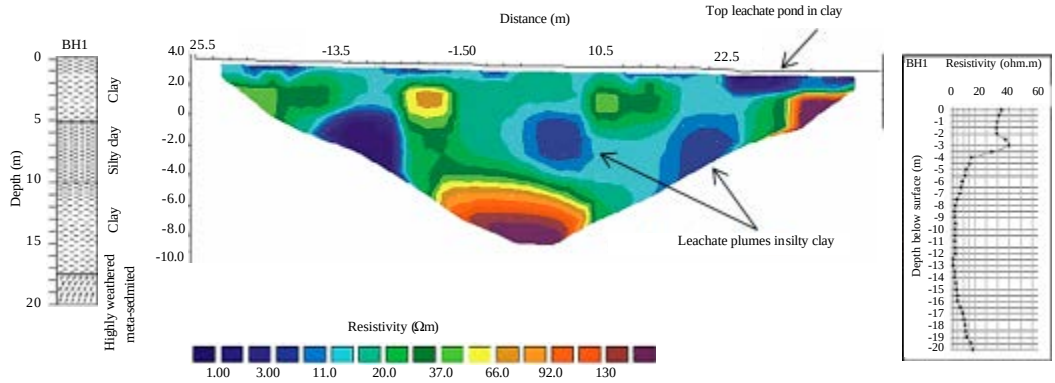

Fig. 13: Inverse model of resistivity line R14

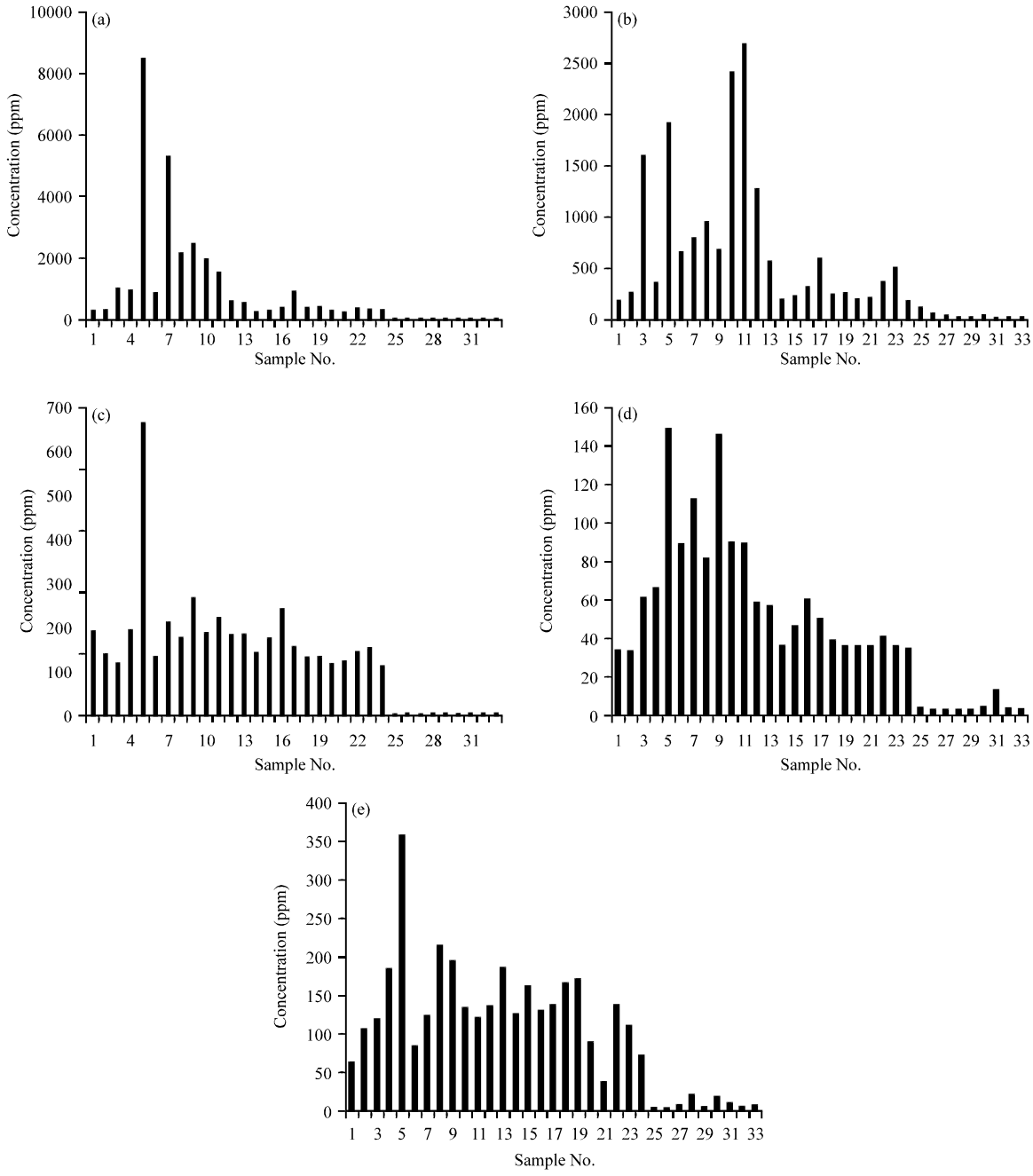

Fig. 14(a-e): Concentration of heavy metals in soil samples, (a) Mn, (b) Zn, (c) Cr, (d) Ni and (e) As

resistivity distribution patterns compared to R6 and R9. In the R14 model, the top layer has very low resistivity values of about 1 Ωm indicating either soft saturated clay of contaminated clay zone. Approximate thickness of this layer is about 4 m which is similar to the top clay layer as reported in borehole 1. Several rounded low resistivity (1 Ωm) features are also shown in the silty clay layer of R14 model (Fig. 13). These features could possibly be leachate-contaminated zones based on its low resistivity and silty material.

Table 1: Concentration of heavy metals in the soil samples

Sample	Zn	Cr	Ni	As	Mn
1	182.05	194.21	34.22	60.96	312.75
2	268.33	140.22	33.26	105.35	374.12
3	1618.74	119.57	61.08	119.18	1025.97
4	347.62	195.11	66.37	184.68	959.84
