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Integrated Study on the Distribution of Contamination Flow Path at a Waste Disposal Site in Malaysia

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1. Introduction

Generally, the amount of solid waste generation is increasing as the economy and population continue to grow all around the world. The world's total solid waste generation was about 12.7 billion tonnes in 2000, and this is predicted to rise to about 19.0 billion tonnes in 2025 (Yoshizawa et al. 2004). In the case of Malaysia, it is estimated that 17,000 tonnes of solid waste is generated every day, and this will increase to more than 30,000 tonnes per day by 2020 consequent upon the increasing population and per capita waste generation (MHLG, 2003). Recently, the per capita generation of solid waste in Malaysia varies with an average from 0.8 to 1.0 kg/day depending on the economic status of an area (MHLG, 2003). Fauziah and Agamuthu (2006) estimated that the generation rate of solid waste may be increased by 3% per year due to the increase in population and the economic development in the country.

According to Mitsuo et al. (2008), solid waste accumulated in waste disposal sites or landfills can be decomposed by a combination of chemical, physical, and biological processes. Those decomposition processes occur as infiltrative water percolates through the solid waste in the landfill. As a result, various organic and inorganic compounds leach out from the landfill. The products of the complex combination of reactions are potentially transported further by the percolating leachate. Thus landfill leachate contains many constituents including potentially toxic substances, and its quality is heterogeneous. In this case the migration provokes environmental pollution especially in the local subsurface zone and hydrosphere. This phenomenon can be found around open-dump sites.

Most of the waste disposal site in Malaysia can be categorized as open dump sites which are usually without proper liner, treatment facilities and final capping. Until 2008, there are 180 landfills still in operation (Aziz, 2009). Most of these landfills are poorly managed and as a consequence leachate will easily migrated to the surrounding area through soils, subsurface geological strata and finally to the groundwater. The high annual rainfall in Malaysia with an average of 3000mm (Department of Irrigation and Drainage 2000, unpublished) also influenced the generation of leachate at these landfills. This situation will give some impact especially to the soil and groundwater contamination beneath a landfill site and poses a continuing risk to human health and the environment. Liquid contaminants can migrate through the soil matrix and leach into groundwater, while solid and semi-solid pollutants may be transported and dispersed through the subsurface (GETF, 1996).

The problem of groundwater contamination by Waste disposal site is steadily growing worse in Malaysia due to the way of managing municipal solid wastes (Mohd Tadza et al, 1999). Previous studies that were carried out at waste disposal sites in Malaysia (such as Gemencheh and Pulau Burung) indicate that the quality of groundwater decreased due to the leachate movement into the groundwater system (Mohd. Tadza et al., 1999 and Mohd Tadza et al., 2005). High concentration of heavy metals such as lead, copper, nickel, cadmium and zinc can cause serious water pollution and threaten the environment (Aziz et al., 2004a; Ngah et al., 2008). To solve these problems, the contaminants must be removed or treated from the leachate (Kadirvelu et al., 2001).

The waste disposal are well known to release large amounts of organic and inorganic contaminants via leachate. In humid and semi-humid regions, leachate is produced primarily in association with precipitation that infiltrates through the refuse in landfill. Continuation of leachate generation at the landfill site will normally result in the migration of leachate plume into the underlying groundwater zone and pollutes it. A variety of heavy metals are frequently found in landfill leachate including, iron, zinc, copper, cadmium, lead, nickel, chromium and mercury (Ozturk et al., 2003; Aziz et al., 2004). In several instances, heavy metal concentrations in leachate increased by time because they are non-biodegradable and they can be accumulated in living tissues and causing various diseases and disorders (Wan Ngah and Hanafiah, 2008).

Since the refuse has the potential to contaminate the ground water system, there is a need to study the degree of pollution in groundwater and to assess the distribution and flowpath of pollutant species and their impact on water quality. In this chapter, integrated study with various approaches was conducted in order to determine the seriousness of the distribution and flow path of the contaminant to the surrounding area in a selected waste disposal site at Taiping, Perak. Malaysia.

2. Description of the site

The Taiping landfill is located in the state of Perak at 4° 49’N, 100° 41’E, covering an area of 50 acres (Figure 1). Since starting its operation in 1995, roughly about 660,000 metric tons (about 200 metric tons daily) of domestic wastes had been dumped in the area. The topography in the vicinity of the landfill is generally flat and low lying with local elevations at the site ranging from a high of 3.3m above sea level to a low of 1.8m. The climate of the area is classified as typical of Peninsula Malaysia (equatorial) characterized by uniform temperature (daily mean minimum and maximum of 30°C and 34°C respectively) and high humidity (80% - 90%).

This area is one of the wettest areas in Malaysia because of high average annual rainfall (an average of 4000mm). Larut River and its tributary Batu Tegoh River border the landfill site on the south and east respectively. The North-South Highway is just west of the site while at the north of the site is another pond and oil palm estate. The site is in a rural area, and has sparse vegetation and poor fauna. Geologically, the site is located in an area where the formation is of the Quaternary period consisting of mainly recent alluvium. The soil investigation carried out by a consultant in 1993 at the site showed that the soil consists of silty sand with tracers of gravel over a layer of sandy silty clay.

