EVALUATION OF REHABILITATION AND MINING POTENTIAL OF A MUNICIPAL SOLID WASTE DUMPSITE

by

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Abstract

This study aimed to evaluate the rehabilitation and mining potential of waste from Nonthaburi dumpsite in Thailand. The influence of heavy metal contamination was explored by conducting sequential extraction analysis and toxic characteristic leaching potential (TCLP) test on waste samples collected from dumpsite. The quality of leachate, groundwater and surface water resources in the surrounding area of dumpsite were determined. The potential toxic effect of leachate to the plant species was evaluated by seed germination and root elongation toxicity test on rice plant (*Oryza sativa* L) that was sensitive dominant species surrounding this study area. The excavated waste was subjected to separation process by using trommel screen with open size of 25mm and 50mm. The waste size fractions obtained were distributed as three different sizes such as < 25mm, 25-50mm and >50mm. The physical and chemical characteristics of the each waste fraction were determined to evaluate the recycling potential of mined waste from the dumpsite.

The results for heavy metal concentration and sequential extraction analysis, showed high concentration and high leaching potential of Zn, Cu and Mn compared to other metals in the waste. Although the concentration of all the metal in the extracted leachate in TCLP test were below the National effluent quality standards, the possible leaching rate of Mn and Zn were high in acidic condition.

The leachate quality analysis showed heterogeneity of solid waste age and the methanogenic condition of dumpsite. The basic pH value leachate illustrates the sufficient acid buffer capacity of the dumpsite to neutralize the organic acid generated from the anaerobic degradation of organic matter. Thus, the leaching of heavy metals from the dumpsite is attributed for the affinity of reducible heavy metal to be released in the reducing condition and formation of heavy metal complex with the dissolved organic compound generated from the organic matter degradation.

The leachate quality in dumpsite was found to be lower than the effluent quality standard especially for BOD, COD, TKN, Cr and Cu. The surface water was found to have high contamination of leachate from dumpsite with the concentration of BOD, ammonia, Mn, Cr and Ni content above the quality standards of surface water and drinking water. In the case of ground water, the concentration of Mn, Pb and Ni was above the acceptable standard limit. Though the heavy meal concentration in the runoff leachate except for Cr were below the National effluent standards, the effect of these metals in any concentration proved to be toxic from the seed germination and root elongation toxicity test on rice (*Oryza sativa* L).

For mining potential of waste, the major component of excavated waste analyzed was of 41% plastics and 31% fine particle. The screened waste of size >50mm except for high Cu and Zn concentration, this waste fraction possessed high calorific value making it suitable for RDF production. The waste fraction of size <25mm was found suitable for composting whereas the non-recyclable waste fraction 25-50mm size need to be landfilled.

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List of Abbreviations

ADP	Adenosine diphosphate
ANOVA	Analysis of variance
ATP	Adenosine triphosphate
BOD	Biochemical oxygen demand
CEC	Cation exchange capacity
Cf^i	Contamination factor
Cf	Global contamination factor
C_L	Heavy metal concentration of extracted leachate
C_s	Heavy metal concentration of solid waste
COD	Chemical oxygen demand
DTPA	Diethylenetriamine penta-acetic acid
EC	Electrical conductivity
EC_{50}	Median effective concentration
EDTA	Ethylenediamine tetra-acetic acid
Eh	Oxidation-reduction potential
GI	Germination index
Hp	Horse power
HR	Heavy metal leaching rate
ICP	Inductively couple plasma
IC_{50}	Median inhibiting concentration
MSW	Municipal solid waste
ND	Non detectable
NH4-N	Ammonium nitrogen
NO3-N	Nitrate nitrogen
OECD	Organization for Economic Cooperation and Development
OM	Organic matter
pH n	Initial pH value of leachate
RDF	Refuse derived fuel
RRG	Relative root growth
RSG	Relative seed germination rate
rpm	Round per minute
S_w	Solid waste sample size
TCLP	Toxic characteristic leaching procedure

TDS	Total dissolved solid
TIE	Toxic identification evaluation
TKN	Total kjeldhal nitrogen
TOC	Total organic carbon
TP	Total phosphorus
TSK	Trimmed Spearman-Karber (TSK)
TVA	Total volatile fatty acid
VS	Volatile solid
VFA	Volatile fatty acid
WHO	World Health Organization

Chapter 1

Introduction

1.3 Background of the study

Municipal solid waste management is one of the major environmental problems in many countries. Increase in population and economic activities are important factors that influence the increase in solid waste generation and solid waste composition. In Thailand, solid waste generation rate is approximately 0.5-1.0 kg/ cap/ day. In 2005, the solid waste generation in Thailand is estimated at 14.3 million tons coming from rural areas (47%), municipality (32%) and Bangkok metropolitan (21%) (Thailand Environmental Monitoring, 2003). The generated solid waste is composed mostly of food waste, plastic and paper. Thus, the government should provide adequate waste management facilities to reduce the negative environmental impacts from solid wastes.

Heavy metals such as Cd, Cr, Cu, Mn, Zn. Pb and Ni present in the municipal solid waste are considered an important source of toxic metal contamination in the environment. Moreover, discarding of household hazardous waste such as dry cell battery, paint, and electrical waste (Tchobanoglous et al., 1993; Slack et al., 2005) into the domestic waste increases the concentration of metals in the waste stream. This practice complicates the problem in municipal solid waste management.

In developing countries, land disposal is the prevalent type of municipal solid waste management. On the contrary, open dumping is commonly practiced in most of the Asian countries owing to limited budget, limited technology and knowledge. Approximately 60% of waste in Thailand is disposed into the open dump sites and the remaining fraction is treated in the sanitary landfill, compost, and incineration among others (Visvanathan and Tränkler, 2004). For open dumping, the solid waste is disposed without soil covering. Suitable leachate and gas management systems are non existent. The open dumping results to leachate contamination of surface water and groundwater resources. Currently, environmental and human health impacts of solid waste disposal are increasing hence increases the problem in solid waste management such as lack of proper land disposal site.

Nonthaburi dumpsite is one of the largest sites in Thailand. It is located in Sai Noi District, Nonthaburi Province, Thailand having a total area of about 108,800 m^2. At present, it receives approximately 750 tons/day of MSW from Nonthaburi province and its neighboring municipalities. There are no leachate and gas collection systems beneath the dumpsite. The runoff leachate of dumpsite is normally collected through an open pipe system and treated in the stabilization pond situated near the site. The dumpsite is surrounded by paddy fields which are of high economic importance to the people.

There are many related studies on heavy metals mobility from a landfill and its impact to the environment (Baccini et al., 1987; Belevi and Baccini, 1989; Øygard et al., 2004). Under the covered landfill, most of the heavy metals present in the solid waste are still intact. The ion exchange, precipitation with carbonate and sulfide, absorption on Mn/Fe oxide and solid organic matter as well as insolubility property of solid waste itself can immobilize the heavy metals within the landfill. The small amount of metal leaching from landfill is generally regarded as leachate and gas emission (Baccini et al., 1987). However, this may be different from the dumpsite where the expected oxygen diffusion rate into the solid waste is relatively high. The high oxygen diffusion in the dumpsite may be the cause of oxidation-reduction potential increasing in the dumpsite that will enhance the organic matter degradation and remobilization of heavy metals in the dumpsite (Mårtensson et al., 1999). The heterogeneity of environmental condition is observed in landfills that might affect the leaching of the metals. The optimal moisture content and organic matter concentration of waste can maintain the anaerobic condition at the deeper landfill layer. The accumulation of heavy metal in the deeper layer of landfill is observable (Ösman et al., 2006). Hence, determination of the solid waste characteristics and heavy metal mobility in the dumpsite is useful in assessing the risk of heavy metal contamination in the environment.

The leachate contamination can cause ecological toxic effect in the surrounding area. Paddy fields surround the dumpsite, thus rice (*Oryza sativa* L.) is considered to be the most important species in the area. The germination of the plant species is sensitive to the toxicity of heavy metals and organic compounds (Wang, 1991; OECD, 2003). Application of rice in the toxicity test is therefore necessary to describe the potential environmental impact of toxic compounds specific to the dumpsite. A variety of toxicants in the leachate such as organic matter, heavy metals and nitrogen influences the toxicity level. Determination of the contribution of heavy metals to the leachate toxicity level is necessary in understanding the environmental toxic impact of heavy metal leaching from the dumpsite. Also, it is important to investigate the toxic pollutant in the leachate needed for treatment to reduce the toxicity.

Landfill reclamation is a process wherein the stabilized solid wastes is excavated and recovers recyclable materials. In addition, it reduces the problem of ground water contamination existing in the dumpsite. The earliest reclamation of a landfill was conducted at Naples Landfill in Collier Country, Florida. The soil component of the solid waste was segregated and recycled as a soil cover in the new landfill, whereas the combustible material was recovered and used as fuel for waste-to-energy facilities (Reinhart and Townsend, 1998). Useful materials such as metal and glass can be recycled, while the soil from the stabilized landfill can be reused as a composting product. Recycling of the reclaimed waste is dependent upon the characteristics of the waste present, in particular heavy metals that were mostly retained in the solid waste. Moreover, the degradation of organic matter leads to the reduction of solid waste volume which increases the concentration of toxic metals in the degraded waste (Das et al., 2002). As a result, the quality of the reclaimed waste from the dumpsite should be properly characterized before reuse for environmental and health reasons.

1.4 Objectives of the research

This research aims to investigate the environmental impacts of municipal solid waste open dumping practice and to determine the possibility of dumpsite mining for waste recycling. The specific objectives of this study are:

(1) To determine characteristics of a municipal solid waste in a dumpsite and its leaching ability of heavy metals.

(2) To determine the leachate toxicity and investigate the important toxic elements that influences the toxicity of leachate in the dumpsite

(3) To determine the mining potential and characteristics of degraded solid waste for recycling as fuel, compost and the possibility of non-recyclable waste disposal into a new landfill.

1.3 Scope of the study

(1) Solid waste deposited in the dumpsite for 3-7 years was excavated to determine the solid waste composition. Physical and chemical characteristics such as concentrations of Mn, Cr, Cd, Cu, Pb, Ni, Zn and Hg in solid waste and leachate were also identified.

(2) The binding form of heavy metals in solid waste was classified using the sequential extraction analysis. The binding form of each metal was divided into five fractions which includes exchangeable, acid soluble, reducible, oxidizable and residual fraction.

(3) The Toxic Characteristic Leaching Procedure (TCLP) test was applied to evaluate the leaching ability of metals from the dumpsite under acid condition resulting to biodegradation and acid water precipitation.

(4) The concentration of heavy metals in the runoff leachate and leachate borehole samples were analyzed to determine heavy metal leaching in the actual condition of the dumpsite.

(5) Evaluation of toxic pollutant contamination in the environment was conducted through surface and ground water characterization. Surface water within 500 m radius from the dumpsite was randomly collected and analyzed. Similarly, groundwater quality in the four monitoring wells installed in the area was analyzed.

(6) Determination of leachate toxicity was performed by means of acute toxicity test to inhibit the germination rate of rice (*Oryza sativa* L.). The median inhibiting concentration of leachate (IC_{50}) was then determined.

(7) The physical and chemical characteristic of various waste sizes was analyzed to evaluate the recycling potential of waste for fuel and compost. Additionally, seed germination toxicity test of soil was performed to evaluate the phytotoxicity of the compost product. Sequential exaction analysis and TCLP leaching tests were conducted to investigate the risk of heavy metal leaching from the non-recyclable waste to be used as a new landfill.

Chapter 2

Literature Review

2.1 Introduction

Municipal solid waste management problem is increasing in Thailand as a result of population increase and economic growth. Presently, the solid waste generated in Thailand is about 0.5-1.0 kg/cap/day and tend to increase with the population growth. In 2005, approximately 14.3 million tons of solid waste was generated and disposed from rural area (47%), municipality (32%) and Bangkok metropolitan (21%). Most of MSW is disposed from household and commercial area which constitutes 67% of total waste, whereas the remaining fractions are generated and disposed from industrial, commercial and agriculture area (Thailand Environmental Monitoring, 2003). The MSW in Thailand and other countries in Asia are mainly composed of organic waste, plastic, paper and glass (Visvanathan and Tränkler, 2004). Table 2.1 shows the MSW composition in the two municipalities of Thailand, China and USA.

Table 2.1 Municipal solid waste composition in Thailand, China, USA & Columbia

Composition (% w/w)	**Thailand**		**China**	**USA**	
	Chiangmai	**Pathumthani**	**Guangzhou**	**New York**	**Columbia**
Food waste	59.3	49.6	58.1	12.7	9.0
Paper	11.0	4.5	6.3	31.1	41.0
Plastic	11.6	24.0	14.5	8.8	16.0
Glass	3.2	1.7	2.0	5.0	3.0
Metal	5.6	2.9	0.6	4.3	6.0
Rubber/Leather	1.0/3.6	2.0/1.9	0.4	0.2	na[a]
Textile	1.4	5.5	4.8	4.7	4.0
Yard waste	2.5	6.5	3.1	2.2	7.0
Ceramic	0.4	1.0	na[a]	na[a]	na[a]
Other	0.8	0.4	11.9	31.0	14.0
Source	Visvanathan and Tränkler (2004)		Chung and Poon (2001)	Themelis et al. (2002)	Zeng et al. (2005)

[a] No available data

2.2 Heavy metal contamination of MSW

Household hazardous waste disposal into the MSW has been the major source of heavy metal contamination in the waste stream. The heavy metal comes from paint, fluorescent tubes, batteries, electric and electronic waste (Slack et al., 2005). Souza and Tenorio (2004) determined heavy metal content of a dry cell battery. Concentration of Zn, Mn, Pb, Hg and Cd was found to have relatively high concentration as shown in Table 2.2. The study indicates that a dry cell battery can be a possible source for Zn, Mn, Pb, Hg and Cd in MSW.

Table 2.2 Metal concentration present in an alkaline battery

Heavy metals	**Concentration**
Zn (% w/w)	21
Mn (%w/w)	45
K (%w/w)	4.7
Fe (%w/w)	0.36
Pb (%w/w)	0.03
Hg (mg/kg)	1
Cd (mg/kg)	0.06
Other (%w/w)	±30

Source: Souza and Tenorio (2004)

Prudent et al. (1996) identified the source of heavy metal contaminations in MSW. Concentration of Cd, Cu, Cr, Ni, Pb and Zn found in the composite waste were 4, 77, 350, 57, 230, and 380 mg/kg, respectively. Most of Cd contamination in the waste is a result of plastic waste disposal which represents 50% of the total. Approximately 50% of Cr in the waste came from non-ferrous metals, 40% Ni and 30% Zn from scrap metals, and 70% Pb were present in non-ferrous metals. Based on the analysis of heavy metal concentrations in the MSW, therefore, plastic, ferrous and nonferrous metals can be considered as the major source of heavy metals. In addition, the concentration of Zn is highest in the composite waste.

Rotter et al. (2004) analyzed the concentration of heavy metals in the MSW. The results showed the relatively high concentration of cadmium, lead, and Zn content of batteries, electronic waste, shoes, rubber, non-packaging plastic and composite waste. The source of heavy metals is shown in Table 2.3.

Table 2.3 Important source of heavy metals in the MSW

Metal	**Application**
Cr	Metal, plastic, glass,
Cd	Batteries, paint, alloy, plastic, glass,
Pb	Batteries, paint, metal, plastic, food waste, textile
Ni	Batteries, alloy, plastic
Zn	Batteries, packaging, glass, food
Cu	Batteries, electrical product and electronics, alloy, paint, chemical and pharmaceutical
Mn	Batteries, steel, alloy, chemical compounds, pesticide, fruit and vegetable
Hg	Batteries, lamps

Source: ASTDR (2000); He et al. (2006); Slack et al. (2005)

Moreover, relatively high concentration of Zn was found in the study of Riber et al. (2005). The average concentrations of Zn, Cu, Pb, Cr, Ni, Cd, As and Hg content of combustible waste are 1020, 620, 370, 41.8, 25.7, 6.89, 13.6, and 0.6 mg/kg, respectively.

Also, analysis of heavy metal contamination in Thailand showed that Zn concentration is highest in the organic waste. Schouw et al. (2002) investigated Zn concentration present in kitchen wastes in the south of Thailand. The nutrients and heavy metals generation rate of kitchen waste per capital are presented in Table 2.4. The average Zn being disposed into the biodegradable waste ranged from 2.3-5.0 mg/cap/day. This study revealed that in Thailand, most of the heavy metal content present in organic waste was caused by the high percentage of food waste in the MSW.

Table 2.4 Chemical characteristics of kitchen waste in Southern of Thailand

Parameters	**Generation rate (mg /capita / day)**		
	Phathalung municipality	**Prik municipality**	**Kuan Lang municipality**
N	370	270	410
P	78	140	78
K	110	360	150
S	40	30	14
Ca	140	300	140
Mg	0.02	0.04	0.05
Zn	5.00	3.60	2.30
Cu	0.05	0.14	0.17
Ni	0.045	0.023	0.006
Pb	0.008	0.010	0.020
Cd	0.025	0.032	0.083
Hg	0.005	0.003	0.002

Source: Schouw et al. (2002)

Zopas et al. (2000) reported that concentration of Mn, Ni, Pb and Zn content in the organic fraction of MSW was about 106, 12, 113, and 263 mg/kg, respectively. The concentration of Zn is highest in this waste

2.3 Municipal solid waste management

Most of the solid waste generated in Asia is disposed into open dump sites. Open dumping is the traditional municipal solid waste disposal technology mostly found in developing countries. Compared to incineration and sanitary landfill, it is easier and cheaper. Figure 2.1 shows the municipal solid waste management system in selected countries. Presently, around 60% of solid waste generated in Thailand is disposed into the open dump (Visvanathan and Tränkler, 2004).

Most of the MSW is disposed into the dumpsites without any leachate and gas controlling system. Furthermore, there is no control on the amount of hazardous waste for dumping. Lack of suitable leachate and gas management causes the diffusion of leachate into the surface water, groundwater and its surrounding area.

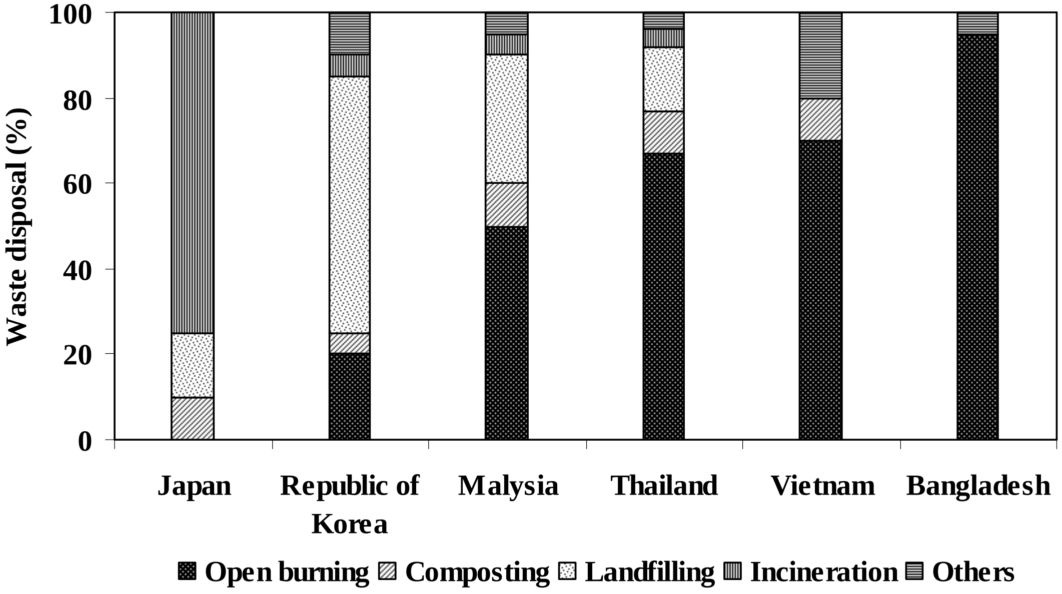


Figure 2.1 Municipal solid waste disposals in selected countries
(Visvanathan and Tränkler, 2004)

2.4 Contamination of toxic compound into surface water and groundwater

The contamination of toxic compound in the surface water resource greatly affects the environment. Organic compound and ammonia are the major toxicants of leachate in the landfill. Contamination of organic compound and ammonia in surface water causes dissolved oxygen depletion, and generation of stress in the aquatic organism (Barlaz et al., 2002). In addition, an increase in ammonia concentration in the surface water leads to eutrophication.

The composition of municipal solid waste landfill is of complex mixture, thus, the risk of leachate in the environment is difficult to assess with chemical analysis alone. Toxicity test of leachate revealed the synergistic, antagonistic and additive characteristics of the toxicant (Isodori et al., 2003; Kaneko, 1996; Fjällborg et al., 2005). Therefore, leachate toxicity using bioassays have been conducted to determine the potential effect in the aquatic environment.

The Toxic Identification Evaluation (TIE) was used by Isodori et al. (2003), to analyze the toxicity of the leachate. The results showed that leachate is associated with the leachate pH (pH 3, pH11, initial pH). Leachate toxicity increases with an increase in pH, and decreases at a lower pH level. Moreover, toxicants in leachate could be in the form of cations, basic chemical, suspended solid and polar compounds.

The generated unionized ammonia is toxic and commonly present in the basic leachate pH level of 8.8. As the leachate pH decrease, in contrast, ionized –ammonia is predominant and the toxicity of leachate is decreased. Clément et al. (1996) analyzed the leachate toxicity using a variety of aquatic organism such as primary producers (*Scenedesmus subspicatus* and *Lemna minor*), micro-crustaceans (*Daphnia magna*, *Ceriodaphnia dubia* and *Thamnocephalus platyurus)*, rotifers (*Brachionus calyciflorus*), protozoa (*Spiristomun ambigum*) and luminescent bacteria (*Vibrio fisheri*). The results confirmed that ammonia, alkalinity, and COD content in a landfill affect the leachate toxicity.

Similarly, heavy metals, chloride, toxic organic compound and the conductivity level of the leachate are also found as an important toxicant in the leachate (Kjeldsen et al., 2002). Seco et al. (2003) identified the toxicity of heavy metals present in the leachate derived from TCLP extraction of inorganic industrial waste. The concentration of heavy metals in the TCLP leachate was analyzed and acute toxicity was tested using *Daphnia magna*. The median effective concentration (EC_{50}) of leachate was determined. The results showed that heavy metals and pH value is toxic to the aquatic organism. The estimated EC_{50} of As, Cd, Cr, Pb, and Zn were about 5.71, 1.96, 0.43, 5.49 and 11.56 mg/L, respectively. Moreover, EC_{50} of leachate pH value was estimated in terms of EC_{50} of H^+ and OH^- ion in which the EC_{50} was 0.02 and 13.5 mg/L, respectively. The result shows the potential toxic effect of heavy metal leaching into the environment. However, the study is still insufficient to support the actual cause of the observed toxicity.

In the same way, the contamination of leachate in ground water resource is mostly affected by dissolved organic compound, ammonia and toxic organic compound. The leachate diffused into the groundwater is attenuated by biodegradation, ion exchange, precipitation, absorption, and dilution. The contamination potential of heavy metal into the ground water is relatively low due to the attenuation process of leachate in soil (Barlaz et al., 2002; Bagchi, 1987). The attenuation process of heavy metals in soil is shown in Table 2.5. During the biodegradation process of organic compound in soil, the oxygen and redox potential in soil is decreased. This increases the leach of Mn and Fe from soil.

Table 2.5 Attenuation mechanisms of heavy metals in landfill

Heavy metal	**Attenuation Process**
Cd	Precipitation, Adsorption
Cr	Precipitation, ion exchange, adsorption
Cu	Adsorption, ion exchange, precipitation
Pb	Adsorption, ion exchange, precipitation
Mn	Precipitation, ion exchange
Hg	Adsorption, precipitation
Ni	Adsorption, precipitation
Zn	Adsorption, ion exchange, precipitation

Source: Bagchi (1987)

In an anaerobic condition, degradation rate of toxic organic compounds is rather slow. The toxic compound can transfer from the landfill and contaminate the receptor area. Baun et al. (2003) investigated the attenuation potential of xenobiotic organic compound (XOC) in the leachate plume in order to determine the attenuation of toxic organic compound under anaerobic condition. The results showed that leachate plume is unchanged after a 10-year period even though the concentration of XOC, chloride and non volatile organic compound was significantly lower. Table 2.6 shows groundwater quality at different time and distance in a landfill.

Table 2.6 Concentration of toxic compounds in groundwater at different time and distance in landfill

Parameters	**Unit**	**Distance (13 m)**		**Distance (47 m)**	
		1989	**1999**	**1989**	**1999**
pH		6.4	6.7	6.2	6.5
Conductivity	mS/cm	4.6	4.3	2.4	2.1
Non volatile organic compound	mg/L	346	105	82	51
Chloride	mg/L	1125	475	589	124
Ammonium	mg/L	278	211	92	84
Sulfate	mg/L	63	0.2	-	4.6
Methane	mg/L	-	1.0	6.4	2.5
Mn	mg/L	0.7	1.6	2.9	2.4
Fe	mg/L	3.3	37	88	37
Benzene	µg/L	3	3	2	4
Toluene	µg/L	39	1	1	0.5
Ethylbenzene	µg/L	96	16	9	0.4
m/p-Xylene	µg/L	224	133	2	0.5
o-Xylene	µg/L	16	7	1	0.2
Benzyl succinic acid	µg/L	-	1.5	-	0.2
C3-benzene	µg/L	143	1230	2	1.5
Alkylphenol	µg/L	-	5.3	-	0.3
Chlorophenol	µg/L	-	0.2	-	0.01
MCPP	µg/L	250	159	95	69
4-Cl-cresol isomer	µg/L	33	5.4	11	1.2
Camphor	µg/L	426	91	46	<1.0
Fenchone	µg/L	126	31	21	6
Naphthalene	µg/L	24	13	2	7
1-methylnapthalene	µg/L	6	5	<1.0	<0.1
2-methlynapthalene	µg/L	5	4	<1.0	<0.2

Source: Baun et al. (2003)

2.5 Biotransformation of solid waste in landfill

The biotransformation of solid waste in landfill is categorized into two: aerobic and anaerobic process. In an aerobic condition, the aerobic biodegradation occurs and produces carbon dioxide and water as end products. In contrast, methane and carbon dioxide are produced in the anaerobic biodegradation of waste. The aerobic and anaerobic degradation of solid waste are described in Equation 2.1 and Equation 2.2.

$$\text{Org. matter} + O_2 + \text{Nutrients} \longrightarrow \text{New cells} + \text{resistance org. matter} + CO_2 + H_2O + NH_3 + SO_2^{2-} + \text{Heat} \qquad \text{Equation 2.1}$$

$$\text{Org. matter} + H_2O + \text{Nutrients} \longrightarrow \text{New cells} + \text{resistance org. matter} + CO_2 + CH_4 + H_2S + \text{Heat} \qquad \text{Equation 2.2}$$

Under the aerobic condition, the biodegradation rate of solid waste is faster compared to the anaerobic condition. The aerobic degradation of waste reduces the retention time of solid waste stabilization. Controlling the oxygen concentration in MSW landfill can accelerate the solid waste stabilization (Das et al., 2002; Reinhart and Townsend, 1998). Prediction model of solid waste degradation in an uncovered landfill compared to the covered landfill showed that a high oxygen diffusion rate can increase the organic matter degradation; and reduce the retention time especially for partially water saturated landfill (Bozkurt et al., 2000).