5	1918.79	666.21	149.88	356.98	8482.14
6	669.65	135.34	89.88	83.94	875.57
7	802.86	211.28	112.64	122.27	5330.56
8	947.68	178.83	81.45	215.37	2203.08
9	694.37	268.13	146.27	195.31	2487.81
10	2419.36	189.40	89.94	132.62	1969.68
11	2697.35	222.80	89.83	121.95	1550.05
12	1274.35	186.02	58.56	134.71	638.77
13	574.42	183.59	57.11	185.49	578.44
14	206.22	142.10	36.16	124.56	276.23
15	232.51	177.50	46.65	160.87	294.18
16	331.52	241.94	60.39	129.75	407.64
17	599.20	157.89	50.21	137.32	937.36
18	245.90	132.10	39.79	165.36	378.49
19	269.09	136.17	36.19	170.98	461.52
20	207.68	118.19	36.75	89.84	325.86
21	216.83	123.54	36.65	37.32	254.80
22	377.16	146.72	41.12	136.61	412.07
23	515.13	155.62	36.25	110.40	359.23
24	189.19	112.21	34.92	70.72	321.49
25	123.46	6.30	3.78	4.45	7.69
26	57.89	7.33	3.11	3.36	6.44
27	47.91	5.51	3.45	6.85	31.19
28	36.97	8.15	3.57	22.11	8.19
29	36.17	8.58	3.72	5.21	7.03
30	46.15	7.86	4.55	20.03	18.13
31	30.94	7.66	13.06	9.73	6.51
32	38.54	6.91	3.85	5.35	25.19
33	34.14	8.94	3.39	7.00	8.39