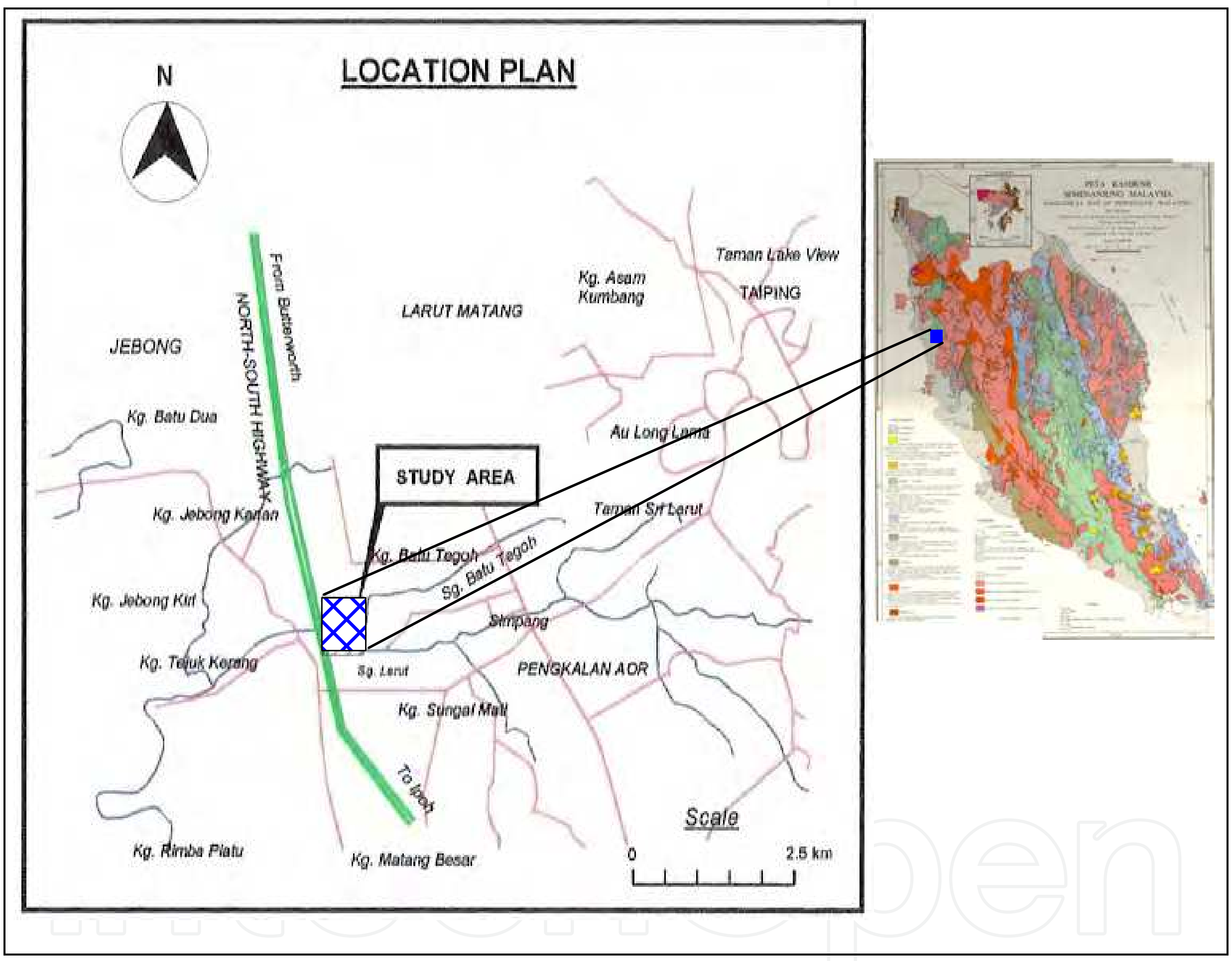


Fig. 1. Map of study area at Taiping waste disposal site.

3. Material and method

This chapter deals with field survey, sampling and laboratory test. Field survey involves geophysical investigation and groundwater flow study. In this study, electrical resistivity imaging (ERI) and colloidal boroscope system (CBS) were carried out to detect the flow path of leachate plume to the groundwater contamination at a waste disposal site. In addition, groundwater was sampled at every existing borehole within the study area in order to understand the scenario of the leachate plume distribution. The groundwater samples were analyse for their heavy metals content in the laboratory by using Inductively Couple Plasma Spectrometer (ICP-MS, model, Perkin – Elmer Optima 3000). Surfer software was used to plot the contours of heavy metals concentrations within the study area. These findings will help Local Authorities to take some immediate action to improve the existing landfill site for instances improving the leachate treatment facility and upgrading the infrastructure inside the landfill site.

3.1 Electrical resistivity imaging

Groundwater contamination investigation at the study site begin with minimally intrusive technique, called initial field screening technique. This technique is less expensive than the more intrusive techniques such as soil borings, test pits, and well monitoring. One of the principal categories of initial field screening techniques is shallow or surface geophysical survey, which include electrical resistivity imaging (ERI) technique. Knowing the depth of interest and data density necessitate, the configuration setting should be highly sensitive to ground conditions.

Shallow geophysical investigation can be considered as effective and reliable approach for characterize landfill sites. Recently developed geophysical hardware and software tools provide the opportunity to image the vertical structure of a landfill and its geologic setting. Electrical methods with multiple arrays have been widely used to detect spread of contamination, conductive media and groundwater contamination monitoring (Mota et al. 2004; Rosqvist et al. 2003; Buselli and Kanglin Lu 2001; Buselli et al.,1999). This methods also used to identify the limits and thickness of the dumpsite, delineated the base of a landfill and mapping the geometries of the host sediments (Cardarelli and Bernabini 1997; De Iaco et al. 2003; Gilles 2006).

ERI utilizes the injection of electrical current directly into the ground through current electrodes. The resulting voltage potential difference is measured between a pair of potential electrodes. The current and the potential electrodes are generally arranged in a linear pattern (**Figure 2**). The apparent resistivity is the bulk average resistivity of all soils and rock influencing the flow of current. It is calculated by dividing the measured potential difference by the input current, and multiplying by a geometric factor. The geometric correction is based on the arrangement of the current electrode or transmitter and the potential electrode or receiver in relation to each other.

The RES2DINV.EXE software is used to process the measured data involving inversion and to determine a 2-D resistivity model (Loke and Barker 1996). The Wenner-L and Wenner-S arrays were chosen due to it highly sensitivity to vertical-horizontal changes and the combination has a good vertical resolution to image the contaminated groundwater boundaries. The ERI survey at this site was carried out using ABEM Terrameter SAS4000 connected to LUND electrode selector 464 system (ES464) (ABEM 1998a, 1998b).

In practice, a line of multiple electrodes is deployed across the land surface. Electrodes are sequentially activated as either current or potential electrodes, and apparent resitivities are determined for numerous overlapping electrode configurations. The Wenner array was chosen in this study for several reasons. It is a robust array in the presence of measurement noise. It is well suited to resolving horizontal structures because it is more sensitive to vertical changes in resistivity than to horizontal changes in resistivity (Loke 2003).