(1) Phase I: Initial phase

As the solid waste is disposed into landfill, the organic compound content in solid waste is aerobically degraded using the oxygen remain in void space of soil and solid waste. Degradation rate of organic matter in this phase is low due to insufficient moisture content. This condition will be maintained until such time the water accumulation in the landfill is sufficient for microbial activity.

(2) Phase II: Transition phase

Once the moisture content in the landfill is suitable for microbial activity, the oxygen retained in the landfill is quickly consumed. In this process, carbon dioxide, hydrocarbon, water and heat in the landfill increases. The high oxygen consumption in the waste leads to the oxidation – reduction potential (Eh) in the landfill decrease. The nitrate, manganese oxide and ferric hydroxide as well as sulfate compounds containing in the waste will then be used as electron receptors at different level of redox potential. The variation of organic matter degradation influencing to oxygen concentration in landfill is shown in Figure 2.2.

Moreover, the effect of redox potential change to the oxidation reaction of nitrate, Mn, Fe, sulfate, and organic compound within the landfill are described in Equation 2.3 to Equation 2.9 (Flyhammer, 1997). In this stage, ammonia, hydrogen sulfide and methane gas are evident. In addition, Mn oxide and Ferric hydroxide are reduced and changed into its water soluble form.

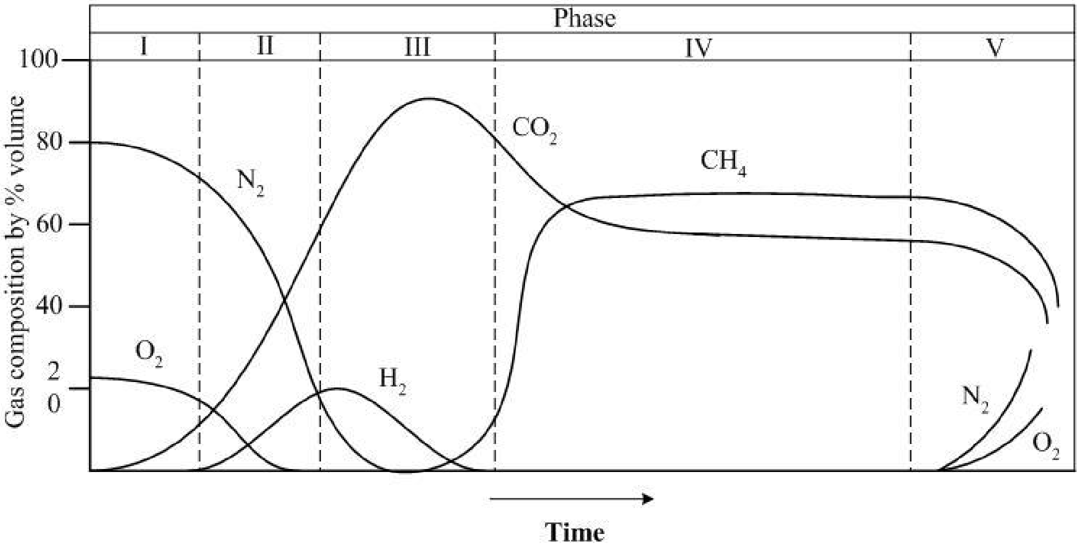


Figure 2.2 Biodegradation variation in landfill (Tchobanoglous et al., 1993)

- Oxygen reduction (Eh $\geq$ 300mv)

$O_2 + 4H^+ + 4e^- \longrightarrow 2H_2O$ Equation 2.3

- Nitrate reduction /Manganese reduction (100 $\leq$ Eh $\leq$ 300mv)

$NO_3^- + 6H^+ + 5e^- \longrightarrow 0.5N_2 + 3H_2O$ Equation 2.4

$NO_3^- + 10\ H^+ + 8e^- \longrightarrow NH_4^+ + 3H_2O$ Equation 2.5

$MnO_2 + 4H^+ + 2e- \longrightarrow 2Mn^{2+} + 2H_2O$ Equation 2.6

- Ferric reduction (-100 $\leq$ Eh $\leq$ 100mv)

$Fe(OH)_3 + 3H^+ + e^- \longrightarrow Fe^{2+} + 3H_2O$ Equation 2.7

- Sulfate reduction (-200 $\leq$ Eh $\leq$ -100mv)

$SO_4^{2-} + H^+ + 8e^- \longrightarrow HS^- + H_2O$ Equation 2.8

- Methane formation (Eh $\leq$ -200mv)

$CH_2O + 4H^+ + 4e^- \longrightarrow CH_4 + CO_2$ Equation 2.9

As concentration of oxygen is decreased, facultative microorganism dominates. The extracellular enzyme produced by bacteria breaks down carbohydrate, protein and lipid of the solid waste. The protein content in the solid waste is converted into amino acid, carbohydrate is changed into simple sugar and fat is changed into a long chain fatty acid.

(3) Phases III: Acid formation phase

The compound in the previous stage will be used to produce the organic volatile fatty acid (VFA), alcohol and other compounds by the acid forming bacteria. The generated VFA observed in leachate are acetic acid, propionic, butylic, lactic and formic acid. Because the concentration of organic fatty acid was increased in the leachate, the solubility of nutrients and heavy metals increase and leach due to the landfill pH decreases. Also, carbon dioxide and hydrogen gas increases dramatically. The concentration of BOC and COD found in the leachate increased from the previous phase. Harmsen (1983) revealed that approximately 95% organic matter (TOC) content in leachate under the acid formation phase is volatile fatty acid, while the remaining fraction is volatile amine and ethanol which constitutes 0.8% and 0.7% TOC, respectively.

(4) Phase IV: Methane formation phase

Methane gas in the landfill is generated using the methanogenic bacteria, which converts acetic acid, and hydrogen gas to methane and carbon dioxide gas. The neutral and basic pH condition is evident in the landfill because of a decrease in the volatile fatty acid. Therefore, the acid buffer capacity of the landfill increases during this phase. In contrast, the concentration of COD, BOD, heavy metals and conductivity of leachate decreases. Methanogenic bacteria are oblique anaerobes; hence an increase in the amount of oxygen concentration in the landfill can inhibit the microbial activity and methane gas formation. The characteristic of leachate in various solid waste degradation phases is shown in Table 2.7.

Table 2.7 Characteristics of Leachate in the landfill

Parameter	**Unit**	**Phase II Transition**	**Phase III Acid Formation**	**Phase IV Methane Formation**	**Phase V Final Maturation**
BOD	mg/L	100-10000	1000-57000	600-340	4-120
COD	mg/L	480-18000	1500-71000	580-9760	31-900
TVA	mg/L [a]	100-3000	3000-18800	250-4000	0
BOD/COD		0.23-0.87	0.4-0.8	0.17-0.64	0.02-0.013
NH_4-N	mg/L	120-125	2-1030	6-430	6-430
pH		6.7	4.7-7.7	6.3-8.8	7.1-8.8
Conductivity	µS/cm	2450-3310	1600-17100	2900-7700	1400-4500

Note: [a] mg/L as acetic acid
Source: Reinhart and Townsend (1998)

Fortuny and Fuller (1982) determined the concentration of humic acid and fulvic acid in an anaerobic landfill leachate. The result showed that concentration of humic substance is 60% higher than the TOC and tend to increase with an increasing age of the leachage. This is different from fulvic acid that is commonly found in the younger leachate and decreases with an increasing landfill age. Humic substance is difficult to decompose. Thus, low BOD concentration which includes BOD/COD ratio is observed in the old landfill. Determination of leachate quality in the old anaerobic landfills showed that BOD/COD ratio of leachate is 0.1-0.3 (Chen, 1996; Kjeldsen and Christophersen, 2001).

The concentration of inorganic substances in leachate varies in the solid waste degradation landfill. Ehrig (1983) compared the leachate quality measured in the methane and acid phase. The results showed that concentration of Mn, Sr, Zn and Fe content in leachate varies in parallel with COD and BOD values. During the acid phase, the concentration of Fe, Ca, Mg, Mn, Zn and Sr increase significantly. This is different from NH_4-N, Cl, K, and Na that tend to increase with the age of the landfill and decreases in the future by washing out with time. There was no significant difference in the values of NO_3-N, P, Pb, Ni, As, Cu, Co and Cr. The result also confirmed that Mn, Zn, Fe, and Zr in leachate can be released due to acid dissolution. In addition, the hydrogen ion (H^+) reduces the Mn oxide and Ferric hydroxide and releases them into the leachate (Bozkurt et al., 2000). The characteristic of heavy metal leaching during acid and methane production phase is shown in Table 2.8.

Table 2.8 Leachate characteristic

Parameter	**Acidogenic phase**	**Methane formation phase**
pH	6.1	8.0
COD (mg/L)	22000	3000
BOD (mg/L)	13000	180
Fe (mg/L)	925	15
Ca (mg/L)	1300	80
Mg (mg/L)	600	250
Mn (mg/L)	24.0	0.65
Zn (mg/L)	5.6	0.64
Sr (mg/L)	7.2	0.94

Source: Ehrig (1983)

(5) Phase V: Maturation phase

The biodegradation rate of organic matter within the landfill is relatively low during the maturation phase. It is noted that most of biodegradable organic matter in landfill has been converted to methane and carbon dioxide gas. The organic matter retained in this stage is difficult to decompose through microbial activity. The organic matter retained in the landfill is mainly composed of humic and fulvic organic matters. Furthermore, the moisture and nutrients content in landfill are lost due to leachate and gas production which decreases microbial activity. Methane gas production rate is relatively low and the concentration of BOC and BOD/COD ratio decreases gradually. The landfill will maintain this existing stage until the moisture and oxygen increases. The increase of moisture content in stabilized landfill can activate the biodegradation of solid waste inside the landfill (Mårtensson et al., 1999)

Anaerobic biodegradation of organic matter in the bioreactor landfill showed that 45.7% moisture content is sufficient for the stabilization of solid waste in the landfill. The anaerobic degradation process is indicated by an increase of leachate pH and temperature at the bottom of landfill (Townsend et al., 1996).

2.6 Leachate generation

Figure 2.3 shows the factors influencing leachate generation in the landfill. The leachate results from the precipitation of rain fall into the landfill, moisture content in solid waste by itself, and biodegradation of solid waste. The solid waste can hold the water in the landfill until it reaches its water holding capacity. When the holding capacity of landfill is attained, water percolating into the solid waste can leach from landfill as leachate. Aside from leachate generation, the moisture content in the landfill is released through landfill gas emission and water evaporation. Thus, high precipitation rate of rainfall in during the rainy season increases leachate generation and contamination of the environment (Chen, 1996; El-Fade et al., 1997; Tatsi and Zouboulis, 2002). The estimated leachate generation rate in the landfill is presented in Equation 2.10 (Baccini et al., 1987).

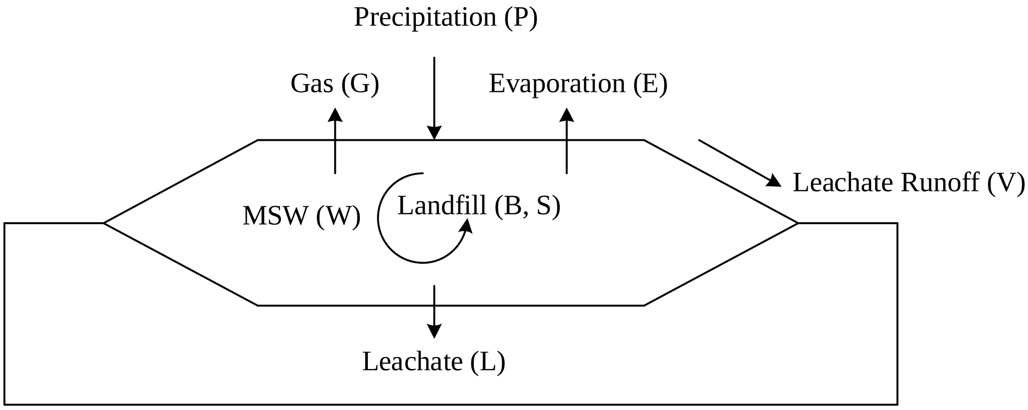


Figure 2.3 Leachate generation in the dumpsite

$$P + W + B - (E+G+L+V) - S = 0 \qquad \text{Equation 2.10}$$

Where;

P = Specific precipitate
W = Water input due to incoming MSW
B = Biochemical water production
E = Specific out put by evaporation
G = Specific out put by gas
L = Specific out by leachate
V = Loss due to the percolation and runoff
S = Specific retention by deposit MSW

The moisture content of landfill decreases at surface of landfill. Ösman et al. (2006) found that at varying moisture content (saturated and unsaturated), the redox potential is different within the landfill. Solid waste concentration of Fe^{2+}in the upper layer (Unsaturated zone) of the dumpsite is 25µg/L and 400µg/L of Fe^{2+} at the deeper layer (Saturated zone). This indicates that redox potential is correlated with moisture content and landfill depth. The lower redox potential at the saturated zone indicates the ability of water and organic matter content in maintaining the anaerobic condition.

2.7 Heavy accumulation in landfill

Many studies on the leaching ability of organic and inorganic compound showed that very small amount of heavy metal leaching comes from the landfill. In Baccini et al. (1987) paper, the anaerobic landfill has high capacity of retaining heavy metals. Approximately, 90% of non-metals and 99% of metals are retained in the stabilized landfill. Similarly, Øygard et al. (2004) found that the leaching rate of metals from landfill was around 0.06% Cd, 0.01% Pb, 0.02% Hg, 1.0% Cr and 7.9% of Fe, respectively.

He et al. (2006) found that approximately 0.13% of Cu, 1.8% of Cd, 0.15% of Pb, and 0.19% of Zn can be released via leachate contamination. Zn has the highest mobility in the landfill. The sequential extraction supported that Zn can be released from solid waste through ion exchange and acid dissolution reaction. This is different from Cr and Pb where 80% of these metals is insoluble and will be retained into the landfill for a long period of time.

(1) Ion exchange

Cationic heavy metal ion in solid waste can bind with the negative charge on soil surface, which is a reversible process. The ability of each heavy metal to bind with soil depends on its valency, the higher valency heavy metal has higher ability to bind with soil such as $Na^{+} < Li^{+} < K^{+} < Rd^{+} < Cs^{+} < Mg^{2+} < Ca^{2+} < Ba^{2+} < Cu^{2+} < Al^{3+} < Fe^{4+}$ (Bagchi, 1987). The ability of soil to adsorb cationic metal on its structure is measurable in terms of cation exchange capacity of soil (CEC). This value can increase the organic matter content in soil which intensifies the ability of the soil to adsorb heavy metal. The reported measurement CEC of refuse in the landfill ranges from 128-170 mmol/kg (Xiaoli et al., 2007).

He et al. (2006) found that the exchangeable fraction of heavy metals in the landfill is in the following order: Cd> Zn> Cu> Ni> Pb> Cr. This indicates the possibility of Cd to be adsorbed in the landfill by soil- ion exchange. On the other hand, Cl^{-} content in leachate can bind with the exchangeable Cd and is released from the landfill (Kjeldsen et al., 2002).

(2) Heavy metal precipitation

Heavy metal precipitation is a mechanism in which the dissolved heavy metal specie is changed into a non-dissolvable species. The carbonate, hydroxide, and sulfide can precipitate heavy metals in the landfill. The precipitation of heavy metal depends on the ionic species, concentration, temperature, pH, redox potential and concentration of sulfate and carbonate (Bagchi, 1987). Under the reducing condition, the sulfate compound is reduced to sulfide to precipitate Pb, Cd, Zn, Cu and Ni in landfill. On the other hand, Cr tends to be precipitated with hydroxide when it is in the neutral or basic pH level (Kjeldsen et al., 2002; Ösman et al., 2006).

The carbonate can be dissolved and released from the landfill when the pH level and acid buffer capacity of landfill is depleted. The acid precipitation rain fall and the hydrogen ion generated from the biodegradation process can act as consumers of the acid buffer carbonate compound. Whenever the acid buffer capacity is depleted, additional hydrogen ion in the landfill decreases the leachate pH (Mårtensson et al., 1999; Bozkurt et al., 2000).

(3) Oxide of Manganese, Iron, and Aluminum

The oxide of Mn, Fe and Al formed in the landfill can adsorb heavy metal. At high redox potential, Mn, Fe and Al are oxidized and transformed to Mn-oxide and ferric hydroxide. The oxidation reaction of Mn and Fe present in the landfill is shown in Equation 11 and Equation12 (Bozkurt et al., 2000). This reaction is also related with pH level. In an acidic condition, Mn oxide will be reduced and remobilized whether the redox potential of soil decreases or not (Alloway, 1995). Thus, Mn oxide and ferric hydroxide are unstable under anaerobic condition. Mn oxide is easy to be dissolved under acidic condition of the soil, and low redox potential compared to Ferric hydroxide and Zn. (Flyhamma, 1998; Flyhamma and Hakanssan, 1999).

$$FeOOH + Me^{n+} \longrightarrow FeOOH{:}Mn^{n+} \qquad \text{Equation 2.11}$$

$$Fe(OH)3 + Me^{n+} \longrightarrow Fe(OH)_3{:}Mn^{n+} \qquad \text{Equation 2.12}$$

(4) Organic matter complexation

The humic acid of organic matters has high capacity to adsorb heavy metals in the landfill. Heavy metals can form complex with the negative group on the humic compounds such as hydroxyl, phenoxyl and carboxyl. The humic acid formed during the solid waste degradation in landfill can adsorb heavy metals in landfill such as Zn, Cr and Cu (Flyhamma, 1997). The degradation of organic matter leads to heavy metals is released into leachate. Moreover, the dissolved organic compound chelating agent generated from organic matter enhances the solubility of metal from the solid organic phase and increases its mobility. The organic matter absorbed in particulate and colloid also enhances the heavy metal absorption on colloid (Jensen et al., 1999).

2.8 Seed germination and root elongation in leachate toxicity

Seed germination and root elongation of higher plant have been used to determine the phytotoxicity in both liquid and solid phase. During the germination stage, a plant seed is sensitive to the environmental stress which causes adverse affects to the metabolism, nutrient, and cell division. The plant species highly recommended for seed germination and root elongation test is presented in Table 2.9.

Table 2.9 Plant species recommended for toxicity test

EPA	cabbage, carrot, common onion, corn, cucumber, lettuce, oat, ryegrass, soybean, tomato
FDA	Bean, cabbage, carrot, corn, cucumber, lettuce, oat, rye grass, soybean, tomato, wheat
OECD	Mung bean, cabbage (Chinese), cress, fenugreek, lettuce, mustard, oat, rape, radish, red clover, rye grass, sorghum, turnip, vetch, wheat

Source: Wang (1991)

Wang (1994) determined the toxicity of metals that inhibits germination and root elongation rate of rice seed. The medium inhibiting concentration (IC_{50}) was determined. The results revealed that rice is sensitive to Cu, Ag and Ni then Cr, Pb, Zn, Mn and NaF with the IC_{50} of 0.22, 0.55, 0.85, 4.8, 9.7, 26, 100, 320 mg/L, respectively.

The comparative test of toxicity of Cd in different plant species showed that sweet corn (Zea may) is more sensitive than wheat (*Triticum aestivum*), cucumber (*Cucumis sativus*) and sorghum (*Sorghum bicolor*) The observed EC_{50} Cd of sweet corn, wheat, cucumber, and sorghum ranged from 22-35, 88-102, 98-113, and 208-265 mg Cd/kg, respectively. The study also showed that root elongation is more sensitive to Cd contamination in soil than seed germination (An, 2004).

Pataranawat et al. (2001) also studied the influence of leachate that inhibits germination rate and root growth of rice, corn, soybean and cucumber. Based on the study, rice is more sensitive compared to corn, soybean and cucumber. Furthermore, root elongation is more sensitive to leachate than seed germination rate with the IC_{50} at 12.3% and 18.5% v/v, respectively. The characteristic of leachate used in this test is summarized in Table 2.10.

Table 2.10 Leachate characteristics in seed germination and root elongation test

	pH	TS	SS	COD	BOD	TKN	Alk	Pb	Cd	Cr	Cu
Unit	-	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Value	8.0	9527	430	4044	1360	1765	10399	0.018	0.001	0.098	0.849

Source: Pataranawat et al. (2001)

2.9 Heavy metal uptake in plant

Heavy metal uptake of plant root is divided into two different processes which include passive and active process. The passive uptake is the process in which heavy metal ion diffuses into the root endodermis, whereas active uptake needs to have energy to be used to uptake ion agents in the ion concentration gradient. It has been recommended that plant uptake of Pb via passive process, while Cu and Zn can uptake in both passive and active process (Alloway, 1995). For Cr, plant uptakes Cr^{6+} via the transporter used in carrying the essential compound such as sulfate, Fe, S and P. However, plant is able to uptake Cr^{3+} by ion diffusion. The Cr exposure of plant seed could reduce the activity of enzyme amylase and the sugar transportation into the embryo. The toxicity of Cr on root length expansion of cell cycle and the inability of root to absorb water decreases cell division of root (Shanker et al., 2005). Table 2.11 shows the adverse effects of Cr to the germination and root elongation of plants.

Shi et al. (2006) suggested that excess exposure of Mn could inhibit the growth rate of *Cucumis sativa* L. by enhancing the oxidative stress and increasing the Mn concentration in plants. The potential toxic effects of metals in plants are:

- Changes the permeability of cell membrane
- Reacts with sulphydryl (-SH) group with cations
- Competition of sites with essential metabolite
- Reacts with phosphate groups and active groups of ADP or ATP

- Replaces the essential ions
- Binds with the reactive site of essential compound

Table 2.11 Effect of chromium on plant growth and development

Process	**Crop/Plant**	**Effect**
Germination	*E. colona*, bush bean, lucerne, mung bean, sugarcane	Reduce germination rate and produced bud sprouting
Root growth	*Salix viminalis*, mung bean, rice, sorghum, *Caesalpinia pulcherrima*	• Decrease root length and dry weight, • Increase root dimension, and root hairs, • proportional variations in cortical and pith tissue layers

Source: Shanker et al. (2005)

Organic matter in different molecular weights has various effects on the bioavailability of heavy metal in plant. Inaba and Takenaba (2005) investigated the influence of dissolved organic matter of Cu uptake in plants. The high molecular weight organic matter ethylenediamine tetra-acetic acid (EDTA) and diethylenetriamine penta-acetic acid (DTPA) could inhibit the bioavailability and toxicity of Cu in lettuce, whereas low molecular weights (Citric, malic and oxalic acid) increase the toxicity of Cu. In this case, high molecular weight humic acid was suggested to be the most effective organic substance for Cu detoxification in plants. The results also indicated that organic matter in leachate can either increase or decrease the bioavailability and toxicity of heavy metals in plant depending on its molecular weight.

2.10 Landfill mining and reclamation

2.10.1 Landfill mining process

Landfill mining is the process in which waste buried in the dumpsite is excavated to recover recyclable material such as metal, glass, plastic, and other combustible waste, soils, and space. The biodegradation of solid waste in landfill transforms solid waste into humus in the landfill (Morelli, 1990). Many studies indicated that organic fraction can be retained in the landfill a long time (Belevi and Baccini, 1989; Bozkurt et al., 2000). However, the environmental change can affect the biodegradation of stabilized landfill which increases the amount of toxic compounds released into environment.

Landfill mining process involves the excavation process to remove the waste from the landfill. The excavated waste is segregated to recover the recyclable material. The landfill can be rehabilitated. The excavation of landfill can cause public nuisance due to smelly odor and gas. The cost for implementation is relatively high in providing the equipment and labor. Thus, assessment in the economic potential of landfill mining is necessary. Moreover, hazardous material and non-recyclable wastes generated in the dumpsite mine needs proper management. The quality of recyclable waste needs to be improved to meet the required quality standard. Again, this causes increase in the implementation cost, which affects the reutilization of the reclaimed waste (USEPA, 1997; Hogland et al., 2004; Van der Zee et al., 2004). The advantages and disadvantages of landfill mining are summarized in Table 2.12.

Table 2.12 Benefits and limitations of landfill mining

Benefits	**Limitations**
• Land value of site reclaimed for other uses • Reduction in landfill area • Elimination of a potential source of contamination • Mitigation for the existing contamination sources • Energy recovery • Recycled the recyclable material • Reduction in landfill management system cost	• Poor quality for recovered material • Landfill gas and odor emission • Handing and disposal of hazardous material and non-recyclable material • Capital cost and operational cost of landfill mining - Site preparation - Reclamation equipment and labor - Personal safety equipment and training in safety procedure - Administrative and regulatory compliance expenses

Source: Hogland et al.(2004); Van der Zee et al. (2004)

The basic process of landfill mining is shown in Figure 2.4 and Figure 2.5. The stabilized solid waste landfill is recommended for landfill mining to avoid environmental problems during the implementation (Reinhart and Townsend, 1998). The excavated waste can be segregated using a screen to separate soil from fine particles. The ferrous metal containing in the oversize fraction is removed through magnetic, while air classifier is used to separate the waste of harden density (wood, non-ferrous metal, glass) and low density material (plastic and paper). These wastes can be recycled offsite by using waste for fuel or send to the market for recycling. The recovery rate of recyclable waste from landfill is reported at approximately 50-75% plastic, 70-90% ferrous metal and 85-95% glass, while the potential purity of waste is 70-90% plastic, 80-95% ferrous metal, and 90-95% soil (Savage et al., 1993).

2.10.2 Waste recycling approach

(1) Material recovery

The recyclable plastic, nonferrous and non-ferrous metal, glass and rubber can be sent to market and process into a useful product. Muttamara et al. (1994) confirmed that in Thailand, paper, glass, and plastic constitute for 55%, 1-3%, and 10-15% in the waste stream, respectively. The high contamination of the reclaimed waste from landfill can affect the product quality, hence increasing the cost (Carius et al., 1999). In addition, the concentration of heavy metals excavated from the landfill is higher compared to the initial waste present in the landfill (He et al., 2006; Ösman et al., 2006). The concentration of heavy metals in the landfill is shown in Table 2.13.