*Concentrations in ppm

High concentration of heavy metals exceeding the background values was observed in the soil and water samples indicating possible contamination from the disposal site into the surrounding soil and groundwater. Table 1 shows the concentration of 5 types of heavy metals in soil sampled by hand-auger randomly from several localities in the study area. Figure 14 shows the concentrations of Ni, As, Mn, Zn and Cr in soil samples drawn in bar scale. The range of Cr concentration found in samples 1-24 was between 112-666 ppm while the background value of Cr is only about 100 ppm. The highest concentration of Cr which was about 666 ppm was detected in sample number 5. The Cr concentration representing samples 25-33 were only between 6.3-8.9 ppm. These low Cr concentrations were from samples located away from the waste disposal site. High Zn concentrations exceeding 300 ppm were detected in samples 3-13. The highest concentration was 2697 ppm found in sample 11. Very low Zn concentrations between 34-57 ppm were detected in samples 26-33. The same low concentrations of Cr were also detected in these

samples. High concentrations of Ni above 20 ppm of the background value were detected in samples 1 to 24 with values ranging from 33-150 ppm while concentrations of less than 13 ppm were detected in samples 25-33. As for the toxic arsenic, concentrations above the background value (40 ppm) between 60-195 ppm were detected in samples 1-24 while samples 25-33 had concentrations less than 13 ppm. Finally, the results obtained for Mn show similar pattern of concentrations as other heavy metals detected in the soil samples. High anomalous concentrations (578-5330 ppm) above 500 ppm of the background value were detected in samples 3-13. Mn concentrations of less than 500 ppm were detected in samples 14-33. Significant correlations were found between Mn and As ($r = 0.96$), Cd ($r = 0.91$) and Co ($r = 0.99$). Co also shows good correlation with As ($r = 0.94$ and Mn ($r = 0.99$). Acidic soil and leachate infiltration are major contributions to the strong correlation between heavy metals and the Mn-oxides.

Fe content of about 9000 ppm observed in the soil samples was significantly very high compared to its background value of about 3700 ppm. The presence of groundwater converts the Fe into Fe hydroxide. The Na and Ca concentrations in the soils were 497 and 2400 ppm, respectively and relatively lower than their background values indicating no infiltration process from the waste disposal site. Calcium shows good correlation ($p = 0.05$) with Cu ($r = 0.8$). Potassium shows high concentration of about 1733 ppm than its background value and also shows good correlation with Zn and Cd. Magnesium concentration of 643 and 1288 ppm higher than its background value (500 ppm) were observed in the soil samples and it shows good correlation with Fe ($r = 0.95$). Cadmium concentration in soils shows values less than 1 ppm and it has significant correlation with Zn ($R^2 = 0.98$) and As ($R^2 = 0.92$). Precipitations of Zn, As in the soil with Cd are considered as important indicator of leachate migration.

In general, the high concentration of each heavy metal detected in samples within the waste disposal site implies the effect of contamination by leachate migration from the waste disposal site outwards into the surrounding areas and hence can be considered as anthropogenic. The high concentration of heavy metals in the soil samples in and near the waste disposal site is by no means originated from the leachate migration into the surrounding soil. In contrast, the concentrations of heavy metals in soils sampled outside of the dumping area were found very much lower than the background values.

The contamination of As, Mn, Zn and Cr in soil and water samples show a significant correlation with Cd. The heavy metals (As, Mn, Zn, Cr, Cd and Mg) concentration in the surface water are also found higher than their concentration in normal and uncontaminated condition indicating the effect of leachate migration into the river close to the waste disposal site. Concentrations of sulphate, nitrate and ammonia in the water samples are within the background values or significantly low.