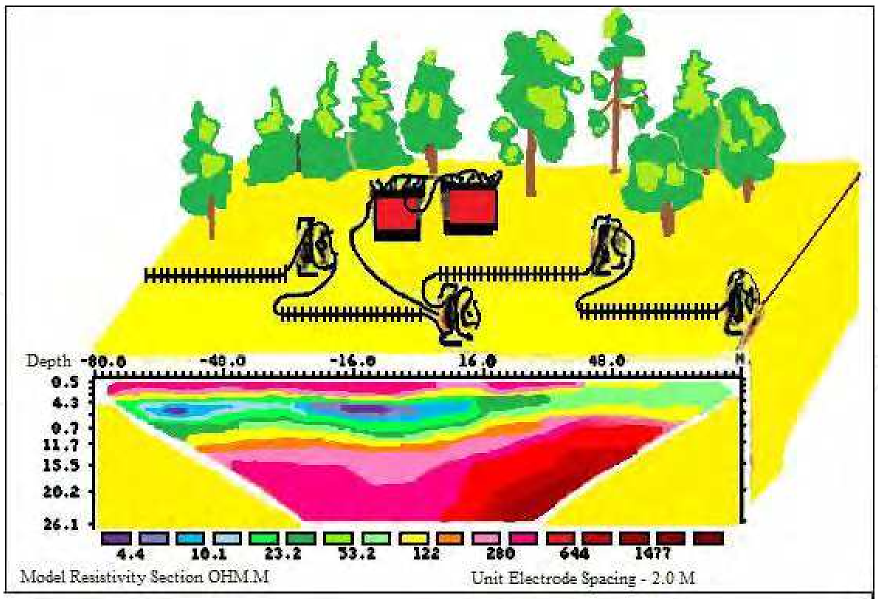


Fig. 2. The general setup and the resulting image processed by 2D inversion

3.2 Colloidal Borescope System (CBS)

The colloidal boroscope consists of two CCD (Charged-couple Device) cameras, a digital compass, an optical magnification lens, an illumination source and stainless steel housing. The device is approximately 89 cm long and has a diameter 44mm, thus facilitating insertion into a 50 mm diameter monitoring well. Data from the colloidal borescope is transferred to the camera control unit (CCU) at the surface by high strength electrical cable. The camera housing and light head are made of stainless steel, and are sealed for underwater used to 100 meter depths (**Figure 3)**.

In this study, single well method was used to determine the groundwater velocity and flow direction. The colloidal borescope was inserted into the well at certain depth to monitor the movement of suspended particles. Upon insertion into a well, an electronic image magnified 140x was transmitted to the surface, where it was viewed by one of the CCD cameras in order to align the borescope in the well. As particles pass beneath the lens, the back lighting source illuminated the particles similar to a conventional microscope with lighted stage. A video frame grabber digitised individual video frames at intervals selected by the operator. AquaLITE Software package developed by Ridge National Laboratory compared the two digitized video frames, matched particles from the two images and assign pixel addresses to the particles. Using this information, the software programs computed and record the average particle size, number of particles, speed and direction.

When the colloidal borescope is inserted into a monitoring well, it directly measures the movement of colloids. With the insertion, the flow would initially swirl and manifest as multidirectional. If the borescope were moved after being placed into the well, swirling flow would continue. Consequently, it is necessary to secure the instrument cable on the surface to prevent movement of the borescope. Generally, after 20−30 min, laminar horizontal flow would dominate, and this could be observed in wells for certain periods of time. By plotting the trajectory and speed of colloidal particles across the screen with AquaLITE, the relative flow direction was determined .

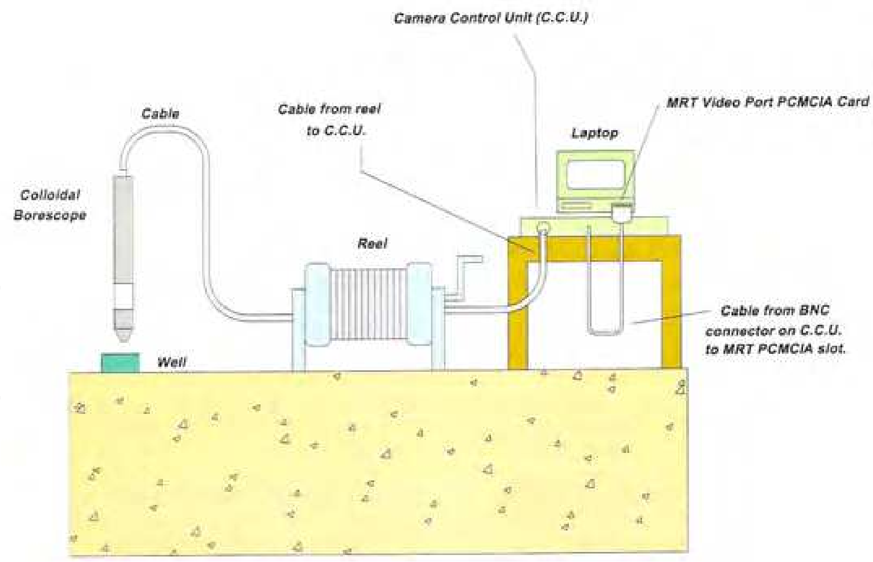


Fig. 3. Schematic diagram of Colloidal Borescope System

3.3 Hydro geochemical

Water sampling programme was conducted purposely to investigate the dispersion and flowpath of the pollutant species. A network of about twenty (20) observation points had been identified and collected for water samples that comprising of twelve (12) groundwater samples, three (3) river water samples, three (3) ex-mining pond and two (2) small streams.

Groundwater in all boreholes was sampled by using portable engine pump (Model Tanaka TCP 25B, maximum capacity: 110litres/min, maximum suction head: 8m and maximum delivery head: 40 m). Boreholes were pumped at least three well volumes before sampling to remove stagnant water in the borehole casing. Water samples for heavy metals analysis were collected in 1 liter High Density Polyethylene (HDPE) bottles which preserved with approximately 8 ml of 65% of nitric acid until the pH is < 2(Appelo and Postma , 1996). This process need to be follow in order to prevent the posibility of heavy metals pricipitated. The water samples were sent to a laboratory and analysed using the Perkin-Elmer Inductively Coupled Plasma Mass Spectrometry (ICP-MS) Model (Perkin Elmer Model ELAN 6000).