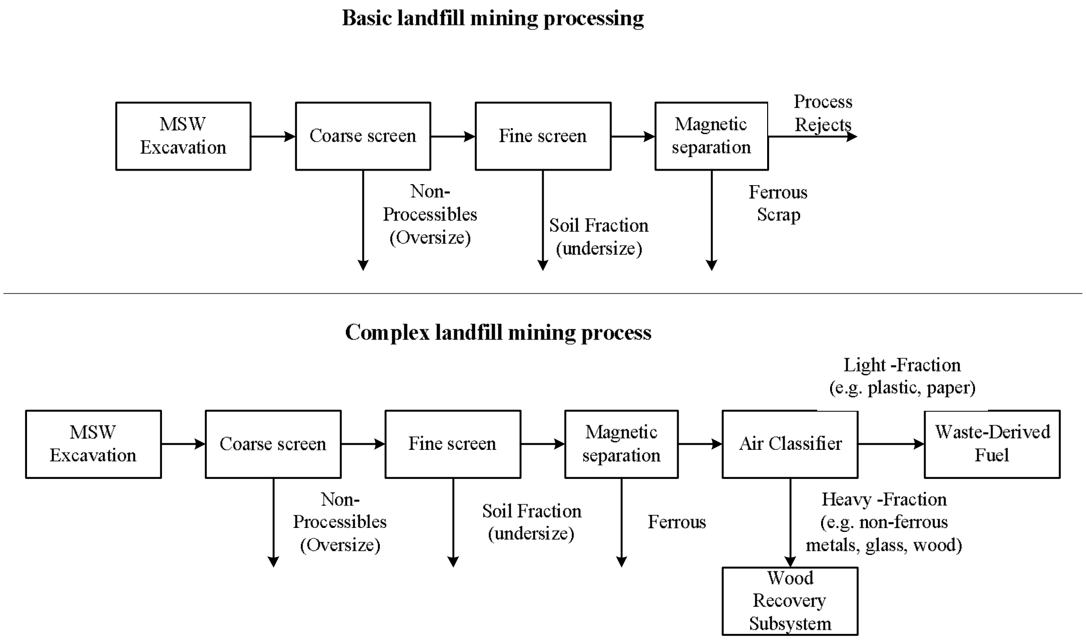


Figure 2.4 Landfill mining process flow diagrams (Savage et al., 1993)

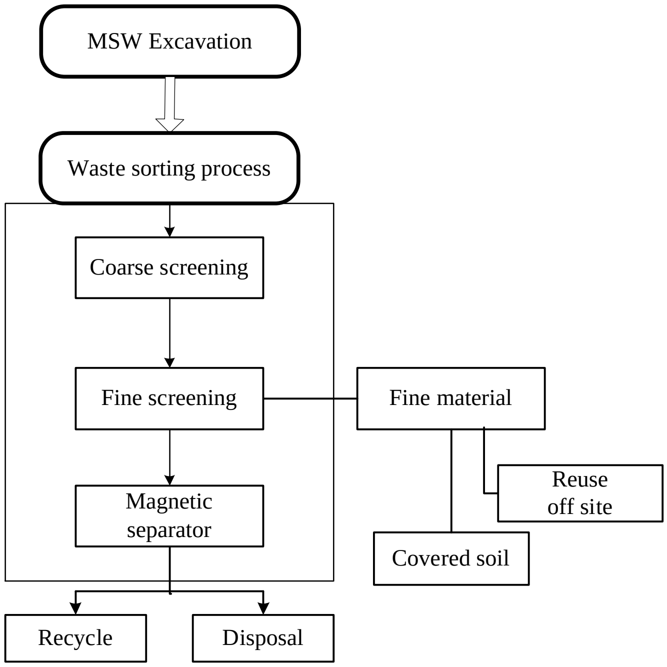


Figure 2.5 Landfill mining process diagram (Reinhart and Townsend, 1998)

(2) Energy recovery approach

The reclaimed combustible material can be recycled into waste-to-energy plant as a supplement fuel. The reclamation project on Frey Farm landfill found that 56% of reclaimed waste is recovered for fuel, whereas 41% is recovered as soil (USEPA, 1997). To recycle waste as fuel, heating value and concentration of toxic compounds in the combustible waste are necessary for local regulation (Rotter et al., 2006)

The contamination of noncombustible and moisture content in the combustible waste fraction should be controlled. Themelis et al. (2002) predicted the influence of solid waste composition with the heating value available from waste combustion. The study showed that moisture content and noncombustible material are important factors in reducing the heating value of waste as described in Equation 2.13. It is recommended that noncombustible wastes and higher moisture solid waste should be removed from the dry solid waste fraction. Separating the dry combustible fraction for recycling is also appropriate.

$$H_{mix} = [H_{comb}X_{comb}^{-}] - [H_{H2O}X_{H2O}^{-}] - [H_{glass}X_{glass}^{-}] - [H_{metal}X_{metal}^{-}] \qquad \text{Equation 2.13}$$

Where;

H_{mix} = Heat value of mixed MSW
H_{comb} = Heating value of combustible waste
H_{H2O} = Heat loss due to H_2O in feed
H_{glass} = Heat loss due to glass in feed
H_{metal} = Heat loss due to metal in feed
X_{comb} , X_{H2O}, X_{glass}, X_{metal} = Fraction of combustible , water, glass, and metal in the MSW

Hogland et al. (2004) determined the recycling potential of waste in a 17-20 year old Måsalycke and 23-25 year old Gladsax landfill. The moisture content of landfill increased from 29, 29 and 30 % at 0.6, 3.0 and 7.0 m depth. The calorific value 7MJ/kg from the sorted waste size > 50 mm contains a large amount of paper (29%), wood (19%) and plastic (6.5%). The lower calorific value was found in the waste size of 18-50mm and < 18mm. Heavy metal concentration in the excavated waste found that the concentration of Zn was highest which ranges from 91-510 mg/kg.

(3) Soil recycles as compost

Recycling the soil fraction as compost product is one way of managing the reclaimed soil from the landfill. Soil fraction in the reclaimed landfill varies and is dependent on the waste age and landfill operation. It has been reported that soil fraction weighs from 44-77% (Morelli, 1990).

Das et al. (2002) studied the feasibility of the stabilized MSW compost from the bioreactor landfill. The waste was separated using the 9.5 mm and 19.1 mm trommel screen. The inert material retained in the compost product was 3.9% and 9.0%, respectively. This value is in compliance with the local compost standard. In addition, concentration of heavy metal is lower than the compost standard. However, this approach is unsuitable for crop cultivation due to high contamination of heavy metals in crop plants (Peanut and water melon) (Zhao, et al., 2007). The heavy metal speciation, pH value, nutrient and other constituents in soil influence the mobility of heavy metals. The soluble fraction, exchangeable fraction and inorganic or organic complex metal have been classified as heavy metals in the soil (Maiz et al., 2000; Remon et al., 2005; Wong, 2003).

Feasibility of a landfill mining in Asia has been reported in many studies. Age and landfill operation affects the solid waste characterization. Kurian et al., (2003) determined landfill mining in Kodungaiyur and Kerungudi, India. The results showed that most of waste in the site was of soil fraction (< 20mm) which constitutes 67.8% and 40.1%, respectively. The concentration of Cr, Cu, Hg, Ni and Pb in the soil was relatively higher than local compost standard. In addition, 50% TOC concentration in soil suggested that the dumpsite was incomplete and unsuitable as compost for edible crops.

Therefore, it is necessary to evaluate the stabilized organic matter of compost before recycling. In non-stabilized compost, the phytotoxic effect in plant is very high and can inhibit the root length and seed germination rate of plant. Pascual et al. (1997) proved that germination rate and root length of barley seed (*Hordeum vulare* L.) found in the stabilized compost has lower toxic value than the non-stabilized waste. In stabilized compost, mobility of heavy metal is expected to be low. It is not toxic to plants if the concentration of phenolic acid and molecular weight acid are at low levels.

Tiquia et al. (1996) studied the phytotoxicity of spent pig-manure sawdust litter during the composting process using seed germination and root elongation test of six plant species of Chinese cabbage, Chinese kale, onion, cucumber, and tomato. The results showed that ammonia content in the spent litter is most toxic to the tested plants. The phytotoxicity of plant decreased significantly in the completed compost. Further in this study, Chinese cabbage and Chinese spinach were also sensitive species.

(4) Others

Zhao et al. (2002) found that solid waste age of 8-10 years with size of <15mm has a high efficiency to be reused as biofilter for leachate treatment in the landfill. The COD and BOD concentration of leachate used in this experiment is 3000-7000 and 540-1500 mg/L. The effluent quality of leachate was COD < 300 mg/L and BOD < 150mg/L, while 99.9% ammonia was removed by converting to nitrate and nitrite.

Hogland et al. (2004) revealed that waste size of 18-25 mm recovered from the waste separation process may be recycled through anaerobic digestion. The high organic matter content of this fraction can be used in methane gas production for energy recovery.

Table 2.13 Concentration of heavy metals in the landfill

Source	**Concentration (mg/kg)**						
	Cd	**Cr**	**Pb**	**Ni**	**Zn**	**Cu**	**Hg**
Hogland et al. (2004)	0.9-1.2	31-78	90-270	10-15	180-510	34-36	0.2-1.6
He et al. (2006)	4.7-11.3	323-545	206-777	39.6-90.3	384-913	107-320	-
Zhao et al. (2007)	10.7-6.6	73.5-252.1	77.9-372.2	-	549.4-652.9	-	-
Xiaoli et al. (2007)	1.0-3.0	110-160	280-440	44-61	970-1360	300-540	-
Kurian et al. (2003)	0.82-1.77[a]	110-261[a]	53-112[a]	21-50[a]	167-503[a]	75-217[a]	0.039-0.78[a]
	0.9-3.07[b]	191-657[b]	81-320[b]	31-247[b]	205-1070[b]	127-968[b]	0.61-2.73[b]

Note: [a] Perungudi dumpsite; [b] Kodungaiyur dumpsite

Chapter 3

Methodology

3.1 Introduction

This research study mainly included three parts; (1) characterization of solid waste and leaching ability of heavy metals; (2) determination of the leachate toxicity and investigation of the important toxic compound that influences the toxicity of leachate and (3) evaluation of the mining potential of the degraded waste in dumpsite. Figure 3.1 shows the diagram of the overall research of this study.

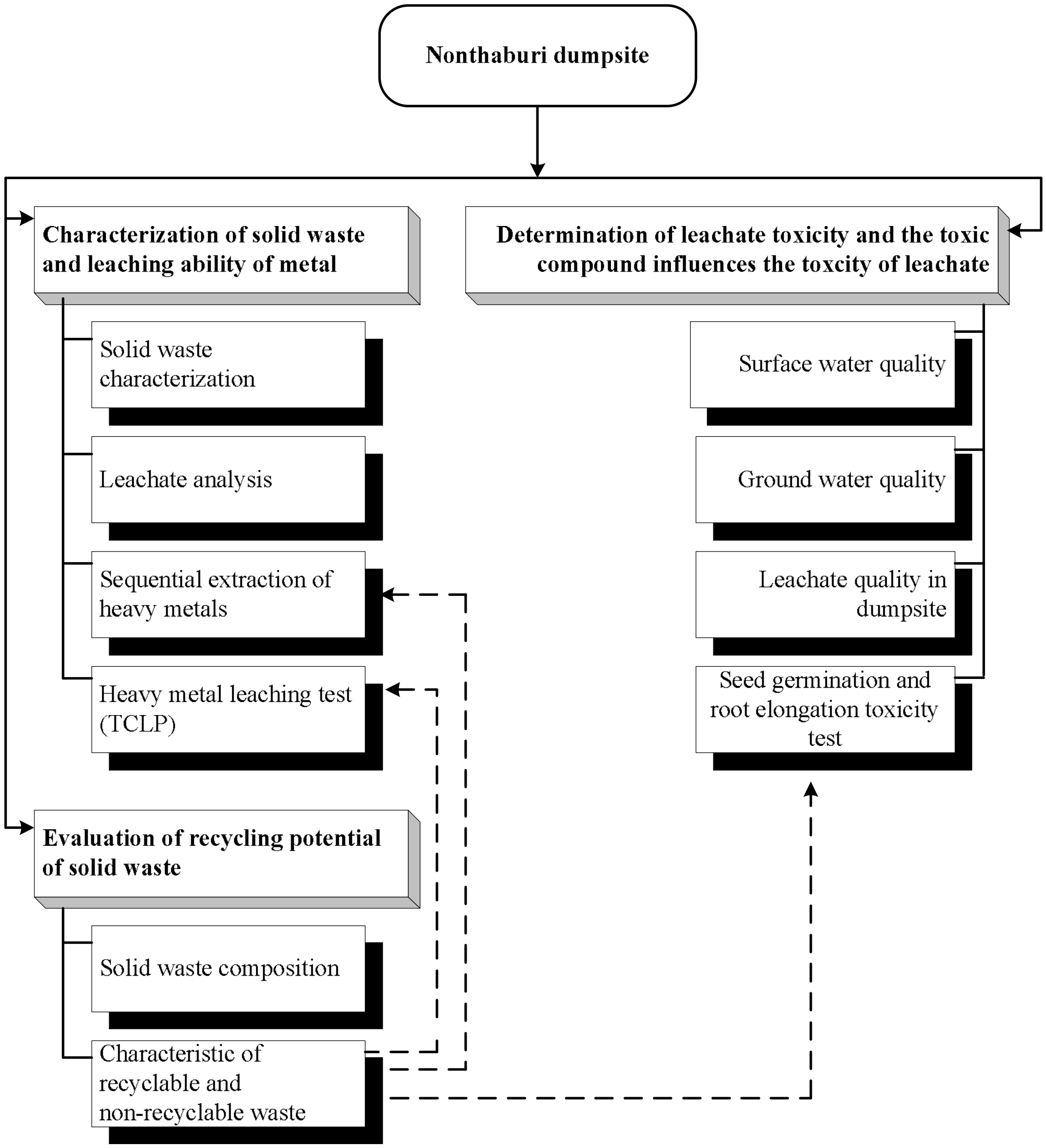


Figure 3.1 Research diagram

3.2 Characterization of solid waste and leaching ability of heavy metal

The objective of this study was to investigate the physical and chemical characteristics of solid waste and the leaching ability of heavy metals into the environment. The solid waste sample was collected from the dumpsite for characterization. The binding forms of heavy metals content in the solid waste were measured by sequential extraction of heavy metals. Moreover, leaching ability of heavy metals under acid condition was determined using the Toxic Characteristic Leaching Procedure (TCLP).

3.2.1 Solid waste sampling points

The solid waste samples were randomly collected from four sampling points (SW1-SW4) in the dumpsite. The backhoe excavator machine was used to collect about 150Kg of solid waste from every 1m depth interval from the surface of dumpsite up to 3m as shown in Appendix-A. The density of waste was then measured and the solid waste was collected in the plastic bags for physical and chemical analysis.

3.2.2 Physical and chemical analysis

To prepare the samples for physical and chemical analysis, the solid waste samples were initially air died until the weight of sample became stable and its air dried moisture content was measured. The samples were then grinded, screened through a 1.0 mm sieve and kept in plastic bag at 5°C. The solid waste characteristics with its analysis method are presented in Table 3.1

Table 3.1 Parameter and analysis method of solid waste

Parameter	**Analysis method**	**Source**
Moisture content	Drying at 105°C	ASTM (1993)
Ash/volatile solid	Ignition at 550°C	ASTM (1993)
pH	Electrometric method	ASTM (1993)
TOC	Walkley and Black' method	Nelson and Sommer (1982)
Mn, Cr, Cd, Cu, Pb, Ni, Zn	ICP-OES (PerkinElmer Optima 2100DV)	USEPA (2006)
Hg	ICP-OES (PerkinElmer Optima 2100DV)	Parkpian and Gambrell (1992)

(1) Solid waste preparation for heavy metal analysis

- An approximate amount of 1 g of solid waste was digested with 10 ml of 1:1 nitric acid at 95 ± 5 °C and reflux for 10-15 minutes and cooled, whereas the digestion of 1 g distilled water was performed as sample blank

- 5 ml of concentrated nitric acid were added and refluxed for 30 minutes (thereafter, nitric acid is repeatedly added until no brown fume was observed)

- Samples were heated continually until they were about 5ml in volume and then left for cooling.

- Other additions were 1.0 ml of distilled water, 3 ml of 30% H_2O_2 which were carefully heated to protect the sample loss during reaction and. Addition by 1 ml of 30% H_2O_2, but not more than 10 ml of total volume, were done repeatedly.

- Heating was done continuously until 5 ml of samples was received and digested by 10 ml of HCl for 15 minutes

- Samples' volume was finally adjusted to 100 ml

(2) Solid waste preparation for mercury analysis

- Approximately 0.2-2.0 g of solid waste was put into the BOD bottle that are weighed and were put in the refrigerator for 1 h for freezing

- 5ml of H_2SO_4, 5 ml of HNO_3, 15 ml of 5%w/v $KMnO_4$ were added. For a 15-minute interval, $KMnO_4$ was added until the purple color appeared

- BOD bottle was closed, incubated in an oven at 60 °C for 2 h and left overnight

- Addition of 5 ml of 5%w/v $K_2S_2O_8$ and 6 ml of Sodium chloride-hydroxylamine-hydrochloride (Dissolve 60g of NaCl and 60g of Hydroxylamine-hydrochloride in distilled water and adjust to 500 ml)

- Volume sample was adjusted by weighting, filtered through filter paper and kept at 4 °C until the time of analysis

- Calculation of the final weight of sample required for volume of sample adjustment is in the following Equation 3.1.

$$\text{Final weight of sample} = BOD + 100 + (A + B + C + D + E) \qquad \text{Equation 3.1}$$

Where

BOD = Weight of BOD bottle (g)
A = Weight of H_2SO_4 (g)
B = Weight of HNO_3 (g)
C = Weight of $KMnO_4$ (g)
D = Weight of $K_2S_2O_8$ (g)
E = Weight of NH_2OH+HCl (g)

3.2.3 Sequential extraction of heavy metals in solid waste

The binding forms of heavy metals except Hg content in the solid waste was measured following the Tessier's sequential extraction method (Rapin et al., 1986). The overall process of sequential extraction of solid waste is presented in Table 3.2. The successive extraction solution in each step was done by separating from the solid waste by centrifugation at 3000 rpm for 30 min. The supernatant was then filtered through the filter paper. The concentrations of heavy metals contents in the extracted samples were then measured by Inductively Couple Plasma - Optical Emission Spectrometer (ICP-OES).

Table 3.2 Sequential extraction method of heavy metal in solid waste

Step	**Fraction**	**Chemical reagents**
F1	Exchangeable	Add 8 ml of 1.0 N $MgCl_2$ (pH7) and shake at 20 ºC for 1 h
F2	Carbonate	Add 8 ml of 1.0M CH_3COONa (pH5) and shake at 20 ºC for 5 h
F3	Oxide of Mn/ Fe	Add 20 ml of 0.04 M $NH_2.OH.HCl$ in 25%CH_3COOH and agitate at 96 ºC for 6 h
F4	Organic matter and sulfide	Add 5 ml of 30% H_2O_2 (pH2) and 3 ml of 0.02M HNO_3 before heating at 85 ºC for 2 h Add 5ml of 3.2 M CH_3COONH_4 in 20% HNO_3, dilute to 50 ml and agitate for 30 min
F5	Residual	According to heavy metal analysis method in solid waste

The contamination factor (Cf^i) of heavy metals content in the solid waste was calculated by dividing the summation of heavy metal present in the mobile fraction (F1-F4) with its non-mobile phase (F5). The global contamination factor (Cf) of heavy metal in different sampling points, in addition, was equal to the summation of contamination of each heavy metal determined at that site (Barona et al., 1999; Fernandez, 1997). The estimation of contamination factor of heavy metal is presented in Equation 3.2 and Equation 3.3

$$\text{Contamination factor } (Cf^i) = \frac{F1 + F2 + F3 + F4}{F5} \qquad \text{Equation 3.2}$$

$$\text{Global contamination factor (Cf)} = \sum Cf^i \qquad \text{Equation 3.3}$$

Where

i = Heavy metals
F1 = Concentration of heavy metals in exchangeable form
F2 = Concentration of heavy metals in carbonate form
F3 = Concentration of heavy metals absorbed on oxide of Mn/Fe
F4 = Concentration of heavy metals absorbed on organic matter and precipitated with sulfide
F5 = Concentration of heavy metal in residual form

3.2.4 Leaching test of heavy metal in solid waste

The TCLP method 1311 proposed in USEPA (2006) was applied in this study to evaluate the leaching ability of heavy metals under the acid condition. The TCLP extraction process in this study included two parts:

(1) Preliminary evaluation

The total solid content in the solid waste was initially analyzed by drying at 103 °C. The suitable pH level of extraction fluid for solid waste was then determined by extraction of 5 g of solid waste with 96.5 ml of distilled water for 5 minutes. Because the pH level of the extracted solution was >5.0, 3.5 ml of 1N hydrochloric acid was added into the sample and heated at 50 °C for 20 minutes. The analysis result indicated the TCLP extraction solution with pH 4.9±0.05 was suitable for this waste. The TCLP extraction fluid was then prepared from 500 ml of distilled water, 5.7 ml of glacial acetic acid, 64.3 ml of 1N NaOH and adjusted to 1000 ml.

(2) Solid waste extraction

The TCLP extraction of solid waste was performed in the polyethylene bottle at 1:20, solid waste to extraction fluid ratio. The sample was agitated at 30 rpm for 18±2 h and filtered through GFC filter. The pH value and heavy metals concentration were then measured. For heavy metal analysis, the preparation and analysis method was done following the analysis method of leachate, groundwater and surface water quality. The overall process diagram of TCLP extraction are summarized in Figure 3.2. In addition, the estimation of heavy metal leaching rate from the waste is presented in Equation 3.4.

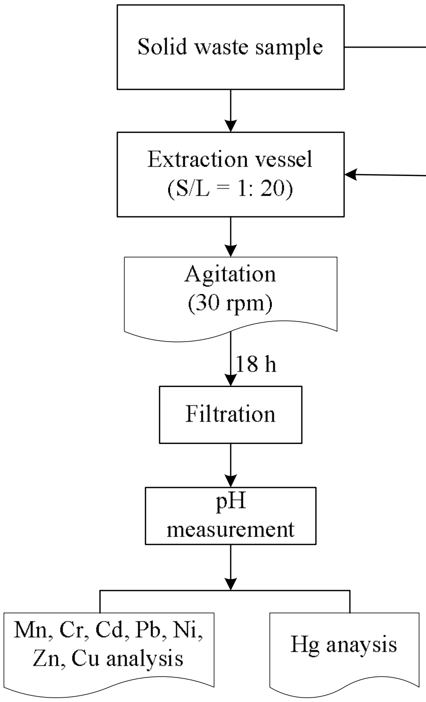


Figure 3.2 TCLP extraction process in this study

$$HR(\%) = \frac{C_L \times L \times 1000 \times 100}{S_W \times C_S} \qquad \text{Equation 3.4}$$

Where;

HR = Heavy metal leaching rate (%w/w)
C_L = Heavy metal concentration of extracted leachate (mg/L)
C_S = Heavy metal concentration of solid waste (mg/kg)
L = TCLP leachate volume (L)
S_W = Solid waste sample size (g)

3.3 Determination of leachate toxicity and the toxic compound influences the toxicity of leachate

The heavy metals leaching in the actual condition of dumpsite was determined in the runoff leachate and leachate boreholes. In addition, the characteristic of leachate accumulate in the leachate treatment system and leachate ponds were measured to identify the variation of leachate quality within the dumpsite. Contamination of toxic compounds into the environment was investigated through groundwater and surface water resource in the surrounding area. Furthermore, the toxicity of leachate and the important toxic compounds that influenced the toxicity of leachate was investigated using the seed germination and root elongation test.

3.3.1 Leachate, surface water and groundwater sampling points

The leachate samples of dumpsite were collected from eight points. Runoff leachate (L) was collected in the open pipe, and two leachate samples were collected from leachate boreholes (BH1 and BH2) installed on dumpsite. There were two leachate samples collected from the leachate treatment system (T1, T2), and three samples of leachate ponds (P1-P3).

Groundwater characterization was performed in four monitoring wells (MW1-MW4). The first well (MW1) is located behind the dumpsite, whereas the second well (MW2) is between the dumpsite and leachate pond P2. The third well (MW3) is near the leachate pond P1 and the fourth well (MW4) is beside the leachate treatment system.

Surface water samples in dumpsite were randomly collected in ponds and canals nearby the dumpsite (S1-S5, S7). In addition, water quality in Klong Bang Khun Sri (S6) and Klong Ha Roi (S8), which are far from dumpsite, were identified as background water quality in this area. The overall leachate, groundwater and surface water sampling points are presented in Figure 3.3 and Appendix-B.

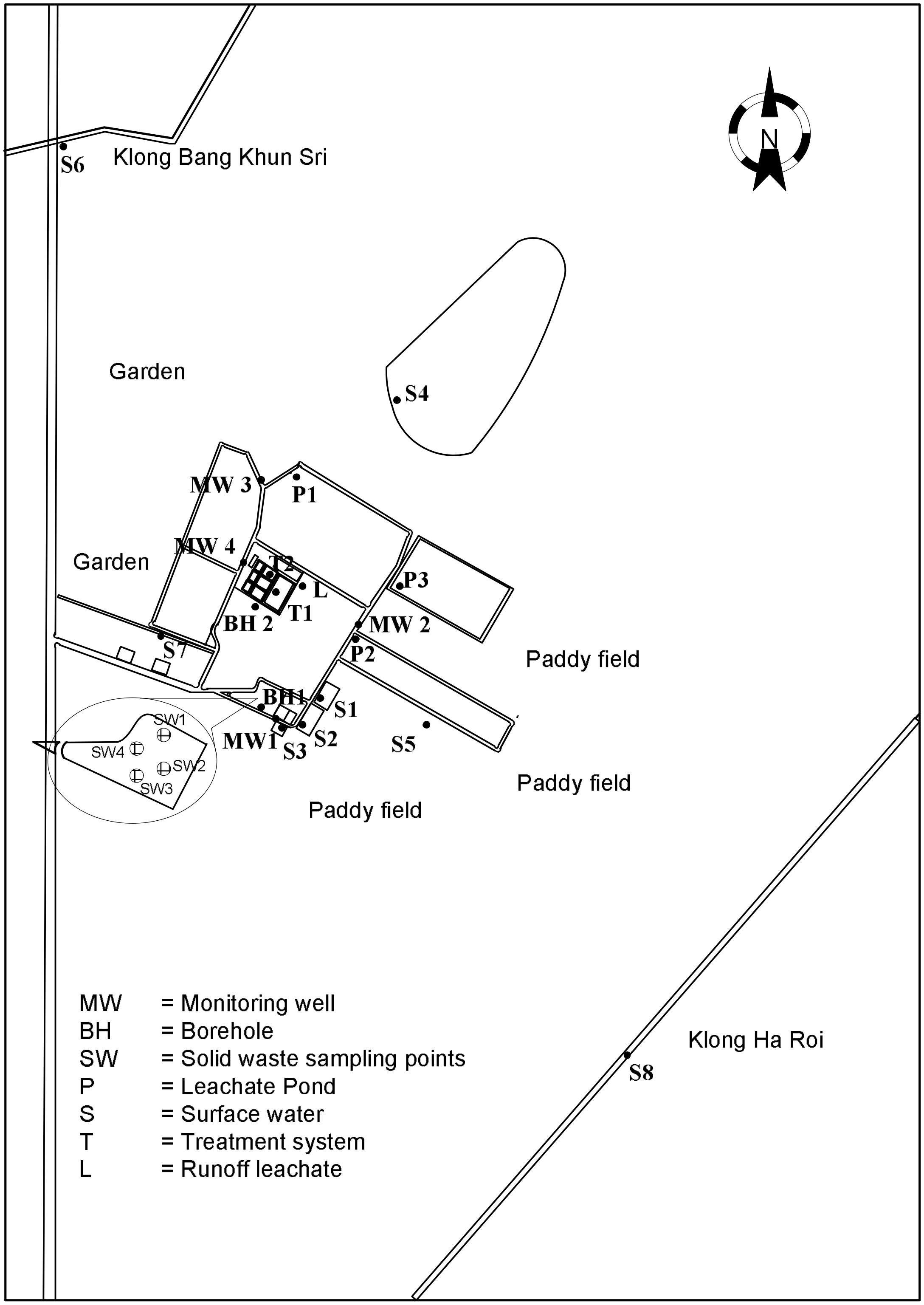


Figure 3.3 Solid waste, leachate, surface water and groundwater sampling stations

3.3.2 Leachate, surface water and groundwater sampling and analysis

Characteristics of leachate, groundwater and surface water samples were measured between November 2005 to June 2006. All the samples were collected in the polyethylene bottle that was properly cleaned by 10% nitric acid and rinsed by distilled water. The samples were preserved and kept at 4 ºC. The characteristic of water and its preservative and analysis method followed the standard method of the examination of water and wastewater (APHA et al., 1998). Details are presented in Table 3.3. The preparation of water samples for Hg analysis, however, followed the method proposed by Parkpian and Gambrell (1992) as summarized below:

Preparation of water sample for mercury analysis

- An approximate amount of 100 ml of water was digested in the BOD bottle for the preliminary weight. The water was left for freezing for 1 hour prior to digestion.