Distributions of anions, cations and heavy metals concentrations were also measured in water samples drawn from 6 boreholes in the study areas (Table 2). The concentrations of Na were quite similar to its background value (200 ppm) but the Mg concentrations were slightly higher than its background (150 ppm). Calcium concentrations for boreholes 1, 2 and 6 were slightly lower than its background (7.5 ppm) but boreholes 3, 4 and 5 showed much higher concentrations of about 24-38 ppm. In the case of heavy metals, all samples showed high Cr concentrations above the background value (0.05) ranging from 6-19 ppm. While Mn and Fe concentrations were within the background values of about 0.2 and 1 ppm, respectively. Cu concentrations of about 1.3-7.5 ppm above the background value (1.0 ppm) were detected in all boreholes. Concentrations of Zn (4.8-5.8 ppm) were slightly higher in 5 boreholes (1, 2, 4, 5 and 6) and slightly lower (1.9 ppm) than

Table 2: Concentration of anions, cations and heavy metals in the water samples

Elements	BH1	BH2	BH3	BH4	BH5	BH6
Na	221.40	101.60	117.10	177.50	168.30	221.40
Mg	172.40	257.20	367.60	367.00	376.10	178.30
Ca	5.80	5.60	37.90	23.90	29.60	6.80
Cr	11.30	5.20	16.10	9.40	18.70	6.30
Mn	0.20	0.80	0.20	0.20	0.40	0.20
Fe	1.20	1.20	1.50	1.20	5.10	1.50
Cu	2.00	6.80	7.50	5.20	5.30	1.30
Zn	5.60	4.60	1.90	5.80	6.30	4.80
As	0.02	0.02	0.07	0.06	0.06	0.02
Cd	0.082	0.005	0.03	0.057	0.016	0.033
SO_4	3.76	4.67	3.27	3.83	3.97	4.37
NO_3	19.25	15.36	14.67	22.54	25.67	18.25
Cl	525.30	415.30	387.20	167.80	332.40	100.30
NH_3-N	28.16	31.56	2.89	38.27	41.56	29.67

*Concentrations in ppm

its background value (3 ppm) in borehole 3. Overall concentrations of Arsenic in boreholes (0.02-0.07 ppm) can be considered very close to the background level of 0.01 ppm. Interestingly in the case of Cadmium, concentrations detected from all boreholes water samples exceeded the background concentration of about 0.003 ppm. The Cd concentrations observed ranged from 0.005-0.082 ppm. As for the anions, the sulphate and nitrate were far below their background values while the chloride concentrations for samples from boreholes 1, 2, 3 and 5 exceeded the background values.

The contaminant movement in soil is very much influenced by the chemical properties of the soil. This was concluded by Vertacnik *et al.* (1997) in their analysis of soil samples collected near a disposal site in Croatia. Parameters analyzed were mineral compositions, Cationic Exchange Capacity (CEC), electrical conductivity and the organic content of the soils.

Table 3 shows the results of physico-chemical analysis of soil samples in the study area. The pH values of all samples range from 3.9-6.9. The high acidity of soil will increase the solubility and the mobility of the heavy minerals into the groundwater (Elzahabi and Yong, 2001). From the X-ray analysis results, Kaolinite, montmorillonite and quartz were found in all of the soil samples. Kaolinite and quartz minerals were much more dominant in all samples. Kaolinite is a type of clay with high aluminium silicate content while montmorillonite is a type of clay with high calcium and magnesium silicate. The presence of kaolinite and montmorillonite clays in the soil will influence the cation exchange capacity. High CEC rate is normally due to high clay content of the soil. The CEC and electrical conductivity of the soil samples are related to each other where the highest CEC value observed was 28.32 meq/100 g. The highest electrical conductivity value of about 8793 mS cm^{-1} was also detected from the same sampling area with high clay content. In some samples with low or absence of kaolinite especially montmorillonite, the CEC value observed was as low as 11.2 meq/100g with electrical conductivity of only 5899 mS cm^{-1}. The high acidity and electrical conductivity representing the clay and sandy clay soil could also be inferred as the effect of leachate contamination originated from the dumping site. Donahue *et al.* (1977) stated that the soil becomes acidic when some of the basic cations such as Na, K, Ca and Mg are substituted by H^+ ion and soil with electrical conductivity of higher than 4000 mS cm^{-1} is not suitable for agriculture