4. Results and discussion

In general this project had demonstrated the use of integrated techniques in assessing the distribution of contamination flow path at selected waste disposal site in Malaysia. This integrated study need to be conducted in order to get more conclusive results.

4.1 Electrical resistivity imaging

The electrodes spacing for ERI survey was set at 5m apart with the length of 200m, 300m and 400m. Such an arrangement would provide resistivity layer output of the subsurface geological information up to approximately 30m and 65m below ground surface respectively. In the study, a total of five 2-D resistivity survey lines were carried out in the survey (SL-1 – SL-5) in order to get data covering the dumping site and its surrounding area (**Figure 4**). For the comparison purposes, one survey line (SL 5) was conducted on the refuse itself (inside the waste disposal – contaminated area). Four survey lines (SL 1, SL2, SL 3 and

SL 4) were located at the outside the dumping site and one of the them was running parallel to the river at the south of the waste disposal site.

Figures 5 show the results of SL 5 which was laid inside the waste disposal show the possible occurrence of leacheate contamination near the surface down to 15 meters depth. This is due to the presence of low resistivity layer (< 10 ohm-m) blue in colour at the depth of about 5-15 meters. This finding is similar to Aaltonen and Olofsson's (2002) study showing that leacheate from the waste disposal has a low resistivity (about 1 ohm). The resistivity values (green colour 10-100 µm) normally indicate the existence of fresh water or sandy layer, while the highest resistivity values of (red color >100 Ohm.m) due to the backfill material as suggested by (Loke and Barker, 1996).

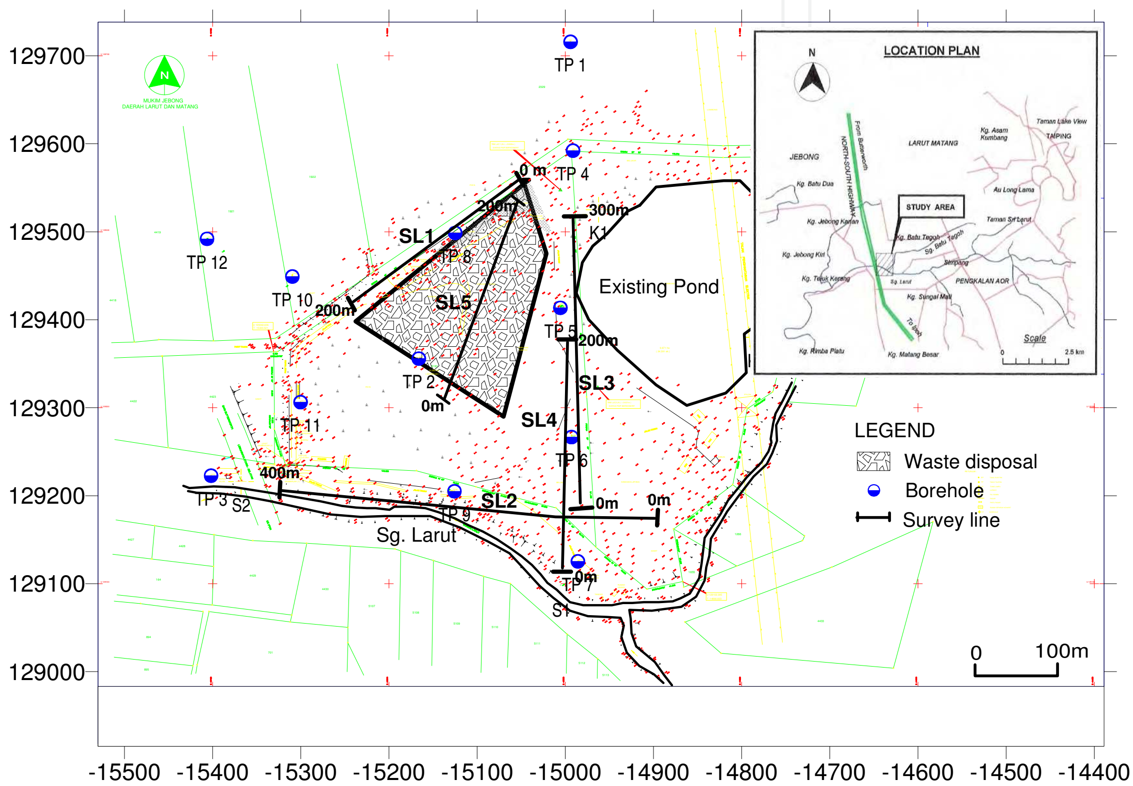
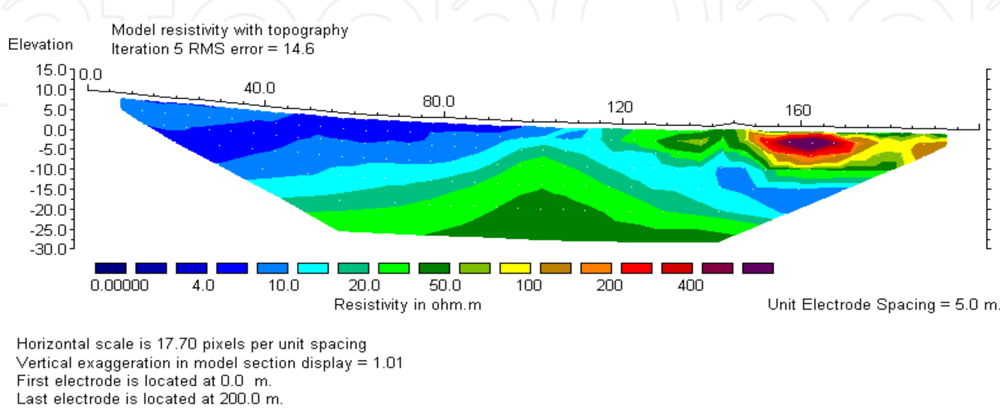


Fig. 4. Location of ERI survey line at the waste disposal site



SL-5

Fig. 5. Profile of ERI survey line inside the waste disposal area

Similar low resistivity values of <10ohm-m can be seen more prominent distributed at SL3 and SL4 which were laid near the waste disposal site (**Figure 6**). This is indicated that the flow path of the leachate is moving towards to the southeast of the waste disposal site and can be infiltrated up to 30 meters depth. Meanwhile, the resistivity profile at SL1 is seen not much effected by the leachate plume. As stated earlier, SL2 was located outside the waste disposal boundary and parralel to the river. The results show that the resistivity values mostly indicate the existence of fresh water.