- 5 ml of H_2SO_4, 2ml of HNO_3, 15 ml of 5% w/v $KMnO_4$ were added and left for 15 minutes. Continuous adding of $KMnO_4$ was performed until the purple color was observed visible

- Addition of 8 ml of 5% w/v $K_2S_2O_8$, close BOD, incubated at 95 °C for 2 h and cooled at room temperature

- Addition of 6 ml of sodium chloride-Hydroxylamine-hydrochloride, left for 5 minutes, filtered and kept at 4 °C until the time of analysis.

Table 3.3 Analysis method of leachate, groundwater and surface water characteristics

Parameter	**Leachate**	**Surface water**	**Groundwater**	**Preservation**	**Analysis/Equipment**
pH	Yes	Yes	Yes	_	pH meter
EC	Yes	Yes	Yes	_	Electrical conductivity meter
TDS	Yes	Yes	Yes	_	Drying at 104 ºC
Alkalinity	Yes	Yes	Yes	_	0.02 N H_2SO_4 titration method
COD	Yes	Yes	Yes	H_2SO_4 ; pH<2	Close reflux
BOD_5	Yes	Yes	None	H_2SO_4 ; pH<2	Azide Modification
TOC	Yes	None	None	H_2SO_4	TOC analyzer (SHIMAZU TOC-2000)
TKN	Yes	None	None	H_2SO_4	Macro-Kjeldhal Method
NH_4-N	Yes	Yes	Yes	H_2SO_4	Distillation and 0.02N H_2SO_4 Titration method
NO_3-N	Yes	Yes	None	H_2SO_4	Cadmium reduction method
TP	Yes	Yes	None	HCl	Ascorbic acid
Mn, Cr, Cd, Cu, Pb, Ni, Zn	Yes	Yes	Yes	HNO_2; pH<2	HNO_3 digestion / ICP-OES(PerkinElmer Optima 2100DV)
Hg[a]	Yes	Yes	Yes	HNO_2; pH<2	Hydride generation system equipped with ICP-OES

Note: [a] Preparation of samples followed to Parkpian and Gambrell (1992)

3.3.3 Leachate toxicity test

The environmental toxicity of leachate was evaluated using the seed germination rate and root elongation toxicity testing with rice seed (*Oryza sativa* L. Pathumthani 1), which is considered as a local sensitive specie of plant. The rice seed used in this test was available from the Department of Agriculture of Thailand. The toxicity test of leachate in this study consisted of two parts (1) determination of leachate toxicity and (2) identification of toxicant that influences the toxicity of leachate. The research flow diagram of study is presented in Figure 3.4.

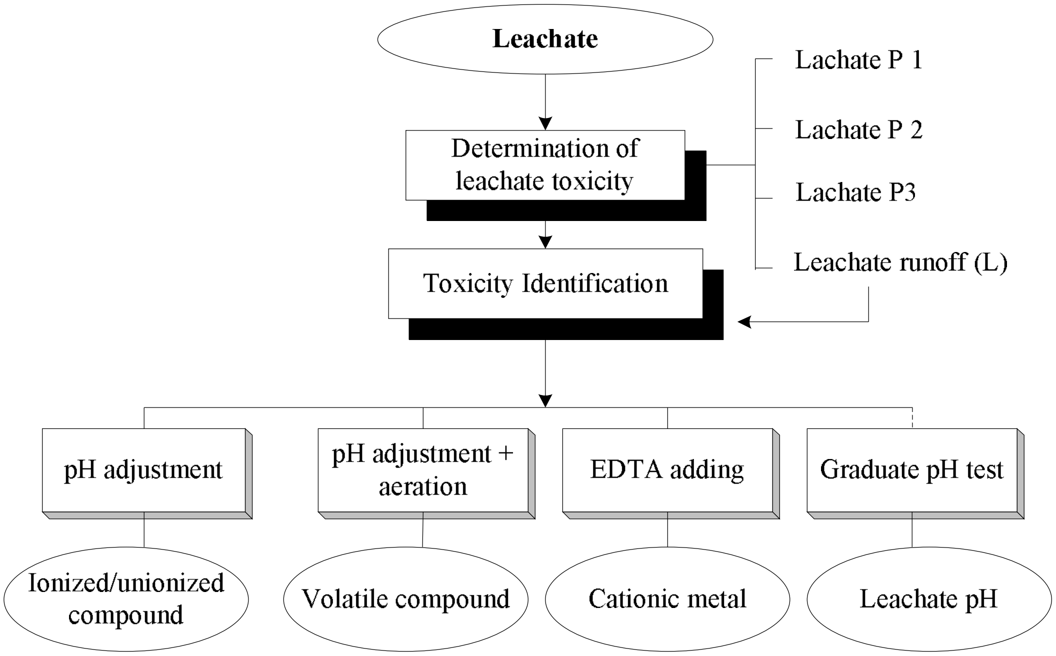


Figure 3.4 Flow diagram of leachate toxicity test

(1) Leachate toxicity testing

To determine the environmental toxicity of leachate, the acute toxicity test of leachate was performed in four leachate samples including the runoff leachate (L) and three samples from leachate ponds (P1-P3) collected in April and May 2006. The leachate toxicity test procedure followed the seed germination and root elongation test guideline (USEPA, 1996). In this test, 15 seeds of rice were placed into the Petri dish containing 10ml of leachate sample that was prepared in six different concentrations. The samples were then incubated at 25 ± 1.0 ºC for 96 h and measured for seed germination and root elongation rate of the rice. The toxicity test condition and seed germination definition are presented in Table 3.4 and Appendix-C. The relative seed germination rate (RSG), relative root growth (RRG) and germination index (GI) was then calculated according to Equation 3.5, Equation 3.6 and Equation 3.7. Moreover, the 50% inhibiting concentration of leachate (IC_{50}) was determined using Trimmed Spearman-Karber (TSK) program version 1.5 (USEPA, 2006).

Table 3.4 Operational procedure in seed germination test of leachate

Test species	*Oryza Sativa* L. (Pathumthani 1)
Pretreatment	No
Temperature of incubation	25 ± 1 ˚C
Light	No
Container and support media	100x10mm Petri dish, Whatman filter paper No.1
Leachate concentration	P1, P2, P3 : 10, 20, 30, 40, 50, 60 %v/v L (April): 2, 4, 6, 8, 10, 12 % v/v L (May): 1, 2, 4, 6, 8, 10% v/v
Leachate volume	10 ml/disc
No. of seeds/disc	15
No. of replications	4
Control group	Distilled water
Test duration	96 h
Definition of seed germinated	Primary root length ≥ 5mm measuring from the transition point of root and hypocotyls to root tip

$$RSG(\%) = \frac{S_S \times 100}{S_C} \qquad \text{Equation 3.5}$$

$$RRG(\%) = \frac{R_S \times 100}{R_C} \qquad \text{Equation 3.6}$$

$$GI(\%) = \frac{RSG \times RRG}{100} \qquad \text{Equation 3.7}$$

Where

Ss = No. of seed germinated in sample
Sc = No of seed germinated in control
Rs = average root length of sample (cm)
Rc = average root length of control (cm)

(2) Toxicity identification of leachate

This study aimed to identify the important of ionized compound, volatile compound, heavy metals and pH level influencing the toxicity of leachate. The overall processes in this experiment are summarized in Figure 3.5 and Table 3.5.

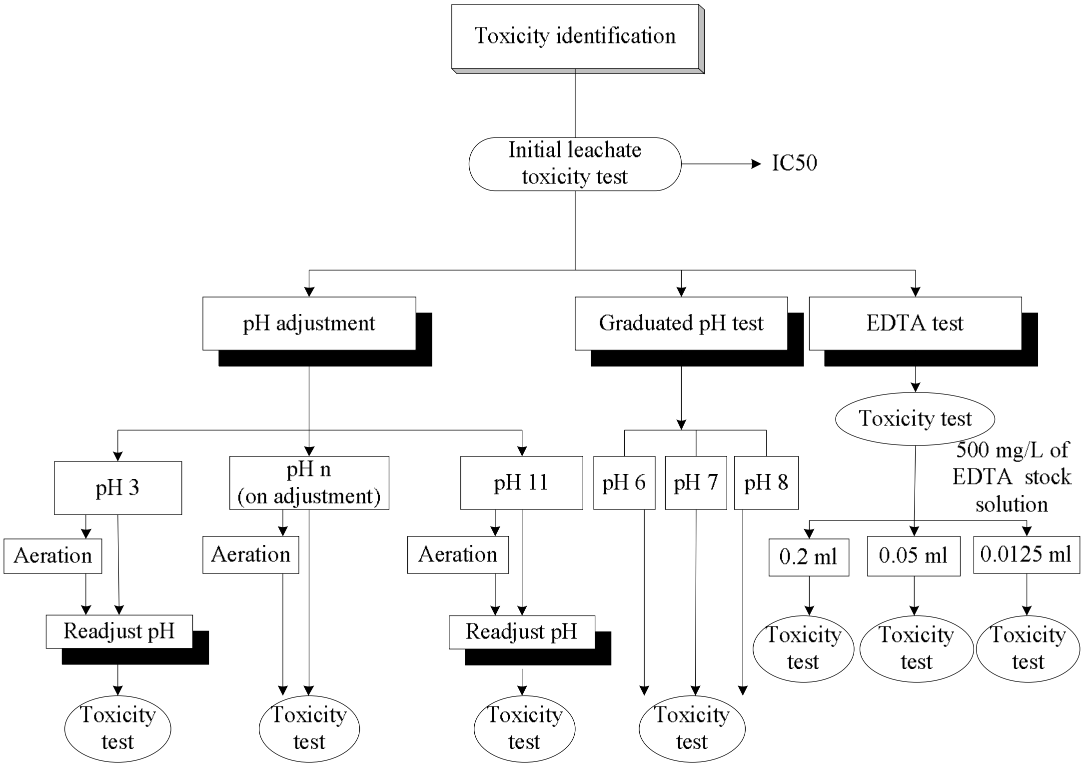


Figure 3.5 Toxic identification processes of leachate toxicity

a. pH adjustment test

To determine the influence of ionized and unionized toxic compound in leachate, the pH value (pH n) of the runoff leachate collected in May 2006 was adjusted to pH 3 and pH 11 by the use of 1.0, 0.1, and 0.01N of HCl and NaOH. The leachate pH 3 and pH11, however, were then readjusted to the initial pH level before resubmitting to toxicity testing. The toxicity for leachate pH n, pH 3 and pH 11 were then examined.

b. pH adjustment and aeration test

The toxicity of volatile compound in leachate was evaluated using air stripping method to eliminate this volatile compound from leachate before toxicity testing. Approximate 100 ml of leachate samples at pH n, pH 3 and pH 11 were aerated for 60 minutes and readjusted to the initial pH level of leachate before toxicity testing.

c. EDTA adding test

The identification of the effect of cationic heavy metal to the toxicity of leachate was conducted. The synthetic heavy metal chelating agent ethylenediamine tetra-acetic acid (EDTA) was added into leachate sample. Before starting with this experiment, however, the inhibiting toxicity of EDTA to the germination and root elongation of rice (*Oryza sativa* L.) was screened by toxicity test of EDTA. The median inhibiting concentration (IC_{50}) of EDTA specific to rice plant was then determined and used in the preparation of the EDTA stock solution. The toxicity test process can be summarized as:

- An approximate amount of 450 mg/L as $CaCO_3$ of hardness and 15 g/L of salinity of synthetic dilution water, which is equivalent to the runoff leachate, was prepared from the $CaCO_3$ and NaCl.

- The toxicity of EDTA to inhibit the seed germination and root elongation rate of rice was screened by toxicity test of EDTA with rice using the synthetic dilution water. The screening test result indicated that the needed amount of $IC_{50}GI$ of EDTA was about 500 mg/L before it could be prepared as a stock solution of EDTA for the toxicity test of leachate.

- 0.2, 0.05, and 0.0125 ml of 500 mg/L EDTA stock solution was added into each plate of leachate samples for toxicity test. In addition the toxicity of EDTA at 0.2, 0.05, and 0.0125 ml were added into the distilled water to identify as control samples.

d. Graduated pH test

The graduated pH test was done to determine whether toxicity of leachate depends on the pH level of leachate. The pH level of leachate (pHn) was adjusted to pH 8, pH 7, and pH6 using HCl and NaOH. The toxicity of leachate at pHn, pH8, pH7 and pH6 were then tested without the readjustment of pH level.

Table 3.5 Operational procedure in seed germination test in the toxic identification part

Test species	*Oryza Sativa* L. (Pathumthani 1)
Pre-treatment	No
Temperature of incubation	25 ± 1 ˚C
Light	No
Container and support media	100x10mm Petri dish, Whatman filter paper No.1
Leachate concentration	$0.25xIC_{50}$, $0.5xIC_{50}$, $1.0x\ IC_{50}$, $2.0xIC_{50}$
Leachate volume	10 ml/dish
No. of seeds/disc	15
No. of replications	4
Control group	Distilled water
Test duration	96 h
Definition of seed germination	Primary root length ≥ 5mm measuring from the transition point of root and hypocotyls to root tip

IC_{50} was received from the initial leachate toxicity test

3.4 Determination of recycling potential of waste in the dumpsite

The objective of this study was to determine the mining potential of dumpsite and its ability to be recycled. The composition of the excavated waste and its size distribution were classified. The physical and chemical characteristics of the waste were determined to evaluate the recycling ability of waste. In addition, phytotoxicity of soil to be recycled as compost was evaluated using the seed germination and root elongation toxicity test. Furthermore, sequential extraction analysis and TCLP leaching test was conducted to determine the leaching potential of heavy metal so that wastes to be recycled are composted and non-recyclable waste to be disposed into the landfill.

3.4.1 Solid waste classification

a. Solid waste classification based on types

The composition of solid waste in each sampling points was determined. The solid waste sample was initially air dried at the open dump. The compositions of solid waste was then manually classified as plastic, paper, wood, textile, rubber/leather, glass, stone/ceramic, foam, metal and fine particle which included the dry cell battery.

b. Solid waste size distribution

In this study, the solid waste size distribution was determined by feeding the solid waste into the trommel screen, which has an opening size at 25mm and 50mm (Appendix-A). The trommel has 3.0 m length, 1.0m diameter and it rotates at 8 rpm using 5 Hp motor. Figure 3.6 shows the diagram of trommel screen. The composition of each solid waste fraction was then classified and taken for physical and chemical analysis.

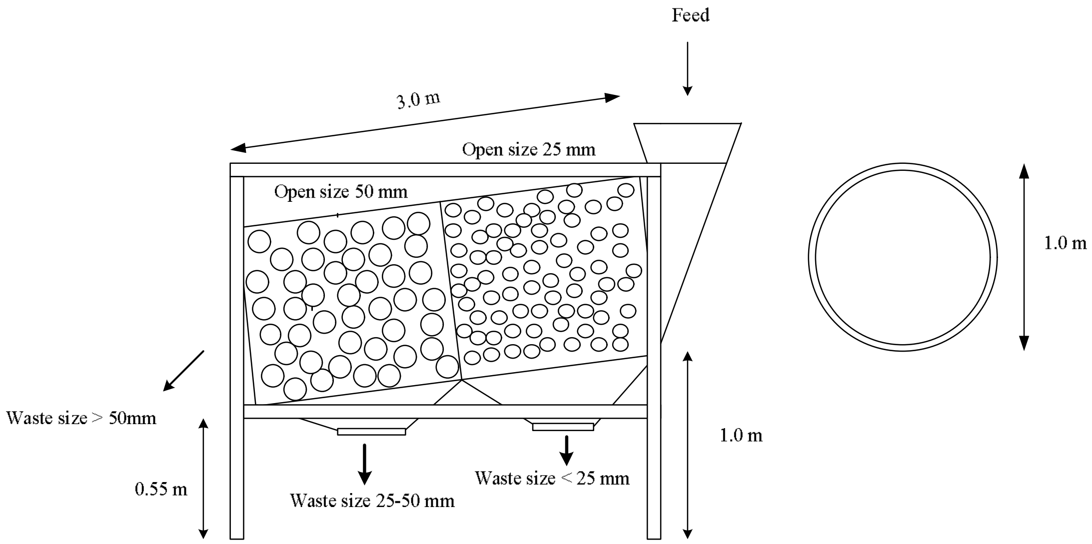


Figure 3.6 Schematic diagram of trommel screen

Table 3.6 Parameter and analysis method of waste reclaimed from dumpsite

Parameters	**Waste< 25 mm**	**Waste 25-50mm**	**Waste > 50mm**	**Analysis method**	**Source**
Ash	Yes	Yes	Yes	Ignition at 550 °C	ASTM (1993)
Calorific value	None	None	Yes	Bomb calorimeter (Cal2K-CAL2K.EC)	ASTM (1993)
TOC	Yes	Yes	None	Walkley and Black' method	Nelson and Sommer (1982)
TKN	Yes	Yes	None	Kjeldahl method	Bremner and Mulvaney (1982)
Total-P	Yes	Yes	None	HClO4 + HNO3 digestion and colorimetric method	Olsen and Sommer (1982)
Total-K	Yes	Yes	None	HClO4 + HNO3 digestion and Flame atomic absorption spectrophotometer	Knudsen et al. (1982)
Mn, Cr, Cd, Cu, Pb, Ni, Zn	Yes	Yes	Yes	ICP-OES (PerkinElmer Optima 2100DV)	USEPA (2006)
Hg	Yes	Yes	Yes	ICP-OES (PerkinElmer Optima 2100DV)	Parkpian and Gambrell (1992)

3.4.2 Characterization of the segregated waste from dumpsite

The physical and chemical characteristics and analysis method of each waste fraction are presented in Table 3.6. Concentration of heavy metal content in plastic waste was measured. Moreover, the estimated concentration of heavy metal in the composite waste was determined according to Equation 3.8 (Jian et al., 2005).

$$\text{Concentration of heavy metal (j) in composite waste } = \frac{\sum_i CijPi}{\sum_i Pi} \qquad \text{Equation 3.8}$$

Where

i = Solid waste size > 50mm, 25-50mm and < 25mm;

Pi = Percentage of waste ith, which $\sum_i Pi = 100$

Cij = Concentration of heavy metal (j) in the waste ith fraction

3.4.3 Seed germination and root elongation test of soil

To evaluate the recycling potential of soil as compost, phytotoxicity of soil was evaluated by using the seed germination and root elongation test of rice. The 10 g of waste size < 25 mm and 25-50 mm was extracted with distilled water at1:10 ration, solid waste to liquid, for 15 h. The samples were then centrifuged and filtered using the Whatman filter paper No.1 (Walter et al., 2006). The seed germination rate, root elongation rate and germination index of rice were determined as present in Equation 3.5 to Equation 3.7. The toxicity test condition of soil is shown in Table3.7.

Table 3.7 Soil toxicity test condition

Test species	*Oryza Sativa* L. (Pathumthani 1)
Pre-treatment	No
Temperature of incubation	25 ± 1 ˚C
Light	No
Container and support media	100x10mm Petri dish, Whatman filter paper No.1
Concentration	100% v/v of extracted water
Leachate volume	10 ml/dish
No. of seeds/disc	15
No. of replications	4
Control group	Distilled water
Test duration	96 h
Definition of seed germinated	Primary root length ≥ 5mm measuring from the transition point of root and hypocotyls to root tip

3.5 Statistical analysis

The analysis of variance (ANOVA) was performed in this study to compare the leachate, groundwater and solid waste quality between the sampling points by SPSS for window program version 10.0. In addition, the distribution of toxic compounds concentration in leachate and surface water was determined using the Golden surfer program version 8 available from Golden Software Inc. (2002).

Chapter 4

Results and Discussion

The research results and discussion is divided into four sections. In the first section, the solid waste characteristics, binding forms and leaching potential of heavy metals content in solid waste are discussed. Next to this section, the results relate to heavy metal leaching in the leachate and the variation of leachate quality in the dumpsite is discussed. Moreover, the contamination of leachate in surface water and groundwater resources, toxicity of leachate and factors influencing the toxicity of leachate are discussed in this part. The results related to recycling potential of mined waste in the dumpsite are discussed in the third section. Finally, the potential practical application of research result in the municipal solid waste management is discussed in this study.

4.1 Solid waste characteristic and heavy metal leaching potential

The variation of solid waste characteristics was observed in four solid waste sampling points (SW1-SW4) and every 1 m depth interval (0-1, 1-2 and 2-3 m) of dumpsite. The sequential extraction of solid waste showed the binding forms of heavy metals content in the waste. Moreover, the contamination factor (Cf^i) indicated the heavy metal mobility from solid waste. In this study, leaching potential of metal from solid waste under acidic condition was determined by the Toxic Characteristic Leaching Procedure (TCLP) test at pH 4.9±0.05 of extraction fluid. The variation of heavy metal concentration in leachate and its leaching rate from solid waste under acidic condition was observed in this test.

4.1.1 Physical and chemical characteristic of dumpsite

The physical and chemical characteristics of solid waste in various sampling points and depth intervals of dumpsite are presented in Appendix-D (Table D-1). The average bulk density, moisture, volatile solid, pH and total organic carbon in various sampling points are presented in Table 4.1. There was no significant difference of physical and chemical characteristics of solid waste between the sampling points on dumpsite (Appendix-D; Table D-5 to Table D-7). The observed 42-54% w/w of moisture content in solid waste was found to be in the optimal range (40-70%) for microbial activity in biodegradation of organic matter (Lema et al., 1988; Reinhart and Townsend, 1998).

Table 4.1 Characteristic of solid waste in various solid waste sampling points

Sampling point	**Density**	**Moisture**	**pH**	**VS**	**TOC**	**OM/TOC**
	(kg/m^3)	**(% w/w)**		**(%w/w)**	**(%w/w)**	
SW1	286.0	42.0	7.5	36.0	15.0	2.5
SW2	346.0	48.0	7.4	39.0	18.0	2.3
SW3	332.0	54.0	7.5	32.0	20.6	1.7
SW4	292.0	45.5	7.7	54.0	14.6	4.3

The volatile solid (VS) and total organic carbon (TOC) concentration of solid waste are within the ranges 32-54% and 14.6-20.6% w/w, respectively. This indicates the amount of organic matter (OM) and biodegradable organic carbon left in the dumpsite where its biodegradation influenced the environmental condition and mobilization of heavy metal in the dumpsite. The volatile solid concentration was relatively high in SW4, but total organic carbon concentration was relatively low. In addition, the OM/TOC of waste at SW4 was much higher than other points indicating the difficulty in the biodegradability of waste in this point compared to other points. In addition, this indicates the varying biodegradability of waste in dumpsite. Pascual et al. (1997) found that the OM/TOC ratio in the MSW and mature compost was about 2.2 and 2.7, respectively. As the result, pH value of dumpsite was found to be in neutral range indicating the sufficient acid buffer capacity of dumpsite.

It was found that bulk density of dumpsite was relatively low compared to other dumpsites. Kurian et al. (2003) reported that the density of Perungudi and Kodumgaiyur dumpsite in India was about 965 kg/m^{3}and 1106 kg/m^3, respectively. Ratanaudom (2005) also reported that the density of Pathumthani dumpsite in Thailand ranges from 740 to 1730 kg/m^3. The lower density of dumpsite can be attributed to its higher plastic waste composition which comprises 40% of the total waste in the dumpsite. Discussion of solid waste composition in dumpsite is presented in section 4.3.

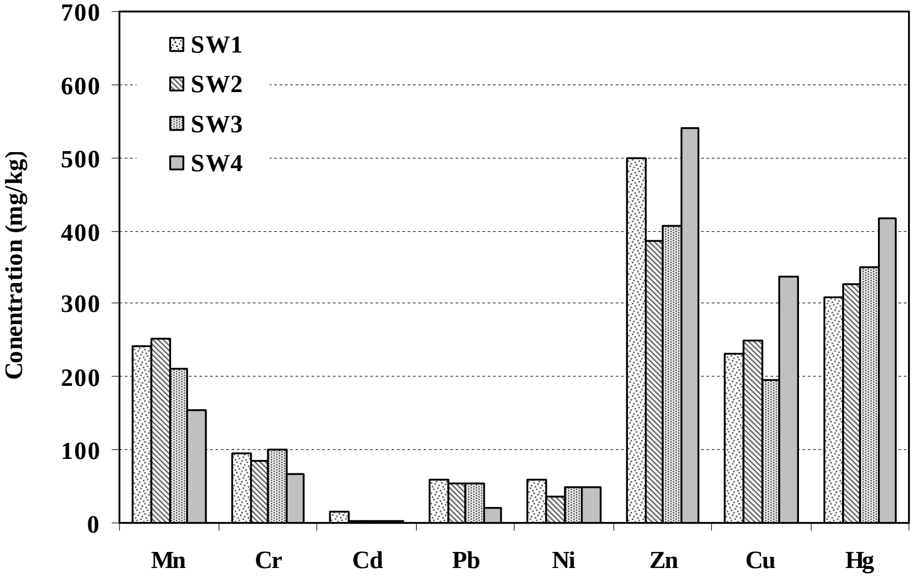
The significant variation of density, moisture and pH level of solid waste were also found in the vertical profile of dumpsite as presented in Appendix-D (Table D-8 to Table D-10). As a result presented in Table 4.2, the observed 260 kg/m^3 solid waste density was lowest at the surface and increases significantly at 1-2 m depth. This corresponded to the moisture content in the dumpsite. The result shows the relatively low concentration of moisture content at the surface layer due to water evaporation. Next to 2-3 m, the moisture content slightly increased to 53.5%. This may have implied the saturation of moisture content at this point. With the high plastic component including leachate accumulation at 2-3 m, the density of dumpsite was found to decrease at 2-3 m depth, which can affect the characteristic of gas and water distribution and biodegradation of organic matter in this point.

Table 4.2 Characteristic of solid waste in various depth intervals of dumpsite

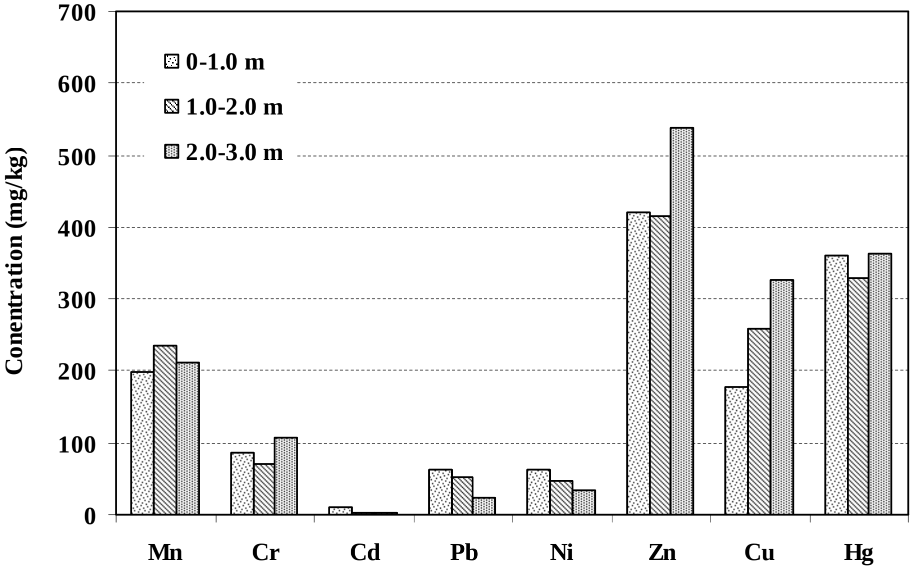
Depth	**Density**	**Moisture**	**pH**	**VS**	**TOC**	**OM/TOC**
	(kg/m^3)	**(% w/w)**		**(%w/w)**	**(%w/w)**	
0.0 -1.0 m	260.0	37.3	7.3	40.0	21.0	2.1
1.0 -2.0 m	392.0	50.6	7.6	41.3	14.6	3.3
2.0 -3.0 m	292.0	53.5	7.7	39.4	15.6	2.6

According to the result, moreover, the variation of biodegradation of solid waste in dumpsite in the vertical profile of dumpsite was observable. There was no significant difference of VS concentration found in various depth intervals which suggest the similar level of organic compound remaining in the dumpsite. On the other hand, approximately 21% of TOC concentration was observed at the 0-1.0 m depth and decreases at the lower layer of dumpsite. In addition, the approximate 2.1 of OM/TOC ratio indicates the relatively high biodegradable organic matter remaining at 0-1.0 m depth. This can be due to the lower biodegradation of organic matter at this depth due to the relatively low moisture content (37.3%). As the moisture content increases at 1-3 m, the biodegradation of organic compound in the waste increased. This is confirmed by the significant increase of pH level from pH7.3 to pH 7.7 with the depth of dumpsite (Das et al., 2002; Townsend et al., 1996). Moreover, the increased pH level indicates the anaerobic degradation at the bottom of dumpsite, which consequently influenced the mobility of heavy metals.