Table 3: Physico-chemical analysis of some soil samples

Sample	Sand (%)	Silt (%)	Clay (%)	CEC (meq/100 g)	pH	EC ($\mu S\ cm^{-1}$)
1	25.96	64.05	9.99	2.32	5.94	3750.00
2	32.27	60.08	7.65	2.54	4.63	3200.00
3	30.80	58.33	10.87	2.74	6.60	4110.00
4	30.60	56.75	12.65	1.34	5.18	3530.00
5	31.26	54.32	14.42	1.98	6.75	3970.00
6	32.70	49.65	17.65	1.54	5.51	3220.00
7	30.14	51.23	18.63	2.78	8.12	2860.00
8	32.25	48.43	19.32	2.21	6.79	4760.00
9	32.58	46.54	20.88	2.43	5.03	3490.00
10	34.01	44.34	21.65	2.87	6.88	3270.00
11	34.45	42.65	22.90	2.65	4.20	3600.00
12	35.48	40.52	24.00	2.98	6.56	3200.00
13	45.58	38.08	16.34	2.69	4.52	1970.00
14	42.63	32.74	24.63	2.91	4.64	3060.00
15	40.64	26.85	32.51	2.79	4.26	2920.00
16	39.64	23.34	37.02	2.95	4.33	2790.00
17	37.54	20.69	41.77	3.19	6.15	3160.00
18	36.87	14.42	48.71	3.54	4.60	3450.00
19	36.94	7.48	55.58	3.44	5.24	3380.00
20	23.66	33.88	42.46	3.61	4.58	3760.00
21	36.25	41.13	22.62	3.31	4.79	3890.00
22	37.54	31.75	30.71	3.27	5.61	3720.00
23	41.07	22.49	36.44	3.25	4.37	3910.00
24	42.64	11.28	46.08	2.90	4.54	3730.00
25	45.31	33.92	20.77	2.96	3.96	2900.00
26	27.25	20.68	52.07	2.67	4.07	2740.00
27	38.54	38.16	23.30	2.81	3.91	3140.00
28	28.68	25.21	46.11	2.71	3.97	2680.00
29	24.07	36.12	39.81	2.65	4.70	3410.00
30	25.21	40.50	34.29	3.01	3.87	3350.00
31	23.90	34.45	41.65	2.52	3.91	3040.00
32	21.85	24.34	53.81	2.46	3.85	2960.00
33	20.56	25.32	54.12	2.59	4.99	2570.00

due to high salt cations content. The organic content in soil samples were found ranging from 2.04-2.98% and believed to be contributed by nearby river sedimentation as well as decay of palm trees and tree roots.

CONCLUSION

The 2D resistivity imaging survey and chemical analysis of the soil and water samples from the study area have successfully proved the movement of leachate mainly from the dumping area into the surrounding soil and water. In general, the maximum leachate infiltration was estimated at 4-6 m depth vertically below the waste pile and also within 50 m laterally away from it. Resistivity values ranging from 1-10 Ωm were observed as representing the most contaminated zones in all inverse models of the resistivity imaging survey lines especially obtained near the dumping area. Much higher values of resistivity greater than 100 Ωm were observed from areas away from the dumping spot. The leachate plumes were clearly observed in the resistivity inverse models just

below the waste deposit proved that the 2D resistivity imaging technique is one of the promising techniques for leachate migration pattern analysis. Results of chemical analysis indicating the presence of heavy metals in soils and water near and around the waste disposal further support the evidence of leachate migration into the surrounding soil as observed in the resistivity models.

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