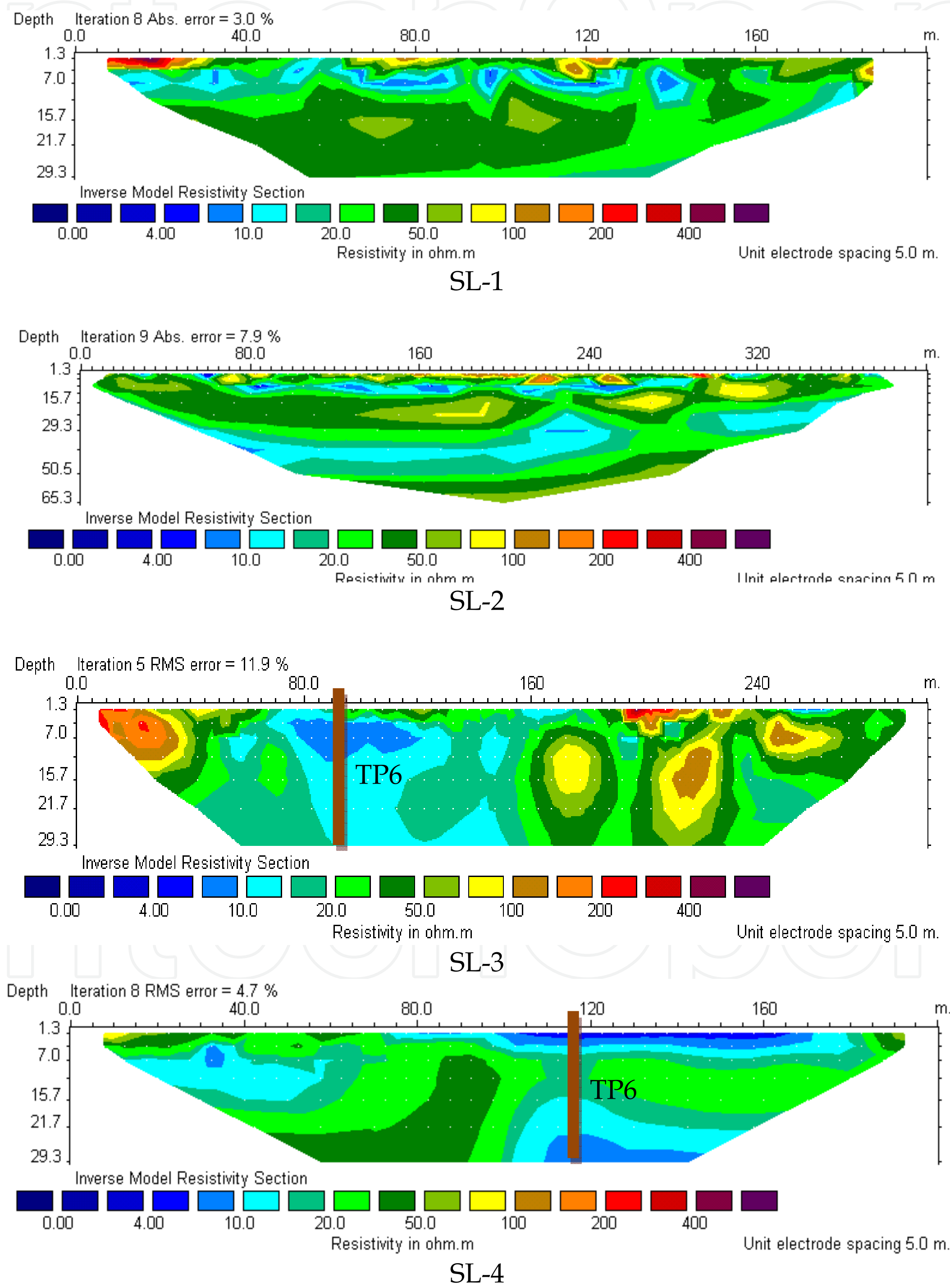


Fig. 6. Profile of ERI survey lines at the sorrounding of waste disposal area

As a summary, this study demonstrates that the electrical resistivity imaging (ERI) is viable tool for mapping groundwater contamination because electrical conductivity is directly related to the dissolved solute content in water. However, this data should be confirmed by groundwater movement and groundwater quality analysis within a particular hydrogeological strata by installing monitoring well.

4.2 Groundwater flow direction and velocity

The colloidal borescope system (CBS) was used at several boreholes at waste disposal site, Taiping, Perak. The purpose of this experiment was to determine groundwater flow pattern within the study area. Determining groundwater flow pattern was very important to obtain information on the migration and dispersion of pollutant materials seeping into the groundwater system. **Table 1** is a summary of the field results of groundwater flow velocity in the boreholes, as measured by the CBS. Based on results, the average of groundwater flow velocities is in the range of 1.09–3.86 x 10^{-4} m/sec. The various values of groundwater flow velocities were due to the difference of soil strata.

Figure 7 shows the regional and localized groundwater flow direction within the study area. Regional groundwater flow direction was obtained by using the conventional hydrological approach (i.e., by plotting the contour of groundwater table above mean sea level). From the plot, regional groundwater flow directions were quite scattered. For more detail, localized flow direction was obtained from colloidal borescope data. At the north of the study area the local groundwater flow is moving to the southeast and similar pattern can be seen at the center part of the study area. Whilst, at the south of the waste disposal site, which is bounded to the Sungai Larut, the local groundwater flow moved towards to the west and formed a localized groundwater, parallel to the river. Overall the localized flow directions dominantly flowed towards to southeast of the study site. These results can be correlated with the resistivity profile within the study site.