4.1.2 Heavy metal concentration



(a) Concentration of heavy metals in various sampling sites



(b) Concentration of heavy metals in various depth intervals

Figure 4.1 Concentration of heavy metals in various sampling points and depth intervals (Hg is present as μg/kg)

Table 4.3 Comparison of heavy metal concentration in Nonthaburi dumpsite with other MSW landfills and dumpsites

Metal	**Nonthaburi dumpsite**		**Sweden** [a]	**China** [b]	**China** [c]	**India** [d]	**India** [d]
	Mean	**Range**					
Mn (mg/L)	217	100-352	-	-	-	-	-
Cr (mg/L)	92	57-186	31-78	323-545	110-160	110-261	191-657
Cd (mg/L)	7.5	0.2-38.0	0.9-1.2	4.7-11.3	1.0-3.0	0.8-1.8	0.9-3.0
Pb (mg/L)	50	13-127	90-270	206-777	280-440	53-112	81-320
Ni (mg/L)	50	26-94	10-15	40-90	44-61	21-50	31-247
Zn (mg/L)	455	275-587	180-510	384-913	970-1360	167-503	205-1070
Cu (mg/L)	265	119-545	34-36	107-320	300-540	75-217	127-968
Hg (µg/L)	352	202-513	-	-	-	39-780	610-2730

Source: [a]Hogland et al. (2004); [b]He et al. (2006); [c]Xiaoli et al. (2007); [d]Kurian et al. (2003)

Figure 4.1 shows the heavy metal concentration in various solid waste collection points and depth intervals. The concentration of all the heavy metals was found to be different insignificantly between the sampling points and depth intervals (Appendix D; Table D-5 to Table D-10). The concentration of Zn was highest in dumpsite, whereas Hg was lowest. Based on the average concentration, the heavy metal content in solid waste was found to be of the following order: Zn> Cu> Mn> Cr> Pb> Ni> Cd > Hg. This can be attributed to the high generation rate of heavy metal in MSW. Schouw et al. (2002) found that generation of Zn in kitchen waste was higher than Cu, Ni, Pb, Cd and Hg. In addition, Zn concentration in MSW was found to be relatively high, whereas Cd and Hg were relatively low (Riber et al., 2005). The concentration of heavy metals content in the excavated waste from dumpsite was found to be in the normal range compared to other studies as presented in Table 4.3.

4.1.3 Binding forms of heavy metals in the dumpsite

The binding forms of heavy metals except Hg content in solid waste are presented in Figure 4.2. Most of the fraction of Mn in solid waste was present as manganese oxide and carbonate bound. However, the concentration of Mn in these forms was different in each collection location. The concentration of Mn oxide with 64% and 83% w/w was found at SW1 and SW2, whereas the carbonate bound Mn was relatively low. In contrast to this, the Mn oxide concentration went lowered to 28% and 39% w/w at SW3 and SW4, whereas the carbonate bound Mn increased significantly. The Mn oxide was relatively sensitive to the redox potential change. Generally, Mn oxide can be formed and is stable in a high redox potential, neutral and alkaline environment. Therefore the observed high portion of Mn oxide at SW2 and SW1 confirms the oxidizing condition prevailing in the locations, whereas the anaerobic condition was found at SW3 and SW4. For the carbonate bound Mn, the higher concentration of carbonated bound Mn at these points was a consequence of alkaline related carbonate compound increasing in the anaerobic biodegradation of solid waste. The remaining fractions of Mn were found in the organic and sulfide, exchangeable, and residual bound, respectively.

Similar to Mn, large fraction of Zn and Cd were found to be adsorbed on the Mn/Fe oxide. The high portion of these compounds was also found at SW1 and SW2. In addition, the carbonate bound Zn and Cd also increased at SW3 and SW4. The above results indicate the consequence of ferric hydroxide, manganese oxide and carbonate compound to adsorb and immobilize Zn and Cd in the dumpsite. The presence of oxidizable and acid soluble fraction of Zn noticed at SW3 and SW4 confirms the prevailing low redox potential at these locations. Among all the metals, Cd was found highly in exchangeable form of about 10 – 20%.

The capacity of organic matter and sulfide to adsorb and precipitate Cu and Cr in the dumpsite was noticed. Approximately, 80-90% of Cu and 30-60% of Cr content in dumpsite was adsorbed on the organic matter or precipitated with sulfide. In the oxidation condition of dumpsite, however, sulfide can be oxidized to sulfate in the oxidation condition. It was found that concentration of organic/sulfide bound Cu was similar on each collection point. This might be due to the high tendency of Cu to be adsorbed on organic matter (Alloway, 1995). The smaller fraction of Cu was found as the residual fraction, while 12-31% of Cr was found in Mn/Fe oxide bound and residual form.

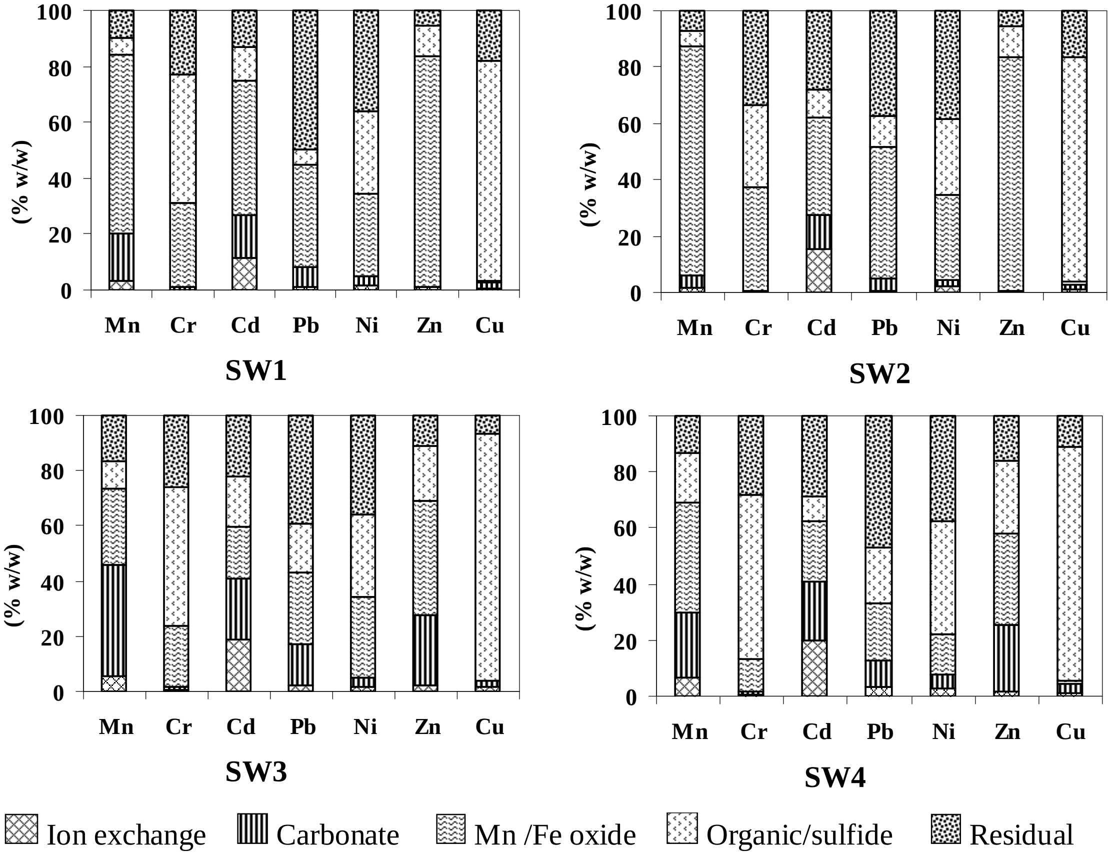


Figure 4.2 Heavy metal binding forms in different solid waste sampling sites

Similar to other metals, Pb and Ni were adsorbed on Mn/Fe oxide and organic matter. On the other hand, a largest fraction of these metals was present in the residual form which is generally insensitive to the environmental change. This fraction, therefore, is considered as an insoluble fraction which is unexpected to release from the waste.

Based on the result, its can be concluded that the variation of oxidation-reduction potential in dumpsite is relatively high. This influences the binding forms of heavy metal in solid waste. The Mn, Zn and Cd are mainly adsorbed on Mn/Fe oxide formed in the oxidation condition. In contrast to Mn/Fe oxide, the organic matter, sulfide and carbonate compounds play a role to adsorb and precipitate heavy metal in the reducing condition. It can be concluded that Cr is mainly adsorbed on organic matter and precipitated with sulfide, whereas most of Cu is adsorbed on organic matter. For Pb and Ni, most of these metals are present in the insoluble form.

4.1.4 Leaching potential of heavy metals from dumpsite

In consideration of heavy metal mobility from dumpsite, heavy metal mobility in dumpsite was found to vary between heavy metals depending on its binding form and the environmental condition in the dumpsite. Table 4.4 shows the possibility of heavy metals in leaching from the dumpsite under different environmental conditions. Cd had the highest ability to form the complex with anion content in leachate such as Cl^- and released from dumpsite (He et al., 2006; Kjeldsen et al., 2002). The relatively higher concentration of carbonate bound Mn, Cd and Zn, moreover, showed the sensitivity of these metals to be dissolved in the acid condition. This is in agreement with other study that Mn has high mobility in acid condition (Watmough et al., 2007). In contrast to Mn, the mobility of Cr was found to be insensitive to the acid environment.

Table 4.4 Mobility potential of heavy metals in dumpsite

Step	Condition	Mobility
1	Ion exchange	Cd> Mn> Zn> Cu> Cr> Pb> Ni
2	Acid dissolution	Mn> Cd> Zn> Pb> Ni> Cu> Cr
3	Reduction reaction	Mn> Zn> Pb> Cd> Cr> Ni> Cu
4	Oxidation reaction	Cu> Cr> Ni> Pb> Zn> Cd> Mn
5	Insolubility	Pb> Ni> Cr> Cd> Cu> Mn> Zn

The presence of a large fraction of Mn/Fe oxide bound Mn, Zn and Cd showed the potential of these metals to be reduced and released under anaerobic condition of dumpsite. This is contrary to Cu and Cr where these two possess a more stable condition. In the sufficient moisture content and organic compound, the anaerobic condition can be maintained and the Cu and Cr can be precipitated with sulfide and adsorbed on solid organic matter. On the other hand, the biodegradation of organic matter in dumpsite produced the dissolved organic compound that is able to increase the solubility of Cu and Cr from solid organic matter again.

Table 4.5 Contamination factor of heavy metals in the dumpsite

Parameters	**Contamination factor (C_f^i)**			
	SW1	**SW2**	**SW3**	**SW4**
Mn	9.2	15.3	5.5	7.6
Cr	2.4	2.1	4.6	2.6
Cd	9.0	2.7	3.7	2.0
Pb	0.6	1.6	1.6	1.1
Ni	1.5	1.8	1.5	1.2
Zn	18.6	17.8	8.0	5.3
Cu	4.1	5.6	14.5	7.4
Hg	ND	ND	ND	ND
$\sum C_f^i = C_f$	45.4	46.9	39.4	27.2

Note: ND = Non-detectable

The mobility of heavy metals in dumpsite can be indicated by the contamination factor (Cf^i) of each metal (Appendix-D; Table D-2). In addition, the global contamiation factor (Cf) indicated the mobility of heavy metal in various sampling points. Table 4.5 shows the estimated contamination factor of heavy metals in dumpsites. The contamination fractor showed the relatively higher mobility and risk of Zn, Cu and Mn contamination in the environment, whereas Pb and Ni were relatively low. This was due to the high residual fraction, which is considered as non- mobile fraction of each metal, in solid waste. The global contamination factors (Cf) were found to be 27.1, 39.4, 45.4 and 46.9 in SW4, SW3, SW1 and SW2 respectively, indicating the variation of leach of heavy metal in different sampling points. The highest leaching ability was found at SW2, whereas the lowest was at SW4.

4. 1.5. Toxic characteristic leaching test of solid waste

Table 4.6 shows the concentration of heavy metals in the extracted leachate in TCLP test. The pH level of leachate was about 6.3-6.9 which is relatively higher than that of the extraction solution which was at an initial value of pH 4.93 ±0.05. The acid buffer capacity of solid waste was taken account as a cause of this result. On the other hand, the leachate pH value in this test was relatively lower than the pH 7.2-7.9 of solid waste indicating the decrease of pH level in solid waste.

Table 4.6 Characteristic of the extracted leachate in TCLP test

Parameter	**SW1**	**SW2**	**SW3**	**SW4**
pH	6.7	6.3	6.5	6.9
Mn (mg/L)	1.275	1.250	1.593	0.442
Cr (mg/L)	0.010	0.026	0.008	0.006
Cd (mg/L)	0.016	0.003	0.002	0.003
Pb (mg/L)	0.022	0.048	0.011	0.029
Ni (mg/L)	0.048	0.040	0.053	0.031
Zn (mg/L)	0.779	0.650	0.804	0.393
Cu (mg/L)	0.079	0.117	0.094	0.064
Hg (µg/L)	< 0.001	< 0.001	< 0.001	< 0.001

The heavy metal analysis result revealed that Mn concentration was highest in the extracted leachate, whereas Hg concentration was very low. However, the concentrations of all the heavy metals in the TCLP leachate were below the maximum concentration limit in the TCLP standard. Therefore, the degree of risk of heavy metal contamination in the ground water is relatively low.

As a result, the concentration order of heavy metal content in TCLP leachate was found to be in the order Mn> Zn> Cu> Ni> Pb> Cr> Cd> Hg, which is different from the concentration of heavy metal in solid waste where it was found that Zn and Cu concentration were higher than Mn (Figure 4.1). Moreover, Cr concentration in the solid waste was relatively higher than Pb and Ni. The conserved concentration of heavy metal in TCLP leachate, therefore, is not only because of the concentration of each metal presenting in the solid waste. To compare the potential of heavy metal leaching from the waste, leaching rate of heavy metal was estimated as presented in Figure 4.3.

Heavy metal leaching in the TCLP leachate also depends on the acid soluble fraction of each metal in the solid waste. Figure 4.3 is a comparison of leaching rates of heavy metals except Hg found in the TCLP test. The leaching rate of Mn was found to be in the range of 6.0-14.7% w/w which was relatively higher than other heavy metals, whereas Cr was lowest. Average leaching rate of heavy metals in the TCLP leachate was found in the following order: Mn> Zn, Cd> Ni> Pb> Cu> Cr. This order was found to be similar to that order of acid soluble fraction of heavy metals found in the waste (Table 4.4). Thus, its leaching rate of each heavy metal in the TCLP leachate can be attributed to the acid dissolution of carbonate precipitated heavy metals content in the solid waste. Moreover, the predominant hydrogen ion (H^+) of acid condition can cause the reduction of Mn oxide and release Mn^{2+} from the waste (Alloway, 1995). Based on the TCLP analysis result, therefore, Mn, Zn and Cd have relatively higher leaching potential from dumpsite under acid condition, whereas Cr had lowest.

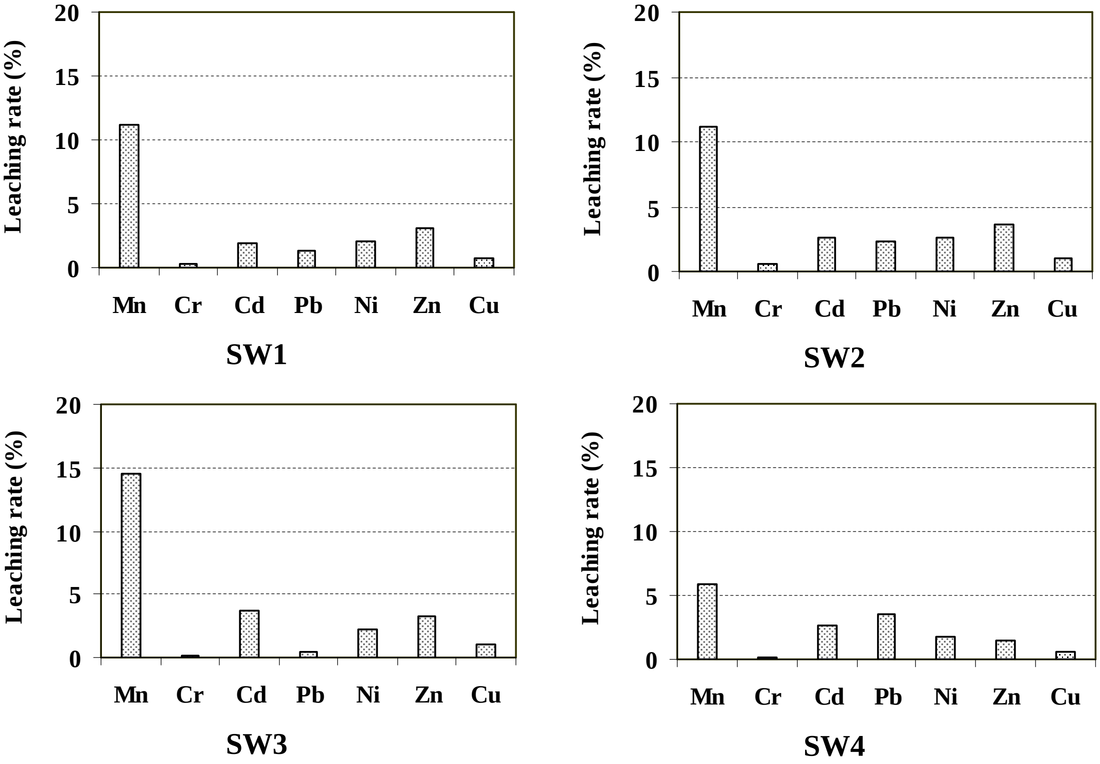


Figure 4.3 Heavy metal leaching rate in acidic condition

4.2 Leachate toxicity and the toxic compound influences the toxicity of leachate

The heavy metal concentration in leachate was determined in the runoff leachate and leachate boreholes (BH1, BH2). Moreover, the characteristics of leachate accumulate in dumpsite was determined in leachate treatment system (T1, T2) and leachate ponds (P1 – P3). In this study, leachate contamination in surface water was determined in a small ponds and canals (S1-S8) surrounding the dumpsite. Moreover, the leachate contamination in groundwater was determined in four monitoring wells (MW1-MW4). In this section, the toxicity of leachate was determined by seed germination and root elongation toxicity test of rice.

4.2.1 Characteristic of runoff leachate and leachate boreholes

(1) Basic physical and chemical characteristic

The characteristic of runoff leachate (L) and leachate in boreholes (BH1, BH2) in the dumpsite is presented in Table 4.7 and Appendix-E. The basic pH value of leachate was observable in all the samples. In addition, the alkalinity, ammonia and TKN were found in a relatively high level. This indicates the methanogenic state of solid waste degradation in dumpsite. Among these sampling points, on the other hand, the runoff leachate was found to have relatively higher contamination of these compounds than the BH1 and BH2, respectively. This suggested the heterogeneity of leachate quality in the dumpsite.

Table 4.7 Characteristic of runoff leachate and leachate boreholes

Parameter	**Runoff leachate**	**Borehole 1**	**Borehole 2**
pH	8.3	8.8	8.0
EC (mS/cm)	30.0	14.0	12.0
TDS (g/L)	20.0	7.5	9.0
Alkalinity (mg/L)	11200	5500	1550
BOD (mg/L)	2100	165	70
COD (mg/L)	8250	1600	500
TOC (mg/ L)	3500	600	185
BOD/COD [a]	0.25	0.10	0.13
TP (mg/L)	34.5	5.5	1.5
NO_3^- -N (mg/L)	6.5	2.5	0.5
NH_4^+-N (mg/L)	2200	915	328
TKN (mg/L)	2600	990	330
Mn (mg/L)	0.490	0.559	1.378
Cr (mg/L)	0.990	0.211	0.032
Cd (mg/L)	0.008	<0.002	<0.002
Pb (mg/L)	0.103	0.065	0.046
Ni (mg/L)	0.500	0.143	0.069
Zn (mg/L)	1.320	0.265	0.200
Cu (mg/L)	0.630	0.043	0.013
Hg (µg/L)	0.355	<0.001	0.136

Note: [a] ratio of mean BOD and COD concentration

As a result, an approximate ratio of 0.25 BOD/COD found in the runoff leachate was relatively higher than that of BH1 and BH2, which was about 0.10 and 0.13, respectively. This indicates the lower biodegradability of solid waste in these boreholes compared to the original waste of runoff leachate. The biodegradable organic compound in solid waste can be degraded and decreased with the waste age. In the old landfill, the humic organic acid which resists in the degradation by microorganism is predominated. Thus, the observed variation of BOD/COD ratio of leachate indicated the heterogeneity of solid waste age and its degradation rate in the dumpsite. Kjeldsen and Christophersen (2001) found that BOD/COD ratio of leachate in old MSW landfill was about 0.11-0.12. Based on the result, the different organic and inorganic concentration in leachate therefore can be attributed to the heterogeneity of solid waste age in the dumpsite.

(2) Heavy metal concentration

The concentration of Zn, Cr and Cu was relatively higher than Ni, Mn, Pb, Cd and Hg. This can be related to the observed high concentration of Zn and Cu in solid waste. As the sequential extraction analysis (Table 4.4), moreover, Zn and Mn were mainly present in the Mn/Fe oxide which can leach from the dumpsite under the reducing condition. For Cu, Cr and Ni, the dissolved organic compound generated during the biodegradation of organic matter in dumpsite could increase the solubility and mobility these metals from the solid organic matter. Jensen and Christensen (1999) found that most of Cu in leachate was present in the dissolved fraction by forming the complex with dissolved organic compound, whereas Zn was mainly present in form of particulate and colloid. In addition, Mn was found in both dissolved and particulate fraction. Moreover, Øygard et al. (2007) found that Mn content in leachate was mainly present in the form of free cation and labile complex, whereas Zn, Cd, Cu and Pb content in leachate was adsorbed on the Fe oxide in particulate and colloid.

Contrary to the runoff leachate, Mn concentration was relatively higher than Zn, Cr, Cu and Ni in both boreholes. Moreover, the concentrations of all the heavy metal in these points were found to be lower than that of the runoff leachate. This observed low concentration of Cu, Cr and Ni may be because of the lower TOC concentration in leachate as found at 600 mg/L in BH1 and 185 mg/L in BH2 compared to runoff leachate (3800mg/L). The observed high Mn concentration, in addition, suggested the leaching potential of this metal in the reducing condition of dumpsite. Alloway (1995) suggested that Mn oxide is more sensitive to the redox potential changing than Fe oxide. The redox potential for reduction reaction of Mn oxide was in the range 100-300mv, whereas that of Fe oxide was in the range -100 – 100mv (Flyhammer, 1997).

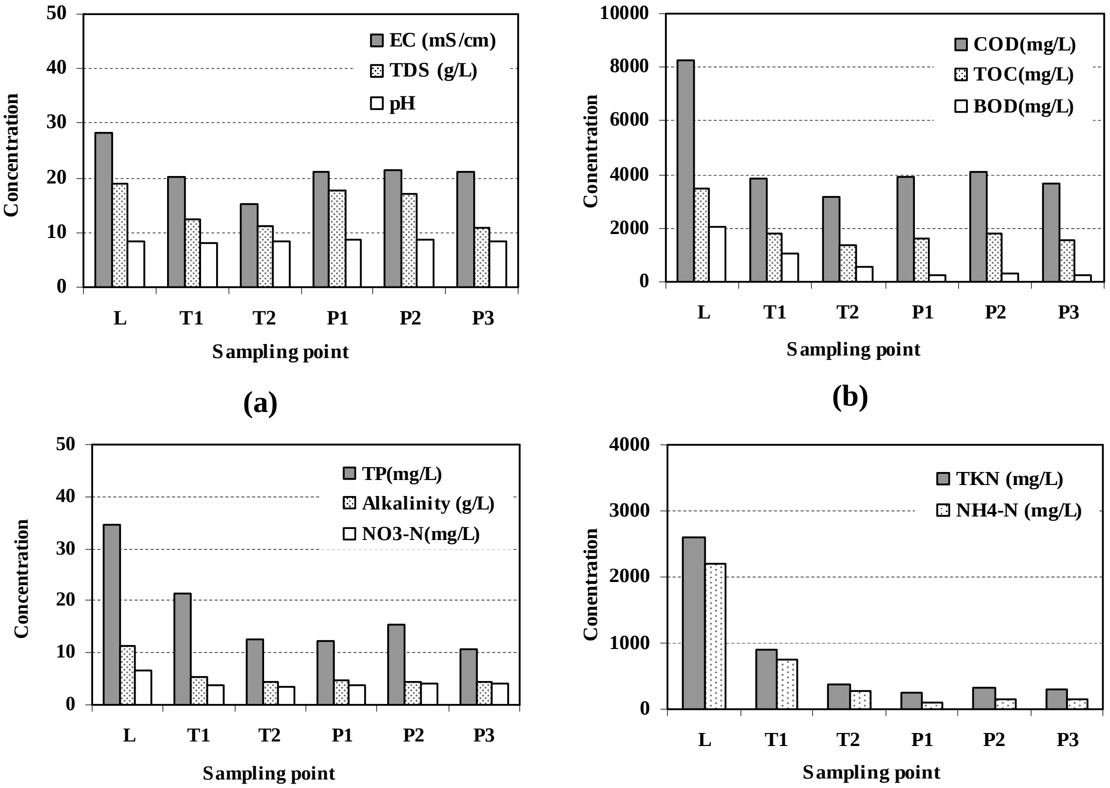
Based on the result, it can be concluded that the heavy metal leaching in the dumpsite depends on its concentration and speciation in each metal. Mn and Zn were found to have higher mobility in the anaerobic condition of dumpsite. Moreover, the relatively high concentration of dissolved organic compound in runoff leachate enhances leaching of heavy metal especially Cu, Cr and Ni. However, the concentration of these metals was observed to decrease with the solid waste age as found in BH1 and BH2.

4.2.2 Characteristic in leachate treatment system and leachate ponds

(1) Basic physical and chemical characteristic

The characteristics of leachate accumulates in the leachate treatment system (T1, T2) and ponds (P1, P2, P3) was measured (Appendix-E). The concentration of all the organic and inorganic compounds decreased dramatically in the treatment system and ponds as presented in Figure 4.4. On the other hand, the characteristic of leachate was found to be different between the treatment system and ponds. It was found that the concentration of ammonia, TKN, TP, TDS, TOC includes pH and EC level of leachate varies significantly between these sites (Appendix-E; Table E-20 to Table E-22), whereas no difference of BOD, COD, alkalinity and nitrate concentration was observed.