Boreholes	**Velocity (m/sec)**
TP1	3.86 x 10^{-4}
TP2	3.80 x 10^{-4}
TP3	2.74 x 10^{-4}
TP4	2.53 x 10^{-4}
TP5	1.09 x 10^{-4}
TP6	1.20 x 10^{-4}
TP7	1.89 x 10^{-4}
TP8	1.27 x 10^{-4}
TP9	1.28 x 10^{-4}
TP10	1.22 x 10^{-4}
TP11	1.09 x 10^{-4}
TP12	2.98 x 10^{-4}

Table 1. Data of groundwater flow velocity at the study area

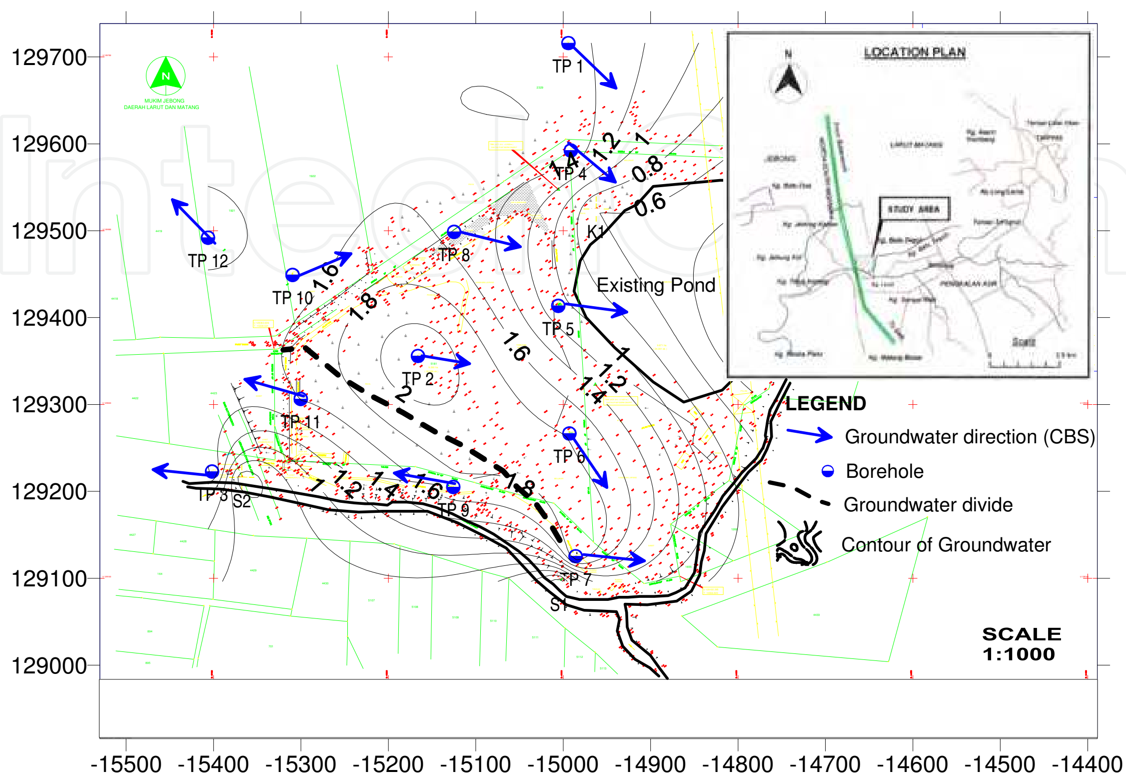


Fig. 7. Localize direction of groundwater movement within the study area

4.3 Flow path of pollutant species in groundwater

The average concentration of the pollutant species such as heavy metals in the groundwater system from several boreholes within the study area was obtained. A number of inorganic constituents detected in the examined samples indicated a small but significant presence of toxic materials. These data play an important role in the determination and visualization of the locations which are affected by the leachate plume. Hence, these results can help the local authorities to take action for remediation.

In this study, groundwater samples were analysed their heavy metals such as Pb, Cu, Fe and Cd. The concentration of pollutant species was plotted using the surfer software. **Figure 8-11** illustrate the flow path of pollutant species (i.e., Pb, Cu, Fe and Cd) in groundwater at the study area respectively. Based on the contouring diagram, the pollutants species seem to be accumulated within borehole TP6 that is located at the southeast of the waste disposal site. In other words, the pollutant species have a tendency to migrate and disperse toward the southeast of the waste disposal site, where the concentrations of pollutants species at this boreholes (TP6) is relatively high compared with other boreholes.

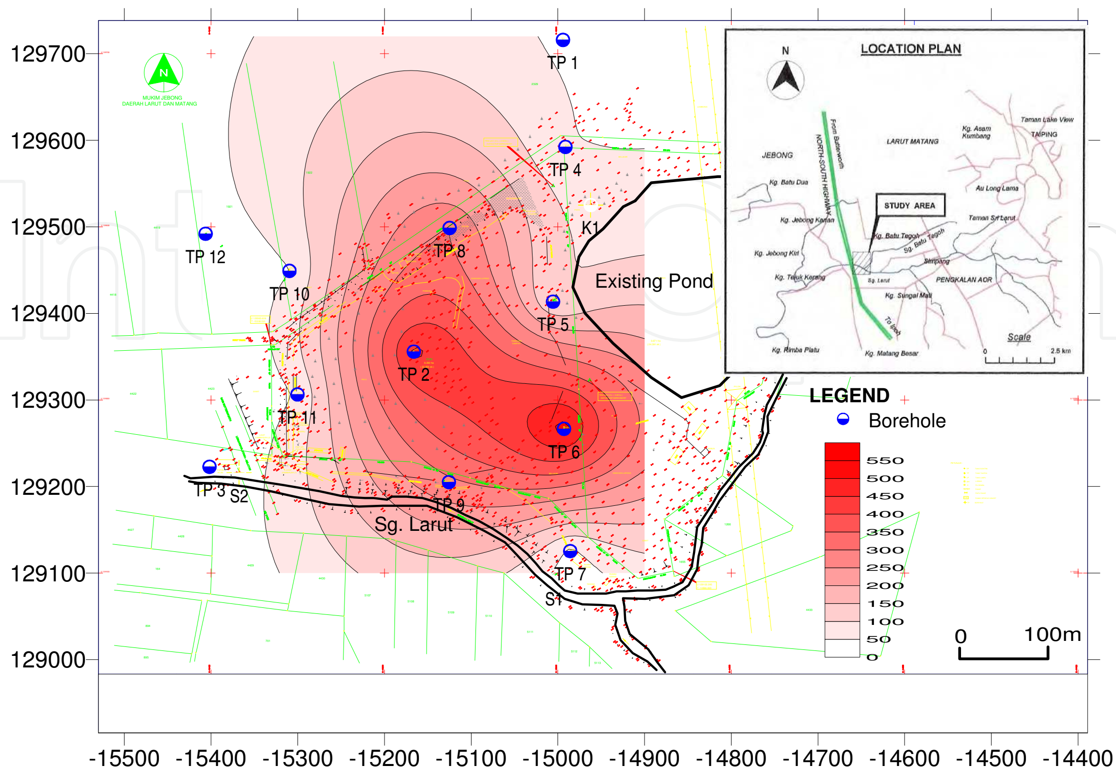


Fig. 8. Distribution of lead (Pb) at the study area

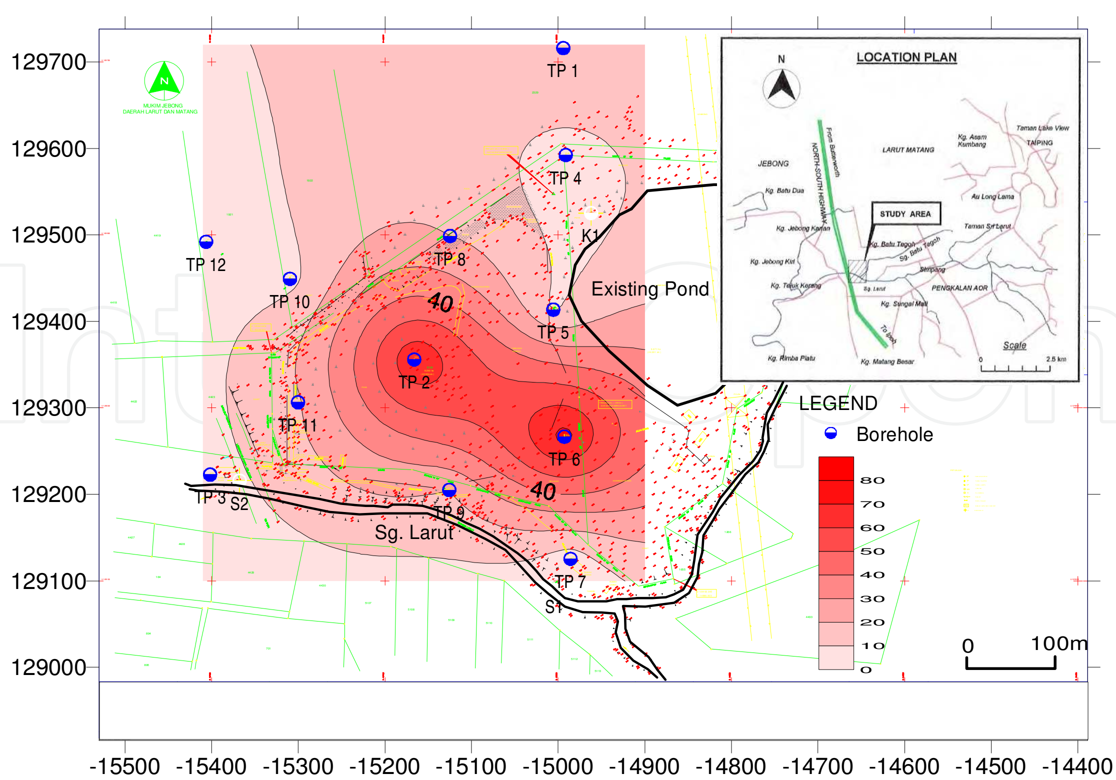


Fig. 9. Distribution of Copper (Cu) at the study area

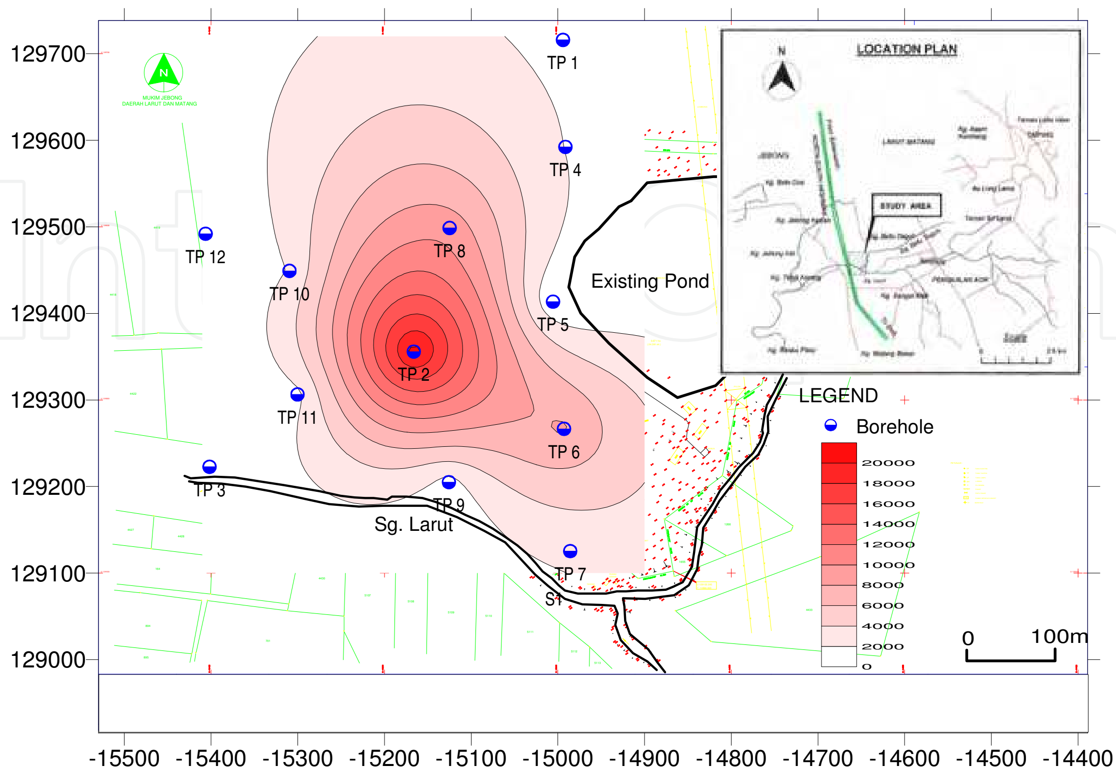


Fig. 10. Distribution of Iron (Fe) at the study area

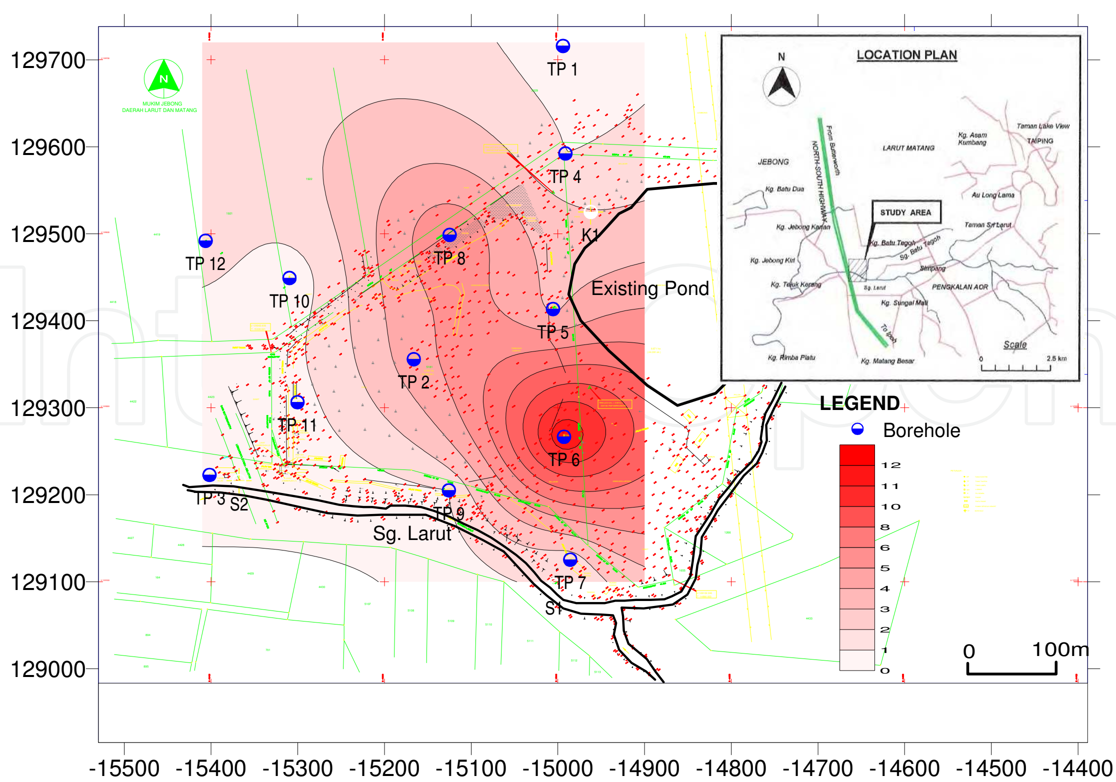


Fig. 11. Distribution of cadmium (Cd) at the study area

However, the distributions of contaminants were localized and confined within the dumping area and not diffuse over a large area. In addition, as previously mentioned that the groundwater flow direction measured by the colloidal borescope was dominantly towards southeast of the study area.

5. Conclusion

Leachate contamination at the Taiping waste disposal can be visually detected through ERI technique. In general, the contours of resistivity results show the existence of inhomogeneous strata in the area. It is quite clear that low resistivity anomalies exist at certain location in this study area is due to leachate plume movement. The result of the study confirms that the occurrence of groundwater contamination can be detected up to 30 m in-depth. The ERI technique had successfully delineated pollution layers. Thus, this method is an effective tool in detecting contaminated groundwater zones or layers in the study area.

With support from the colloidal borescope data, the movement direction of leachate plume can be determined. Generally, the flow pattern of the pollutant species dominantly towards to the southeast of the study area that is follow the flow direction of groundwater with flow velocity ranges between 1.09-3.86 x 10^{-4} m/sec and it seems there is a possibility that the contaminant plume move slowly towards the Larut River.