As a result (Figure 4.4a), the pH level of leachate in the leachate pond and treatment system was in the range pH 8.2 - 8.7. The TDS concentration in the T1 which normally receive the runoff leachate from dumpsite was about 20 g/L and decreased to 15g/L in T2. However, it was observed that TDS concentration content in the treated leachate determined in P1 and P2 was relatively higher than T1 and T2 due to accumulation of TDS in these ponds. This result corresponds to the EC level increasing in the leachate ponds.



(a) (b)

(c) (d)

Figure 4.4 Basic physical and chemical characteristic of leachate accumulate in dumpsite

Figure 4.4b shows the higher TOC concentration in P1 and P2. This may be attributed to the accumulation of non biodegradable organic compound in leachate. As the runoff leachate is treated, the biodegradable organic matter is decreased indicating the reduction of BOD concentration. However, non biodegradable fraction of organic compound can accumulate in these ponds P1 and P2 which consequently increases the COD and TOC concentration. Figure 4.5 shows the average BOD/COD ratio of leachate in the treatment system and leachate ponds. The value shows the reduction of biodegradability of organic matter of runoff leachate when treated in the system and also leachate in the ponds P1, P2 and P3.

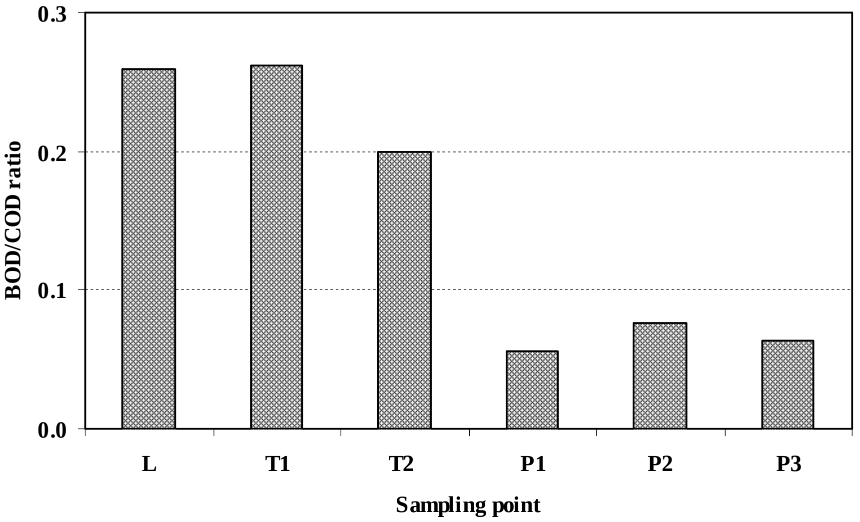


Figure 4.5 BOD/COD ratio of leachate in dumpsite

(2) Heavy metal concentration

Figure 4.6 shows the decrease of heavy metal concentration in the leachate treatment system and leachate ponds compared to the runoff leachate with the exception of Mn. The concentration of Cd, Zn, Cu and Hg in these ponds was found in the similar level, while a small increase of Cr and Ni was found in P1, P2 and P3. For Mn, an average 1.93 mg/L of this metal is highest in P3. In addition, the Mn concentrations in the treatment system T1, T2 and pond P1 and P3 were relatively higher than the runoff leachate. It was found that concentration of Mn and Zn were found to have significant difference among treatment system and ponds as shown in Appendix-E (Table E-20 to Table E-22), but not found in Cr, Ni and other metals. This may be concluded that the behavior of heavy metal contaminated in the dumpsite is varied among these metals.

As in the literature, most of fraction of Zn, Cd, Cu and Pb content in leachate was present in particulate and colloid, whereas the Mn was found in the form of a dissolved fraction as free ion and labile complex (Jensen and Christensen, 1999; Øygard et al., 2007). Thus, the precipitation of particulate and colloid is expected in the treatment system and ponds which consequently decreases the concentration of these metals. This is contrary to Mn which can be maintained in the leachate due to no precipitation of Mn ion. Moreover, the increase of Mn in these ponds may be attributed to the leach of Mn from soil in the anaerobic condition.

The characteristic of leachate in the dumpsite was found to be in the normal range compared to other studies as presented in Table 4.8. However, the quality of leachate was relatively lower than the effluent quality standard. The basic pH level and high alkalinity of leachate are associated to the existing methanogenic biodegradation in dumpsite. The observed high organic compounds in leachate (BOD, COD) can affect the dissolved oxygen depletion of surface water in the surrounding area. The nitrogen concentration (TKN) in leachate can cause eutrophication. In addition, the presence of high ammonia concentration in leachate is harmful to the aquatic organism especially under the basic pH level and high alkalinity (Clément and Merlin, 1995). For heavy metals, the average concentration order of heavy metal was found in following tendency to decrease from Mn>

Cr> Ni> Zn> Cu> Pb> Cd> Hg. This indicates the potential of dumpsite to play an important source of these metals in this area. Moreover, an average of 0.67 mg/L of Cu and 0.16 mg/L of Cr also exceeds the effluent quality standard.

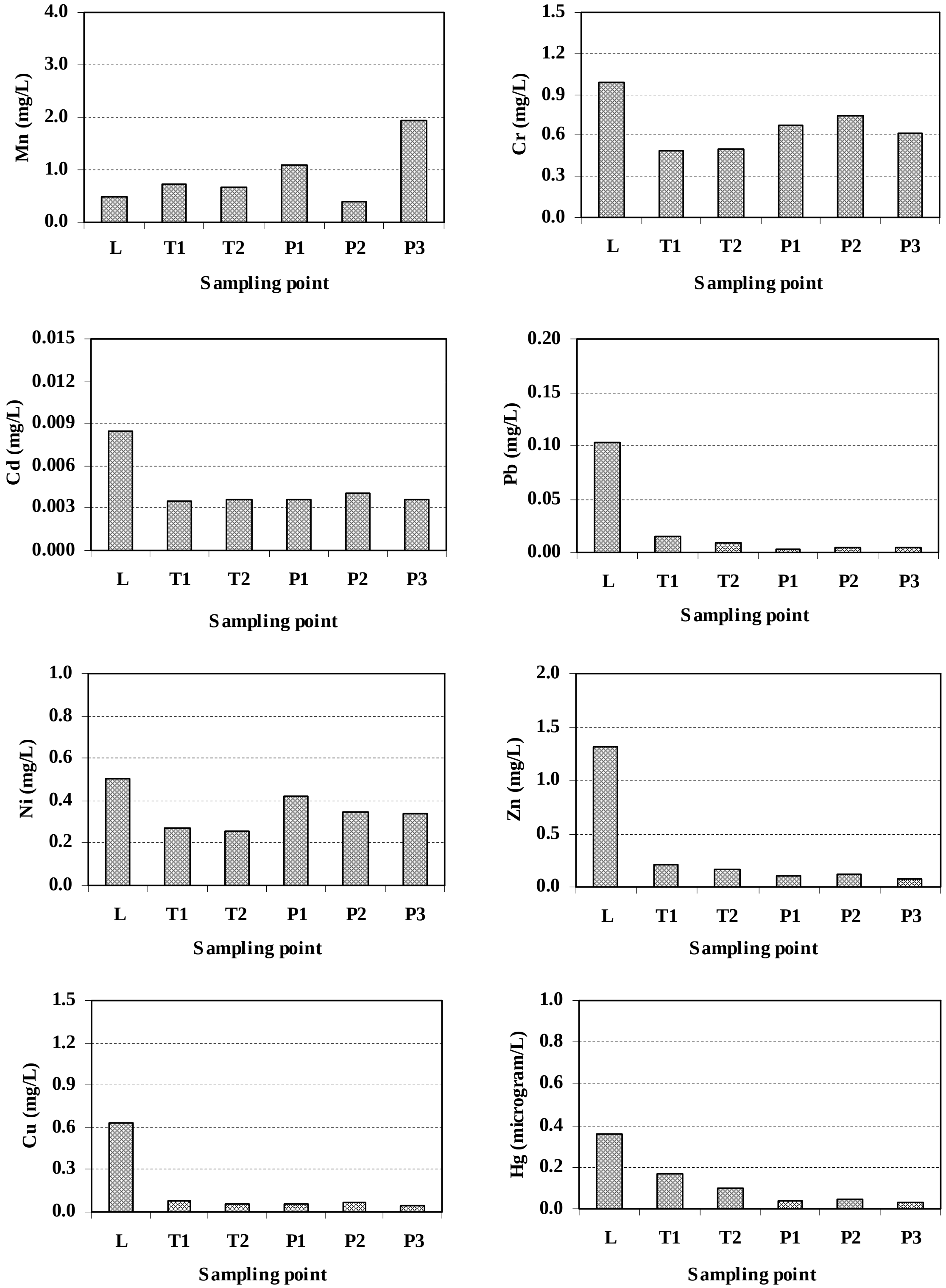


Figure 4.6 Heavy metal concentration in leachate accumulate in dumpsite

Table 4.8 Characteristic of leachate in dumpsite compared to other studies and the effluent quality standard

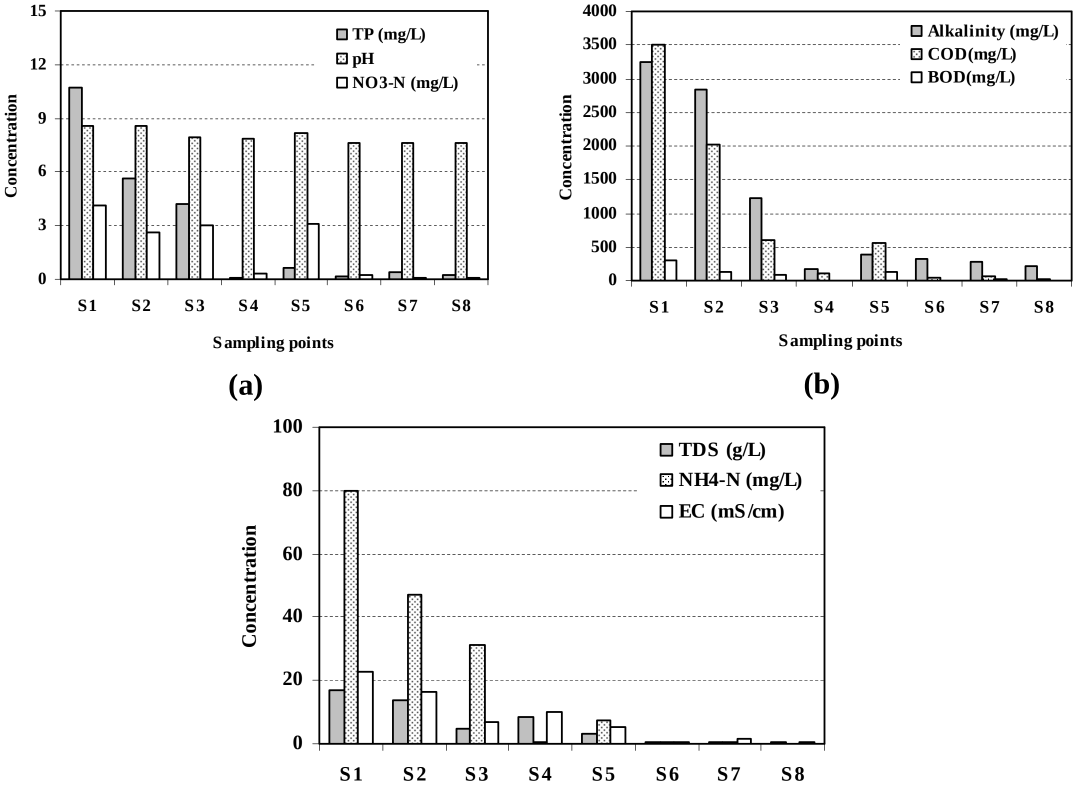
Parameter	**Nonthaburi dumpsite**		**Denmark** [c]	**German** [d]	**Tunisia** [e]	**Thailand Effluent standard** [f]
	Mean	**Range**				
pH	8.5	7.2-9.0				5.5-9.0
EC (mS/cm)	21.3	6.7-34.4				
TDS (g/L)	14.6	4.8-27.8	-	-	-	30-50
Alkalinity (mg/L)	6762	2200-14900	-	-	-	-
BOD (mg/L)	740	95-4800	44	180	2400-11200	20
COD (mg/L)	4490	1250-9600	320	3000	3739-51792	120-400
TP (mg/L)	17.8	1.5-56.0	1.5	5.7	-	-
NO_3-N (mg/L)	4.3	ND-16.8	-	3.3	-	-
NH_4-N (mg/L)	620	40-3400	110	741	-	-
TKN (mg/L)	800	180-4330	-	-	294-500	100-200
Mn (mg/L)	0.886	0.255-5.912	3.5	0.65	-	5.0
Cr (mg/L)	0.667	0.220-1.598	0.076	0.275	0.31-2.99	0.25[a], 0.75[b]
Cd (mg/L)	0.004	0.002-0.013	0.007	0.005	ND	0.2
Pb (mg/L)	0.025	<0.010-0.300	0.070	-	0.09-0.93	1.0
Ni (mg/L)	0.355	0.114-0.752	0.130	-	0.03-0.17	5.0
Zn (mg/L)	0.331	0.010-2.598	0.670	0.640	0.95-4.10	2.0
Cu (mg/L)	0.156	0.017-1.726	0.070	0.065	0.03-0.34	0.03
Hg (ug/L)	0.124	<0.001-1.544	5.2	-	-	5.0

Note: ND = non detectable; [a]Hexavalent Chromium; [b]Trivalent Chormium
Source: [c] Kjeldsen &Christophensen (2001); [d]Ehrig (1983); [e]Zairi et al. (2004); [f] PCD (2004)

4.2.3 Surface water quality

(1) Basic organic and inorganic compound

Figure 4.7 shows the variation of basic characteristic of surface water in the surrounding area of the dumpsite. The relatively high contamination of organic and inorganic compounds was found in small pond S1,S2, S3 and S5, which are near the dumpsite, compared to the control sites (S6, S8), but it was relatively low in S4 and S7. Average pH level in the S1 and S2 was found at pH 8.6 which is relatively higher than the control sites as found at pH 7.6 in S6 and pH 7.7 in S8. Moreover, the relatively higher concentration of all the compounds was found in the S1, S2, S3 and S5 compared to the other sites. On the other hand, the concentration TDS and EC level was found to be relatively high in S4 which is considerably different from other parameters.



(a) **(b)**

(c)

Figure 4.7 Surface water quality in surrounding area of dumpsite

(2) Heavy metal concentration

Figure 4.8 shows the variation of heavy metals concentration in the surface water. Characteristic of heavy metal, however, was relatively different in each metal. It was observed that the concentration of metal except Mn and Hg was relatively high in S1, S2 compared to other sites. The very low concentration of Hg was found in these sites with the high variation of its concentration. In this case, the surface water determined in S4 was found to have higher contamination of Hg. Moreover, the Hg concentration in S6 and S8 is relatively higher than S1 and S2. For Mn, it can be observed that concentration of Mn in S5, S4 and S3 was relatively higher than S1 and S2. Therefore, observed contamination of Mn and Hg this area might come form other sources.

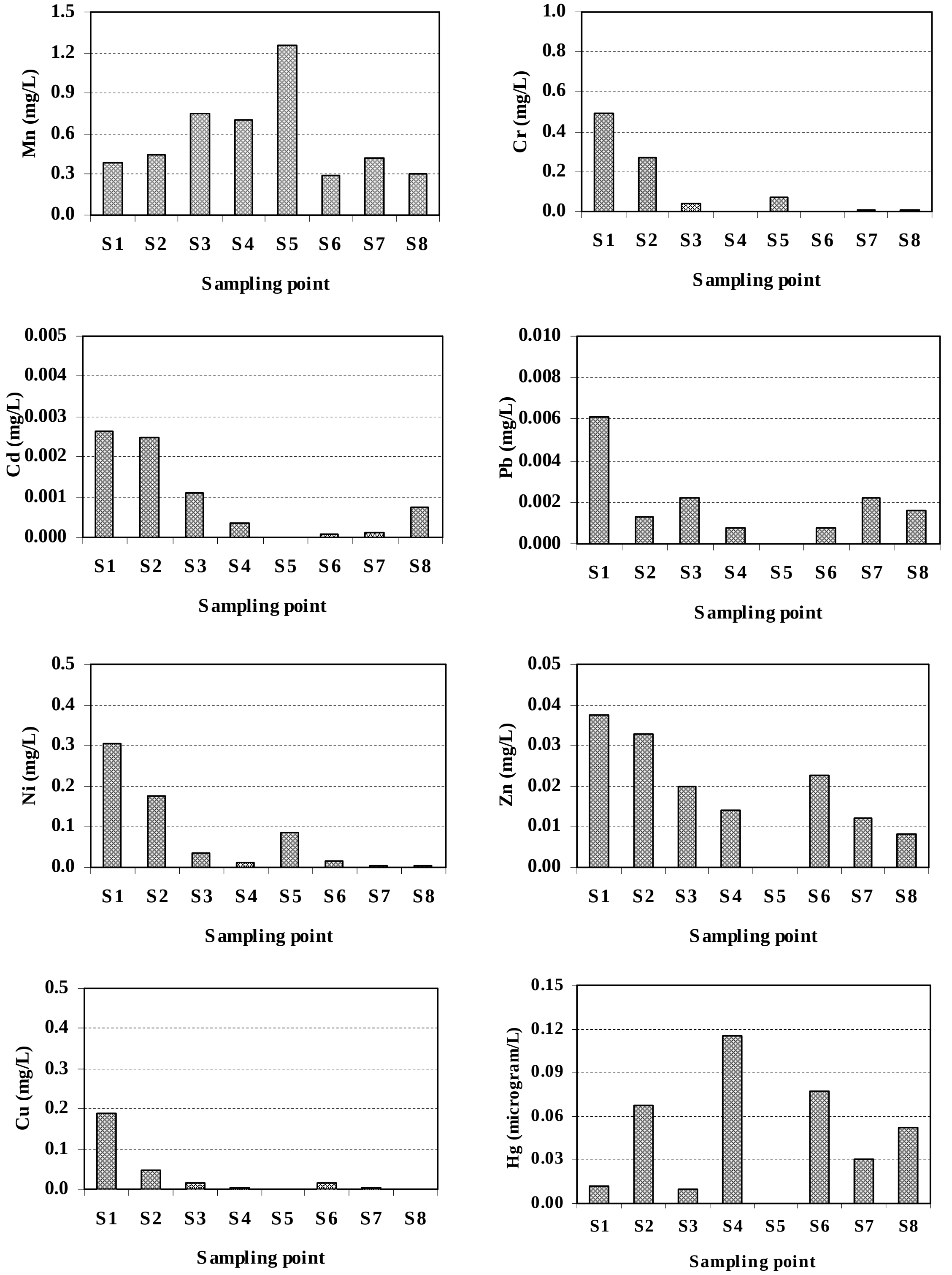
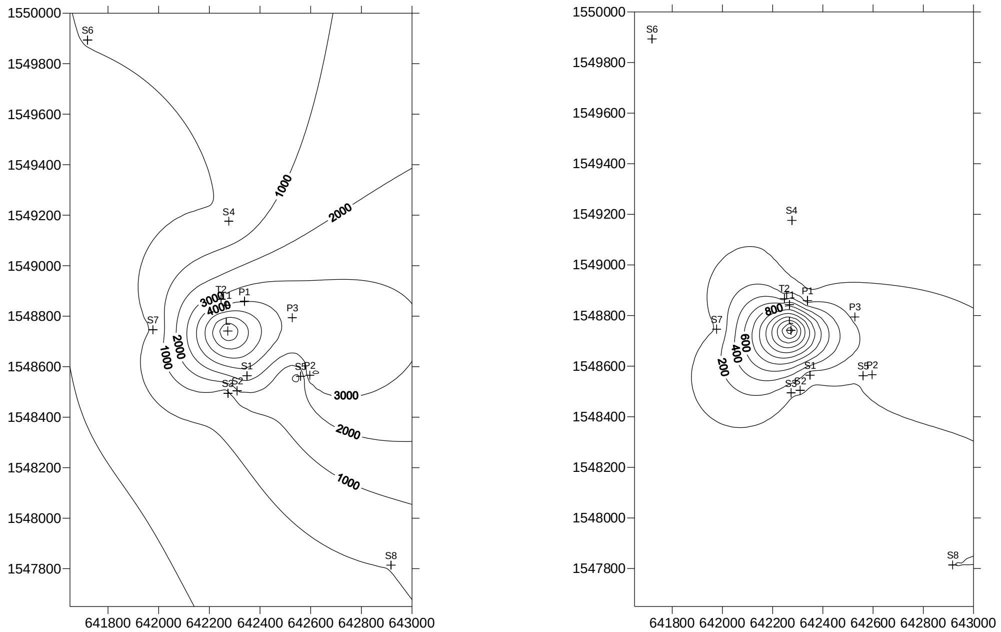


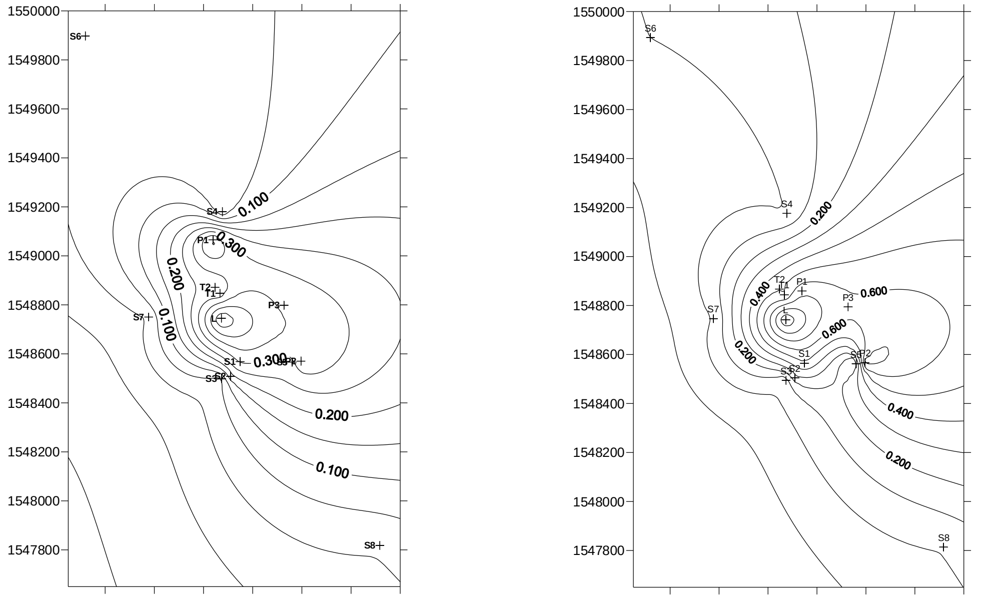
Figure 4.8 Heavy metal concentrations in the surface water

(3) Distribution of toxic compound in dumpsite

The distribution of ammonia, COD and heavy metal in the leachate and surface water is presented in Figure 4.9 and Appendix-F. The relatively high concentration of heavy metals, ammonia and COD in surface water was noticed in small ponds nearby the dumpsite. However, the water level in this pond was found to be highly affected from the seasonal change especially surface water S3, and S5.



(a) COD (mg/L) **(b) Ammonia (mg/L)**



(c) Ni (mg/L) **(d) Cr (mg/L)**

Figure 4.9 Variation of COD, ammonia and heavy metals concentration in the leachate and surface water

Table 4.9 Comparison of surface water quality with the surface water and drinking water standard

Parameter	**Nonthaburi dumpsite**		**Thailand surface water quality standard**	**Drinking water standard**	
	Mean	**Range**		**USEPA (2007)**	**WHO(2006)**
pH	8.0	7.1-9.1	5.0-9.0	6.5-8.5[a]	-
EC (mS/cm)	8.0	0.4-28.5	-	-	-
Alkalinity (mg/L)	1080	80-5520	-	-	-
TDS (g/L)	6.0	0.1-27.8	-	0.5[a]	-
BOD (mg/L)	83	1.8-750	4.0	-	-
COD (mg/L)	863	22-4840	-	-	-
TP (mg/L)	2.8	0.01-28.0	-	-	-
NO_3-N (mg/L)	1.7	ND-12.5	5.0	10	50
NH_4-N (mg/L)	21.0	ND-337	0.5	-	-
Mn (mg/L)	0.570	0.073-2.237	1.0	0.05[a]	0.4
Cr (mg/L)	0.111	<0.003-1.108	0.05[b]	0.1[c]	0.05[c]
Cd (mg/L)	<0.002	<0.002-0.006	0.005[d], 0.05[e]	0.005	0.003
Pb (mg/L)	<0.010	<0.010-0.017	0.05	ND	0.01
Ni (mg/L)	0.080	<0.010-0.545	0.1	-	0.07
Zn (mg/L)	0.018	<0.002-0.132	1.0	5.0[a]	-
Cu (mg/L)	0.034	<0.003-0.473	0.1	1.3	2.0
Hg (µg/L)	0.046	<0.001-0.439	2.0	2.0	6.0

Note: [a] Secondary drinking water regulation; [b] Hexavalent chromium; [c] Total chromium; [d] Cd at hardness < 100 mg/L; [e] Cd at hardness > 100 mg/L; ND = non detectable

The comparison of surface water quality in the surrounding area of dumpsite to the surface water and drinking water quality standard is shown in Table 4.9. The surface water quality in the surrounding area of dumpsite was below the acceptable level for surface water and drinking water quality. Average BOD and ammonia concentration was about 83 and 21 mg/L, respectively. This can affect the dissolved oxygen depletion and cause toxic effect to the aquatic organism. For heavy metals, the average concentration of Mn, Cr, and Ni exceeds the maximum concentration limit of these metals in the surface water and drinking water. Mn can cause adverse neurological effect in human, while Cr (VI) has been classified as human carcinogen. For Ni, allergic contact dermatitis is a general concern in Ni toxicity (WHO, 2006).

4.2.4 Groundwater quality

The characteristic of ground waters determined in the dumpsite is presented in Table 4.10. The variation of ground water quality was observed in the dumpsite. It was found that concentration of pH, COD, ammonia, EC and Mn content in groundwater was significantly different among these wells, whereas no significant difference was found in TDS, alkalinity Cr, Pb, Ni, Zn, Cu and Hg. (Appendix-E; Table E-23 to Table E-25). This result showed that Mn, organic compound and ammonia are important pollutants to contaminate in the groundwater.