Based on the geochemical analysis, higher anomaly pollutant species were detected at TP6 which is located at the southeast of the study area, indicates that the contaminant dominantly migrated through this borehole. However, the migration of leachate plume in the study area is still localized and not disperses in a wide area. This correlates well with low resistivity zone (<10 ohm-m) from the ERI images as shown in Figure 6.

Through this finding, it can assisst the Ministry of Housing and Local Government to formulate strategic and actions planning for improving the management and protection of water resources for long-term growth and sustainability. This can be done by;

i. Providing certain budget to Local Authorities to take some immediate action to improve the existing waste disposal site among others for instances improving the leachate treatment facility and upgrading the infrastructure inside the Waste disposal site. The improvement of the waste disposal at least up to level III of sanitary waste disposal system.
ii. Introducing solid waste management system that associated with the control of generation, storage, collection, transfer and transport, processing and finally disposing of solid wastes in a manner that is accordance with the best principles of public health, economics, engineering, conservation, aesthetics and environmental consideration.

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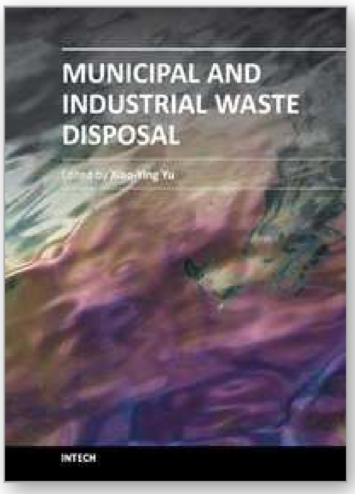

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This book reports research findings on several interesting topics in waste disposal including geophysical methods in site studies, municipal solid waste disposal site investigation, integrated study of contamination flow path at a waste disposal site, nuclear waste disposal, case studies of disposal of municipal wastes in different environments and locations, and emissions related to waste disposal.