Table 4.10 Characteristics of groundwater in dumpsite

Parameter	MW1	MW2	MW3	MW4
pH	7.3	7.6	9.7	7.9
EC (mS/cm)	7.0	5.5	8.4	11.8
TDS (g/L)	6.4	3.9	5.0	8.2
Alkalinity (mg/L)	1615	410	765	2350
COD (mg/L)	143	110	90.0	540
NH_4-N (mg/L)	2.5	9.6	5.4	320
Mn (mg/L)	5.162	2.816	0.264	0.178
Cr (mg/L)	0.005	0.04	0.002	0.034
Cd (mg/L)	<0.002	<0.002	<0.002	<0.002
Pb (mg/L)	0.055	0.039	0.042	0.040
Ni (mg/L)	0.015	0.010	0.021	0.059
Zn (mg/L)	0.153	0.119	0.168	0.212
Cu (mg/L)	0.007	0.020	0.007	0.021
Hg (µg/L)	0.223	0.087	0.110	<0.001

Table 4.11 Comparison of ground water quality in the dumpsite to other studies and ground water quality standard

Parameter	**Nonthaburi dumpsite**		**Denmark** [b]	**German** [c]	**Thailand ground water quality standard** [d]
	Mean	**Range**			
pH	8.1	6.4-11.8	-	-	
EC (mS/cm)	8.2	3.2-16.0	1.4-4.0	0.5-3.9	-
TDS (g/L)	5.9	2.0-19.1	0.9-2.1	-	-
Alkalinity (mg/L)	1285	128-5575	-	-	-
COD (mg/L)	220.8	60-1456	-	-	-
NH_4-N (mg/L)	85.0	1.0-785.0	29-185	-	-
Mn (mg/L)	2.105	0.010-6.699	0.9-2.1	0.035-0.420	0.5
Cr (mg/L)	0.011	<0.003-0.089	-	0.032-0.608	0.05 [a]
Cd (mg/L)	<0.002	<0.002-0.002	ND-0.0001	0.003-0.013	0.003
Pb (mg/L)	0.044	<0.010-0.280	ND	0.023-0.132	0.01
Ni (mg/L)	0.026	<0.010-0.121	0.002-0.009	0.023-0.460	0.02
Zn (mg/L)	0.163	0.028-0.682	ND	0.059-5.800	5.0
Cu (mg/L)	0.014	<0.003-0.050	0.0009-0.006	0.073-0.496	1.0
Hg (μg/L)	0.107	<0.001-0.613	-	-	1.0

Note: [a] Hexavalent chromium

Source: [b]Jensen et al. (1999); [c]Baumann et al. (2006); [d]PCD (2004)

As a result, the highest concentration of all the COD, ammonia and EC was found in MW4 which is near the leachate treatment system and dumpsite. In contrast, the highest concentration of Mn was found in MW1 followed by MW2, whereas the concentration of COD, ammonia and EC was relatively low. This can be due to the leach of Mn from soil in anaerobic condition. The degradation of organic matter polluted in ground water lead to reduction of redox potential in groundwater which consequently increased the Mn leaching from soil.

The concentration of ammonia, Mn and EC content in groundwater of dumpsite was relatively higher than other studies as present in Table 4.11. Moreover, Mn, Pb and Ni concentration exceeds the maximum limit of this metal in groundwater and drinking water quality standard indicating the potential of groundwater to be toxic in consumer.

4.2.5 Toxicity of leachate to inhibit the germination and root elongation of rice *(Oryza sativa* L.)

From the leachate analysis result (Table 4.8), the BOD, COD, TKN, Cu and Cr concentration in the leachate exceed the maximum limit of these compounds in the effluent standard. However, the characteristic of leachate was found to vary between the sampling sites. The variation of environmental toxic effect of leachate in the dumpsite was evaluated by the seed germination and root elongation of rice (*Oryza sativa* L.).

The toxicity of leachate to rice seed is indicated by its median inhibiting concentration (IC_{50}) value to the relative seed germination rate (RSG), relatively root growth (RRG) and germination index (GI). The presence of low IC_{50} value of leachate suggests the high toxicity of leachate.

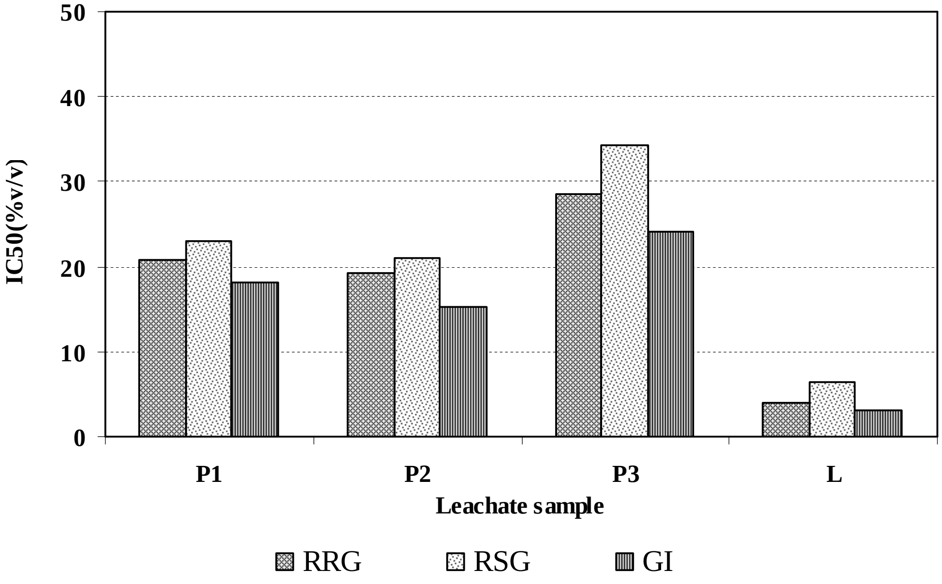


Figure 4.10 Toxicity of leachete to the germination and root elongation of rice

The toxicity level of runoff leachate (L) and leachate in pond P1, P2 and P3 collected in April and May 2006 are presented Appendix G (Table G-1 to Table G-5). In addition, the average IC_{50} of leachate in various sampling points is shown in Figure 4.10. The RRG of rice had higher sensitivity to the toxicity of leachate than RSG. Based on the GI value, moreover, the IC_{50} of rice was found to be 3.0%, 18.1%, 15.2% and 24.1% v/v in the runoff leachate, and leachate in pond P1, P2 and P3, respectively. This implied that toxic effect of leachate to inhibit the germination of rice is varied in the dumpsite. The higher toxicity was found in the runoff leachate, whereas the toxicity of leachate in pond P3 was relatively low.

The observed high toxicity in the runoff leachate can be because of the higher concentration of heavy metal and ammonia contents as shown in Appendix-E. Wang (1994) found that germination of rice seed is relatively sensitive to the toxicity of Cu where its IC_{50} was about 0.22 mg/L. Thus, the average 0.63 mg/L of Cu content in the runoff leachate was relatively high and can cause the toxicity in the runoff leachate. In addition to Cu, the relatively high concentration of ammonia content in the runoff leachate can contribute to a higher toxicity of runoff leachate. In addition, the basic pH level of runoff leachate (pH 8.3) can increase the concentration of unionized –ammonia, which is generally considered as the toxic form of ammonia. Clément and Merlin (1995) found that the estimated IC_{50} of unionized ammonia on duckweed, in addition was about 8.0 mg/L.

4.2.6 Toxicity identification evaluation of leachate

(1) Influence of ionization to leachate toxicity

Identification of the influence of ionization to the toxicity of leachate was conducted for the leachate collected in May 2006 by changing the pH level of leachate to the pH 3 and pH 11. The initial pH level (pH n) of leachate was found at pH 8.4, while the IC_{50} was found to be approximately 1.9% v/v. However, the change of pH level of leachate to pH 3 and pH11 led to the alteration of leachate toxicity as shown in Figure 4.11. The leachate toxicity was found to increase in the pH 11 leachate with the lower IC_{50}, whereas the observed higher IC_{50} of leachate in pH3 indicated the toxicity decreasing, compared to the initial leachate (pH 8.4).

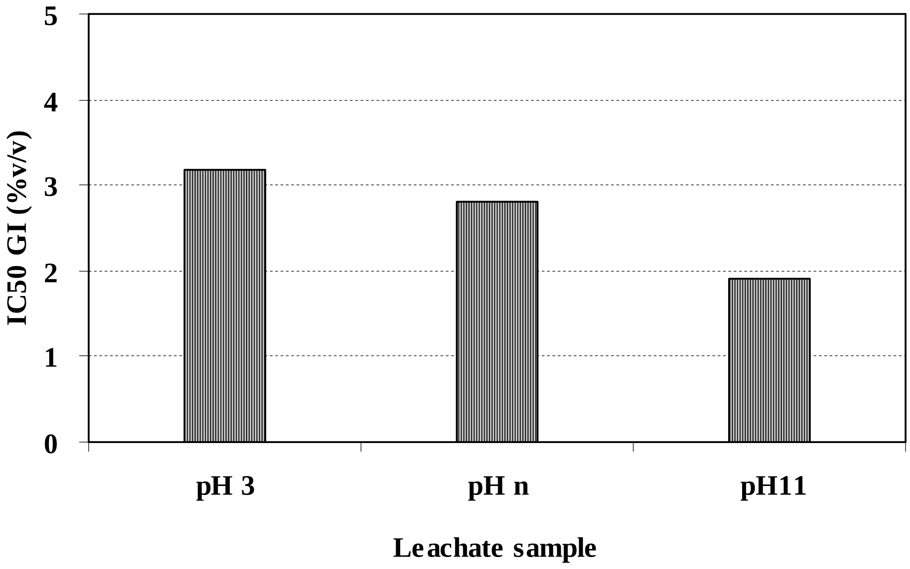


Figure 4.11 Toxicity of leachate to the germination (GI) of rice in various pH levels

From here, it can be concluded that ionization of toxic compound content in leachate is able to affect the toxicity of leachate. The decrease of leachate toxicity in the pH 3 leachate can be due to the decrease of unionized ammonia concentration in the acid condition. On the contrary, the increase of unionized ammonia concentration is expected in the pH 11 leachate, which leads to the leachate toxicity increase in this condition. Clément and Merlin (1995) supported that the toxicity of ammonia on duckweed increases significantly when the leachate pH level increases.

(2) pH adjustment and aeration

The significant reduction of leachate toxicity was found in the pH11 leachate to be aerated. As presented in Figure 4.12, the toxicity of leachate dramatically decreased in pH 11 to be aerated before toxicity test, whereas no significant reduction of toxicity was found in the pH3 leachate. The IC_{50} of GI in the pH3, pH n, and pH 11 was about 3.8, 4.2, and 12.7% v/v, respectively.

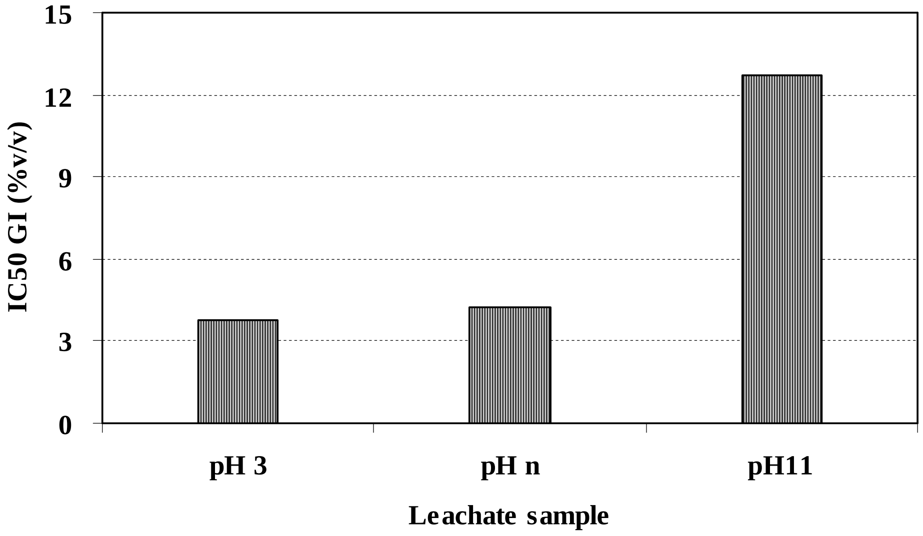


Figure 4.12 Toxicity of the aerated leachate in various pH levels

Determination of the leachate characteristic found that concentration of ammonia content in the aerated leachate at pH 3, pH n and pH11 was about 792, 781 and 605 mg/L, respectively. This result indicates that removal of volatile compound content in leachate could affect the toxicity of leachate. The decrease of toxicity in the pH 11 leachate can be because of the reduction of unionized ammonia compound concentration in this condition. Since the ionized ammonium compound is generally predominated in the pH 3, therefore, the aeration of leachate may be unable to eliminate this compound from leachate, which led to the observation that no significant reduction of leachate toxicity was present.

(3) EDTA test

The toxicity of leacate to be treated by EDTA adding was found to be decreased compared to the untreated leachate as presented in Figure 4.13. The IC_{50} of leachate was found to increase with the increase of dose of EDTA. However, there was no significant difference of leachate toxicity in the 0.0125 ml and 0.05 ml of EDTA. Inaba and Takenaka (2005) found that the characteristic of EDTA to have a relatively high molecular weight can reduce the bioavailability and phytotoxicity of Cu ion. Moreover, Allica (2007) found that the phytotoxicity of a mixture of Pb^{2+}, Cd^{2+} and Zn^{2+}can be decreased by EDTA adding. The toxicity decreasing in the EDTA treated leachate, therefore, can be because of the formation of EDTA complex with the heavy metals content in the runoff leachate. This reduction of leachate toxicity, moreover, indicates the contribution of heavy metals to the toxicity of runoff leachate.

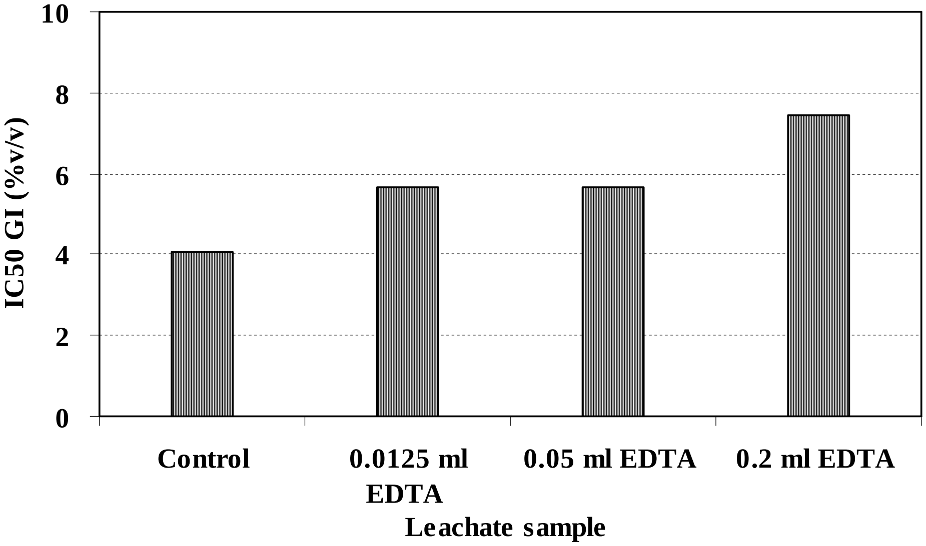


Figure 4.13 Effect of EDTA to decrease the toxicity of leachate

(4) Graduated pH test

The influence of pH level to the toxicity of leachate was evaluated by the toxicity test in the pH8, pH7 and pH6 leachate. Figure 4.14 shows the comparison of leachate toxicity in various pH level compared to the initial pH n (pH 8.4). As the result, decreasing the pH level of leachate to pH 8 would reduce the toxicity of leachate. However, there was no significant reduction of leachate toxicity found in the pH6 and pH 7. This result was contrary to the previous result as found where toxicity of leachate seems to decrease with the decrease of pH level.

Norberg-King et al. (1991) suggested that decreasing the pH level of leachate will increase the ionization of heavy metal complex content in leachate, which consequently increase the bioavailability and toxicity of heavy metal. In addition, Øygard et al. (2007) found that the presence of heavy metal in the form of particulate and colloid is the responsibility of inorganic compound content in leachate especially Fe oxide. This compound is generally sensitive to the decrease of pH level and redox potential. Thus, reduction of the toxicity in the pH6 and pH7 leachate might be attributed to the ionization of Fe oxide in leachate, which increases the availability of heavy metal in plant. Based on the result, it can be concluded that the pH level of leachate plays an important role to the characteristic of leachate and the phytotoxicity level of leachate to inhibit the germination of rice.

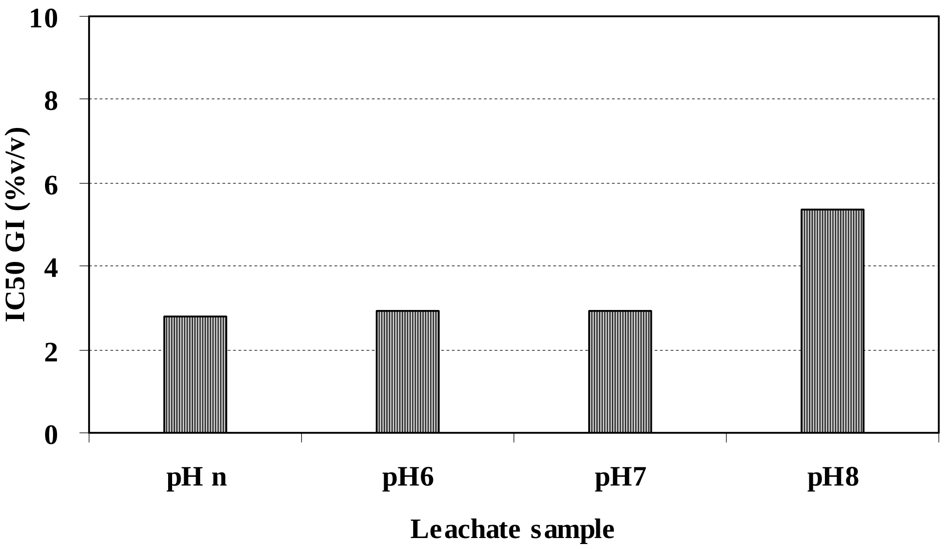


Figure 4.14 Toxicity of leachate in graduated pH toxicity test

4.3 Recycling potential of solid waste in dumpsite

The research relate to solid waste recycling in the dumpsite is presented. The composition and size distribution of solid waste in the dumpsite was determined. Hear, recycling potential of waste as fuel and compost was considered, whereas the possibility of non-recyclable waste to be refilled into the MSW landfill was evaluated.

4.3.1 Solid waste compositions in dumpsite

Table 4.12 Compositions of the excavated waste from the dumpsite

Composition	Concentration (%w/w)			
	SW1	SW2	SW3	SW4
Plastic	45.9	34.9	48.9	36.3
Wood	13.6	9.3	9.6	3.7
Textile	11.9	8.9	10.3	9.5
Paper	ND	2.0	ND	0.7
Rubber	0.4	2.9	0.8	ND
Foam	0.4	1.6	1.4	0.6
Soil like material	21.7	33.7	21.9	46.3
Stone/ Ceramic	1.4	1.3	0.8	ND
Glass	1.1	2.7	1.0	2.5
Metal	3.7	2.7	5.2	0.4
Total	100.0	100.0	100.0	100.0

Note: ND = Non-detectable

Plastic waste and soil like materials were considered as important component of solid waste in the dumpsite. Compositions of waste sampled from the dumpsite are presented in Table 4.12. Hear, it can be seen that there was no significant difference of solid waste composition in different sampling points on the dumpsite as presented in Appendix -H. As a result, average composition of plastic waste and soil like material content in the dumpsite was about 41% and 31% w/w, respectively.

The composition of excavated waste with 41% w/w of plastic and 31% w/w of soil like material, however, are much different from other studies, where soil fraction is the major component (Kurian et al., 2005; Jain et al., 2005). Rattanaoudom (2005) found that approximately 60% w/w of soil composition was found in the excavated waste from MSW dumpsite in Pathumthani, Thailand. This difference might be due to the difference of solid waste age and operation of dumpsite where MSW had generally been disposed into the Nonthaburi dumpsite without any soil covering.

The observed higher plastic and soil composition in dumpsite was found to have much difference from the original municipal solid waste generated in Thailand, where the organic waste (Food waste) and plastic comprise 50-60% and 12-24% w/w of total waste, respectively (Visvanathan and Tränkler, 2004). This difference may be attributed to the biodegradation of organic waste in the dumpsite. During the organic waste degradation, the organic matter can be lost from the dumpsite via leachate and gas emission. The remaining fraction of organic matter can be found as humus, which is relatively difficult to be degraded. As a result, it can be estimated that approximately 16-28% w/w of plastic waste can be increased after degradation of organic waste, whereas 20-30% w/w of organic waste can be lost from dumpsite. This is within a reported normal range of 14-68% w/w of organic matter where when disposed initially into landfill can be transformed to soil and lost from the landfill via leachate and gas (Morelli, 1990). The observed high plastic waste component in dumpsite, therefore, is expected as a result of organic waste degradation in the dumpsite.

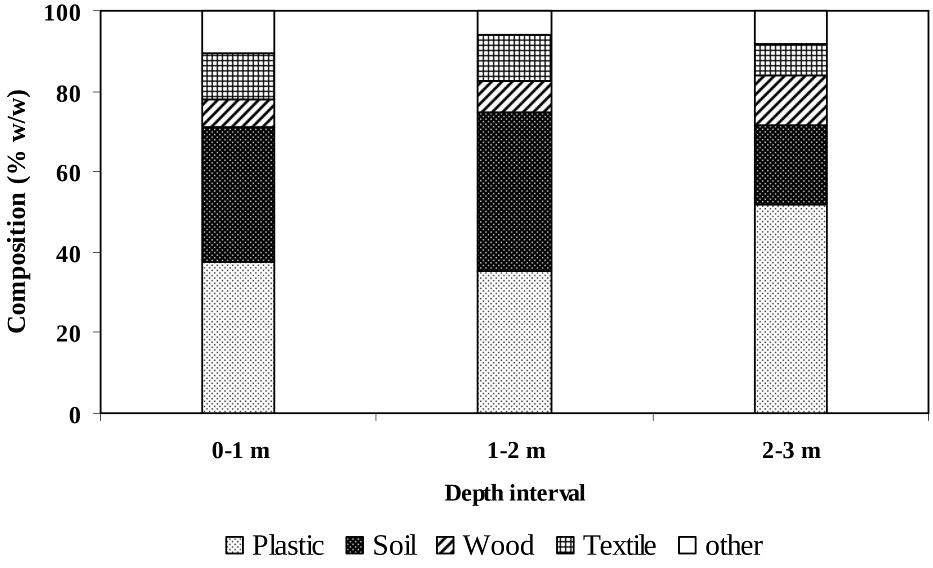
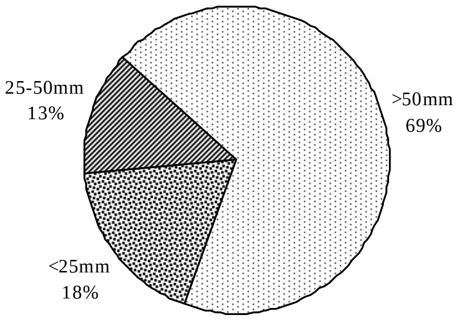


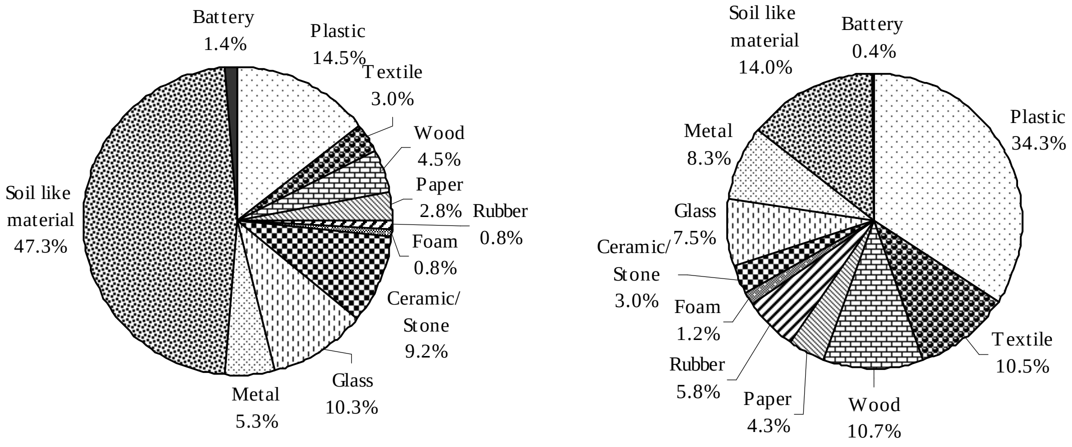
Figure 4.15 Variation of solid waste composition in various depth intervals

The variation of waste composition in each depth intervals of dumpsite is presented in Figure 4.15. Approximately 52% w/w of plastic waste composition at the bottom layer (2-3m) was found to be relatively higher than other layers (Appendix- H; Table H-4 to Table H-6), whereas the soil like material was relatively low. This observed high plastic composition may caused the observed solid waste density decreasing at 2-3m depth as discussed in section 4.1. This increase of plastic component at 2-3 m may be attributed to the reduction of soil like material as the result of older solid waste age and higher biodegradation rate at this point.

4.3.2 Waste size distribution



(a) Size distribution of total solid waste



(b) Composition of waste size 25-50mm

(c) Composition of waste size >50mm

Figure 4.16 Size distribution of the excavated waste (%w/w)

Figure 4.16 and Figure 4.17 show the solid waste size distribution and the composition of waste size > 50mm and 25-50mm received from trommel screen, respectively. Approximately 69% w/w of the excavated waste from dumpsite had the size > 50mm, while the median (25-50mm) and finest size (<25mm) fractions was approximately 13% and 18% w/w, respectively. As the solid waste was fed into the trommel screen, the waste size < 50mm fraction was firstly separated from the waste stream. Most of this waste mainly consisted of soil like material and a small piece of wood, paper, plastic and glass and stone/ceramic. The composition of this waste, however, was not classified. Next to the finest size fraction, the medium waste size of 25-50mm was then separated, where approximately 74% w/w of this fraction was non-combustible waste including soil, metal, glass, and stone/ceramic (Figure 4.16b). In addition, the dry cell battery, which is normally considered as an important source of heavy metal in MSW, was observable in this waste. Finally, the remaining solid waste size > 50 mm was received. Contrary to the medium size faction, the combustible waste was predominated in this waste especially plastic, textile and wood.

Waste size < 25mm **Waste size 25-50mm**

Waste size >50mm

Figure 4.17 Characteristic of solid waste in various sizes

The observed high combustible waste component in the solid waste size >50mm suggested the possibility of this waste to be recycled as fuel, whereas the solid waste size < 25mm might be reused as compost. For the medium size fraction, although the composition of soil like material in this waste is relatively high, however, non-biodegradable waste components especially plastic, metal, glass and foam were also found at relatively high concentration. Application of this waste as a compost can cause aesthetical problem in soil. Therefore, recycling the waste as compost may be unsuitable for the waste size 25-50mm.

Figure 4.18 shows the size distribution of various waste components received from trommel separation process. It can be noticed that approximately 69% w/w of soil content in the waste could be separated into the finest and medium waste fraction, while 50% of dry cell batteries was separated into the medium size fraction. Contrary to soil like material and batteries, most fraction of plastic, textile, wood, rubber, paper, foam, glass and metal component in the solid waste was still left in the waste size > 50mm. As the result, it can be estimated that about 90% of plastic waste (375 kg plastic/ton of waste) in the dumpsite can be recovered from the rotary trommel screen separation, whereas 69% of soil like material and 50% of dry cell battery can be separated and removed into the waste size < 25mm and 25-50mm.

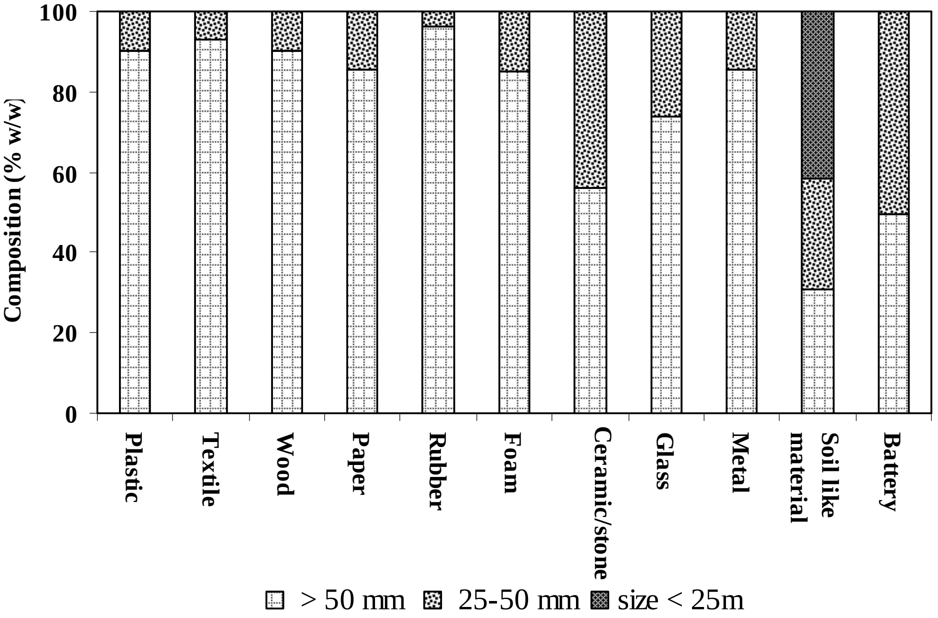


Figure 4.18 Distribution solid wastes size in different waste component

4.3.3 Concentration of heavy metal in various solid waste sizes

The heavy metals concentrations in various solid waste sizes are presented in Figure 4.19 and Appendix-I (Table I-1 to Table I-3). Except for Cd, the concentration of all the heavy metals content in the waste size> 50 mm was relatively lower than that of the medium waste size 25-50 mm and finest waste size <25mm. As a result, the highest concentration of Cu, Zn and Ni were found in the medium size fraction, while Mn, Cr, Pb and Hg concentration were relatively high in the finest size fraction. This indicated that the concentration of heavy metal in the solid waste is affected by differentiation of solid waste size. This variation of heavy metals concentration among waste sizes may be confirmed by Hogland et al. (2004) when they found out that the concentration of Pb and Cr was relatively high in the waste size <18mm, whereas the highest concentration of Cu and Zn was found in the medium waste size 18-50mm .

The estimated concentration of heavy metal content in the composite waste is also presented in Figure 4.19 (Appendix-I, Table I-5). Except for Cd, the concentration of all the heavy metals content in the composite waste was found to be relatively higher than waste size > 50mm. This is revealing the effect of solid waste screening by trommel screen to decrease the concentration of Mn, Cr, Pb, Ni, Zn, Cu and Hg content in the waste size > 50mm. On the other hand, this is ineffective with the decrease of Cd concentration. This is because a major source of Cd in the MSW is plastic waste which have size > 50mm. Rotter et al. (2004) suggested that separation of solid waste by using size differentiation may not be able to reduce the concentration of heavy metal in the waste due to the fact that the distribution of heavy metals concentration does not correspond to the solid waste size distribution.

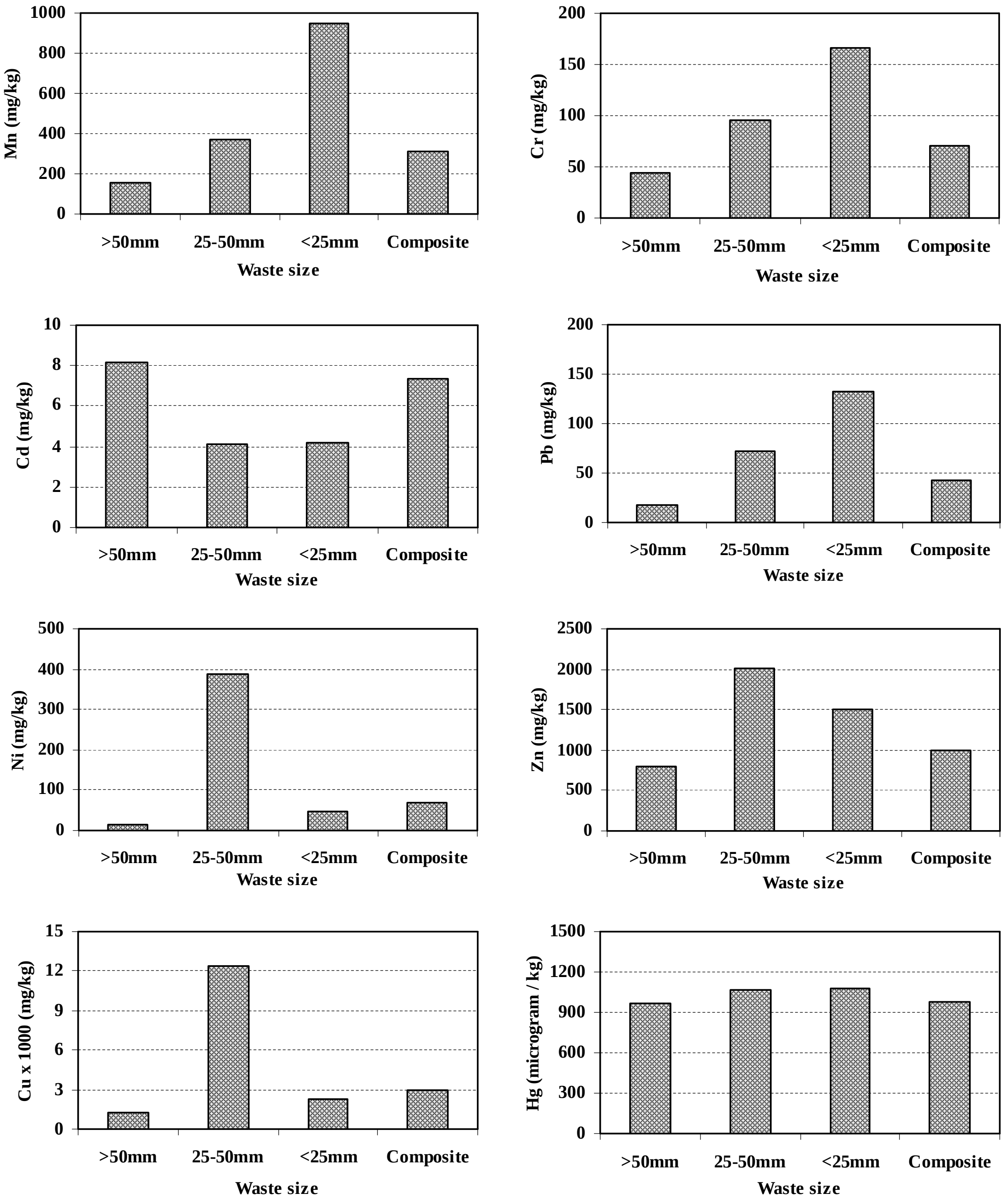


Figure 4.19 Heavy metal concentrations in different sizes of solid waste

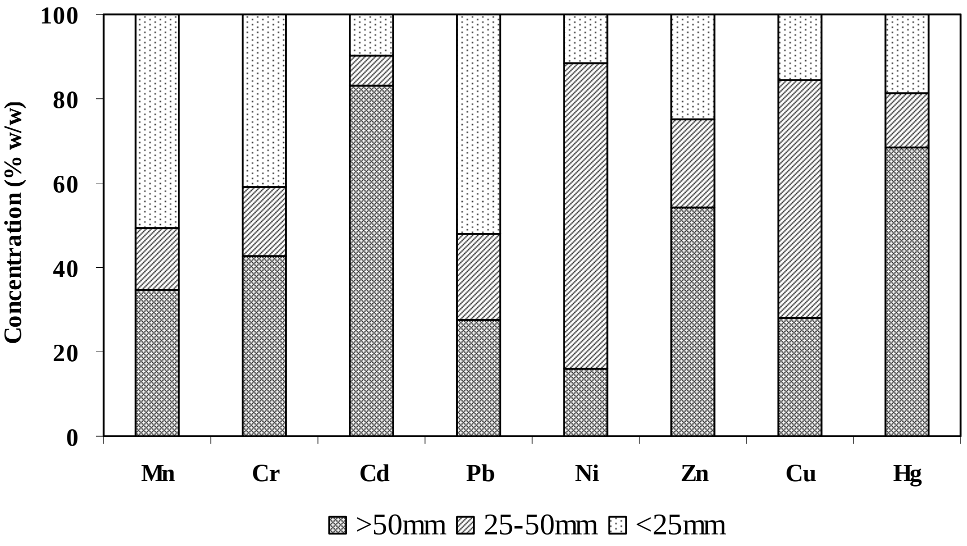


Figure 4.20 Heavy metal mass distributions in waste separation process

Figure 4.20 shows the distribution of heavy metals content in various fractions of solid waste resulting from trommel screen. It was observed that most Mn and Pb content in the solid waste was present in the waste size < 25 mm, while Cu and Ni were mainly found in the waste size 25-50 mm. The Cr content in the waste was found to be distributed equally in both coarsest and finest waste fraction. For Cd, Hg and Zn, a largest portion of these metals was present in the coarsest waste. This can be associated to the relatively high plastic component in the waste size > 50mm. In consideration of the removal efficiency of heavy metal, approximately 84% of Ni and 72% of Cu and Pb content in the excavated waste can be separated and removed into the medium and finest size solid waste by trommel screen, whereas the removal efficiency of Cd, Hg and Zn was approximated at 17%, 32% and 48% w/w respectively. Rotter et al. (2004) indicated that about 5% of Cd content in MSW can be eliminated by screening through 30 mm trommel screen.

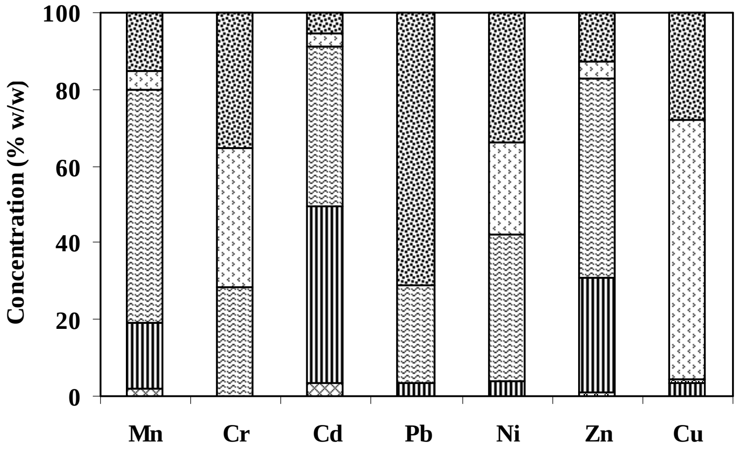
4.3.4 Binding forms of heavy metals content in waste size <25mm and 25-50mm

The binding forms for heavy metal content in the waste size < 25 mm and 25-50 mm received from the trommel screen was measured to evaluate the leaching potential of heavy metals in using as compost and the possibility of waste disposal in landfill. The result is presented in Figure 4.21 and Appendix-I (Table I-6 to Table I-7)

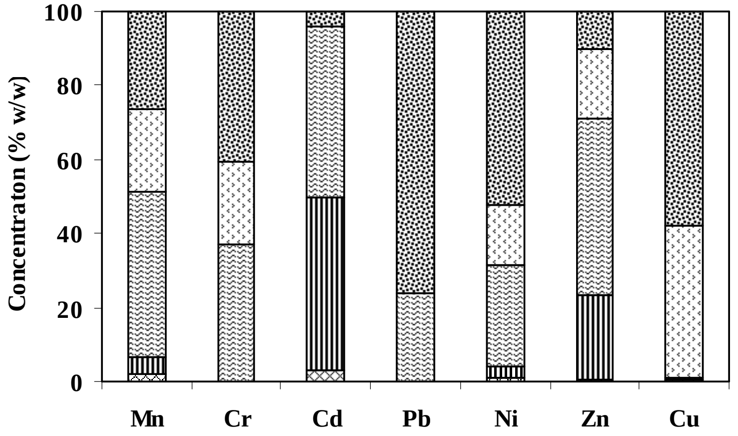
(1) Waste size < 25mm

Figure 4.21a shows the binding form of heavy metals except Hg content in the solid waste size <25mm. According to the contamination factor analysis, the residual fraction of each heavy metal is generally considered as non-mobility fraction and is expected to have low risk for environmental contamination. Comparison of the percentage of residual fraction produced the following order: Pb> Ni, Cr> Cu> Mn, Zn> Cd. This implies that leaching potential of Pb was relatively lower than other metals.

The exchangeable fraction of heavy metal is generally easily released from the waste by the ion exchange mechanism which affects the environmental contamination and toxicity. On the other hand, the proportion of exchangeable fraction of all the heavy metal was much lower than other fractions. Thus, the degree of heavy metal to be released from this waste by the ion exchange mechanism may be relatively low. In this case, Cd and Mn were found to have higher potential to be released from the waste by ion exchange mechanism.



(a) Waste size < 25mm



(b) Waste size 25-50mm

Figure 4.21 Heavy metal binding forms of waste size < 25mm and 25-50mm

In addition to ion exchange, heavy metal leaching from this waste may have occurred due to the acid dissolution of carbonate precipitate heavy metal in the waste especially during the hydrolysis stage of organic matter degradation. As a result, approximately 40%w/w of Cd was precipitated with carbonate compound which is relatively higher than other metals. The concentration of carbonate precipitate heavy metal in this waste was found to decreased from Cd> Zn> Mn> Pb, Ni, Cu> Cr. The similar result was found in other studies as reported where carbonate bound Cd, Mn and Zn in decomposed MSW are relatively higher than Pb, Ni, Cu and Cr (Esakku et al., 2005; He et al., 2006).

The largest proportion of Mn, Zn and Ni content in the waste size < 25 mm with average of 60%, 52% and 38% w/w was bound with Mn/Fe oxide. This is because of the oxidation condition revealed in the dumpsite (Figure 4.2). The relatively high proportion of Mn/Fe oxide bound Mn and Zn was also reported in other dumpsite (Esakku et al., 2005). Under the moderate reducing condition, however, Mn oxide can be reduced and released from this waste. For Zn and Ni, they are suggested to be adsorbed on Fe-oxide which can be released into environment in the lower reducing condition.

Comparing with Mn, about 68% w/w of Cu and 36% w/w of Cr content in this waste were mainly bound with the organic compound. The observed high organic bound Cu in this waste was associated to its affinity to bind with organic compound. Walter et al. (2006) found that about 68-72% w/w of Cu content in the sewage sludge was present in the organic and sulfide bound fraction. Under the oxidation condition, however, organic matter can be degraded and can release Cu and Cr into the environment. In addition, dissolved organic matter produced during the degradation of organic matter enhances the leach of these metals into the environment.

(2) Waste size 25-50 mm

Figure 4.21b shows the binding form of heavy metals content in the waste size 25-50 mm. Similar to the waste size < 25mm, the Mn, Cd and Zn content in the waste size 25-50 mm was mainly bound with Mn/Fe oxide and precipitated with carbonate compound. Moreover, most fraction of Pb was still present in the residual form. However, the increase of residual fraction was found in Mn, Cu, Cr, Pb and Ni. In comparison to other fraction, additionally, the proportion of residual fraction of Cu, Cr and Ni was highest. This is different from the waste size < 25 mm which most of Cu and Cr was present in the organic bound fraction, while Ni was found in the Mn/Fe oxide bound fraction. The observed increase of residual heavy metal concentration in this waste might be attributed to the change of solid waste composition. Based on the result, it can be concluded that leaching potential of heavy metal in this waste size 25-50 mm is relatively lower than that of the waste size < 25 mm. The expected order of leaching potential of heavy metal in this waste was in a decreasing manner that goes from Cd> Zn> Mn> Cr> Ni> Cu> Pb.

4.3.5 Management of the reclaimed waste from dumpsite

(1) Recycling of waste size > 50mm

Based on the result (Figure 4.16 and Figure 4.17), the presence of high combustible waste component showed the possibility of the incineration of waste size > 50mm. The characteristics of solid waste size > 50mm compared to the standard quality of waste derived fuel in cement plant are presented in Table 4.13. The calorific value of this waste was about 36 MJ/Kg which is relatively high and is much higher than other study. Hogland et al. (2004) found that calorific value of the reclaimed waste size > 50mm from landfill was about 7MJ/kg. The observed high calorific value of this waste could be attributed to the relatively high plastic component in this waste. The typical calorific value of plastic has been reported at 28-37 MJ/kg (Tchobanoglous et al., 1993). Moreover, Campbell et al. (2002) reported that calorific value of plastic in MSW was about 33-35 MJ/kg. The European Union for Responsible Incineration and Treatment of Special Waste (EURITS) establishes the quality standard of waste to be recycled as a substitute fuel in cement plant. It was noticed that the calorific value of this waste is much higher than the minimum requirement of solid waste quality standard.

Table 4.13 Physical and chemical characteristic of waste size > 50mm

Parameter	Waste size >50mm	EURITS [a]
Calorific value (MJ/kg)	36.0	15
Ash (% w/w)	32.8	5
Mn (mg/kg)	155.6	200
Cr (mg/kg)	44.0	200
Cd (mg/kg)	8.2	10
Pb (mg/kg)	17.2	200
Ni (mg/kg)	16.2	200
Zn (mg/kg)	790.0	500
Cu (mg/kg)	1256.3	200
Hg (µg/kg)	970.0	2000

Note: [a] Standard quality of waste derived fuel in cement plant (Gendebien et al., 2003)

In addition to the uncertainty of heavy metal concentration (Figure 4.19), the concentration of Zn, Cu and ash content in this waste size > 50 mm still exceeds the maximum limit of waste derived fuel quality standard. This can be due to a low purity of this waste as observed. Thus, direct recycling of waste of size > 50 mm as fuel may be unsuitable. In this case, recycling the plastic waste from this waste size > 50 mm for RDF production can be done in order to improve the quality of waste to be used as fuel. The relatively low concentration of heavy metals content in plastic waste compared to the other studies and its quality standard is presented in Table 4.14. However, approximately 30% w/w of ash content in the plastic waste still exceeds the acceptable level.

Table 4.14 Concentration of heavy metals in the reclaimed plastic from dumpsite

Metal	This study	China	Denmark [a]	German	EURITS [b]
		He et al. (2006)	Riber et al. (2005)	Rotter et al. (2004)	Gendebien et al. (2003)
Ash (%)	30.0	-	-	-	5
Mn (mg/kg)	107.2	-	-	-	200
Cr (mg/kg)	43.4	68.6	41.8	-	200
Cd (mg/Kg)	1.6	9.7	6.9	0.9	10
Pb (mg/Kg)	42.5	119.0	373.0	109.0	200
Ni (mg/Kg)	21.1	224.8	25.7	-	200
Zn (mg/Kg)	313.3	259.6	1020.0	768.0	500
Cu (mg/Kg)	150.5	-	614.0	-	200

Note: [a] Heavy metal in the combustible waste
[b] Standard quality of waste derived fuel in cement plant

(2) Recycling of waste size < 25mm as compost

Physical and chemical characteristic of waste

The characteristic of solid waste size < 25mm compared to compost quality standard is presented in Table 4.15. The pH level of waste is in acceptable level. In addition, the average 2.6 mS/cm EC is acceptable which reflects the soluble salt content in this waste. Approximately 42% w/w of VS shows the organic matter content in this waste. The observed 14.1% w/w of biodegradable organic carbon (TOC), however, was relatively low. As a result, the presence of 15.6 of C/N ratio in this waste indicates that the degradation of organic matter in this waste is complete.

On the other hand, the concentration of K was relatively lower than the acceptable level. In addition, the concentration of Cu is more than four times higher than the maximum limit in the compost standard. This can cause the phytotoxic effect in plant. Wang (1994) reported that seed germination of rice is relatively sensitive to Cu toxicity. Ahsan et al. (2007), moreover, supported that excess exposure to copper induces the oxidative stress generation in rice seed which affects its metabolic process. This can cause starvation of water uptake and failure in the reserve mobilization process.

Table 4.15 Physical and chemical characteristics of waste size < 25 mm

Parameter	**Waste size < 25mm**	**Compost standard [a]**
pH	7.7	5.5-8.5
EC (mS/cm)	2.6	≤ 3.5
VS (% w/w)	42.0	-
TOC (%w/w)	14.1	-
N (%w/w)	0.9	>1.0
P (%w/w)	0.7	> 0.5
K (%w/w)	0.2	> 0.5
C/N	15.6	≤ 20
Mn (mg/kg)	947.1	-
Cr (mg/kg)	166.6	≤ 300
Cd (mg/kg)	4.2	≤ 5.0
Pb (mg/kg)	132.1	≤ 500
Ni (mg/kg)	47.8	-
Zn (mg/kg)	1496.7	-
Cu (mg/kg)	2245.0	≤ 500
Hg (µg/kg)	1080.0	≤ 2000

Source: [a] National Bureau of Agricultural Commodity and Food Standards (2005)

Phytotoxicity of waste

Figure 4.22 shows the relatively low toxicity of waste size < 25mm to inhibit the relative seed germination rate (RSG), root elongation rate (RRG) and germination index (GI) of rice seed. As a result, the average RRG, RSG and GI of rice is relatively high. Moreover, the observed 88% GI of rice seed was in the expectable level vis a vis the 80% GI of the standard quality of compost. In comparison to the control, a little decrease of RRG, RSG and GI was observable. This is not only because of heavy metal, but EC, ammonia, phenolic compound and low molecular weight organic acid can also inhibit the germination of rice. In the stabilized compost, however, the concentration and toxicity of this compound generally decreased (Pascual et al., 1997; Tiquia et al., 1996). Therefore, it can be concluded that degradation of organic matter in the waste size <25mm is sufficiently complete and can be reused as compost.

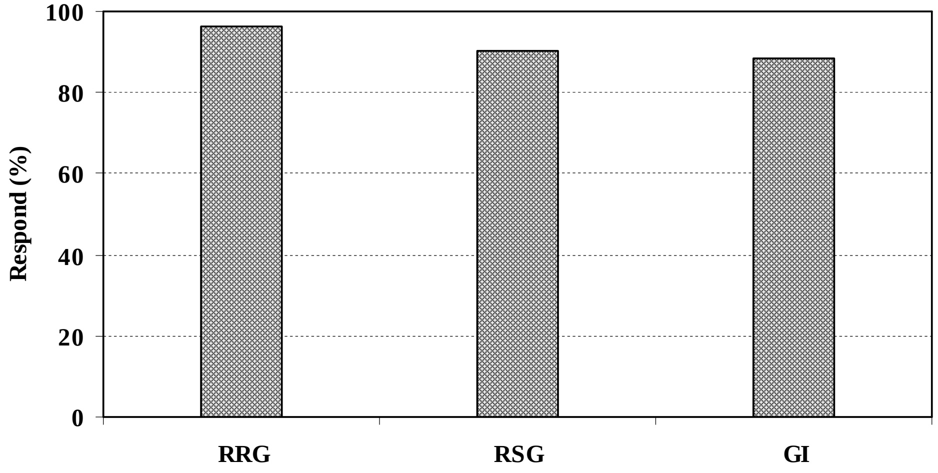


Figure 4.22 Seed germination test of waste size < 25mm

Figure 4.23 shows the relatively low concentration of heavy metals in the extracted water of the waste size < 25mm compared to its concentration presented in this waste. It was noted that heavy metal concentration decreases from Cu> Zn> Mn> Ni> Cr> Pb> Cd. The observed high Cu, Zn and Mn as well as the low concentration of Cd may be associated to the concentration of these metals in the waste. As the sequential extraction analysis result (Figure 4.21a), moreover, heavy metal content in this waste was mainly adsorbed on Mn/Fe oxide, organic compound and also present in the residual form. This leads to the water –extractability of heavy metals in this waste is low especially Pb, Cr, Ni and Cu. For Cu, it was noted that its composition in the waste was mainly adsorbed on the organic matter. The observed higher Cu content in the extracted water, therefore, may be present as the complexation of dissolved humic acid chelating agent which is generally found in the stabilized compost. As reported in Wang (1994), the IC_{50} of Cu in germination of rice was about 0.22 mg/L. This is relatively lower than the concentration of Cu present in this study (Figure 4.23). This implied that the toxicity of Cu in the extracted water may be lowered.

Inaba and Takenaka (2005) found that the high molecular weight dissolving humic acid can reduce the bioavailability and toxicity of Cu in plant. Therefore the observed low toxicity of Cu content in the size <25mm can be related to the binding form of Cu as well as maturity of organic matter degradation. In the mature solid waste, the organic matter remaining from the degradation is mainly humic acid, one that can form the complex with metal and decrease the bioavailability and toxicity of metals in plants.

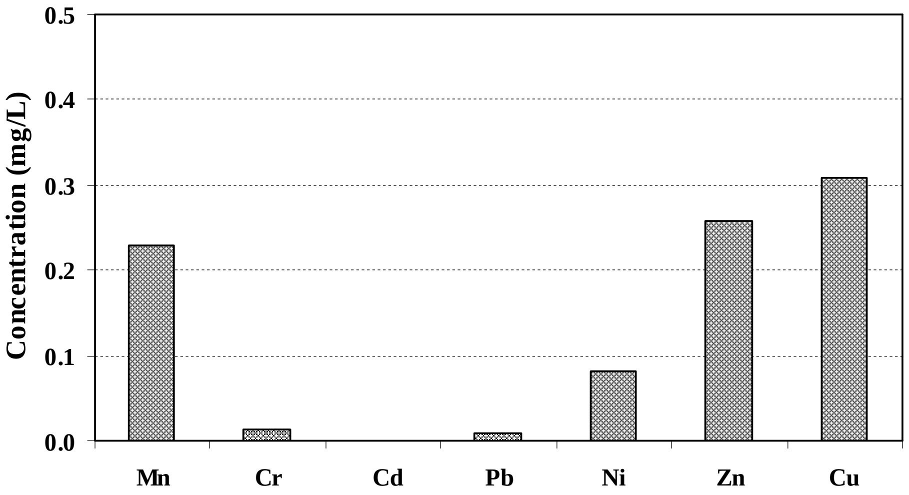


Figure 4.23 Concentration of heavy metal in the extracted water from waste size <25mm

4.3.6 Leaching potential of heavy metal from waste size < 25mm and 25-50mm

Determination of leaching potential of heavy metal in the waste size <25mm and 25-50mm was conducted to evaluate the environmental contamination potential of these waste size<25mm and 25-50mm to be disposed into the MSW landfill. The concentrations of heavy metals the TCLP leachate compared to the TCLP standard was presented in Table 4.16.

Table 4.16 Heavy metals concentration of the leachate in the TCLP test of solid waste received from the waste separation process

Parameter	**Concentration (mg/L)**		**U.S.TCLP standard** [a]
	< 25 mm	**25-50 mm**	
pH	7.05	7.03	-
Mn	0.679	0.514	-
Cr	0.004	0.006	5.0
Cd	0.002	0.001	1.0
Pb	0.017	0.011	5.0
Ni	0.142	0.043	-
Zn	0.428	0.283	-
Cu	0.070	0.055	-
Hg	<0.001	<0.001	0.2

Source: [a] USEPA (2006)

The pH level of leachate was found to be neutral in both samples that are result of the alkalinity of these wastes. Except for Cr, the concentration of all the heavy metals in the TCLP leachate of waste size <25mm was found to be relatively higher than that of waste size 25-50mm. This corresponded to the higher concentration of Mn, Cu, Pb, Hg and Cd in the waste size < 25mm and the higher residual fraction of these metals in the waste size 25-50mm.

The concentration of Mn and Zn leaching from these wastes was relatively higher that other metal. This is attributed to the presence of higher concentration of these metals and their acid soluble fraction (Carbonate bound) in these wastes. For Cu, although its concentration is relatively high in these wastes, the very low concentration of acid soluble fraction was observable in this metal. Similar to Cu, the acid soluble fraction of Cr was found to be very low. In addition to the acid soluble fraction, the Mn oxide content in the waste can also be released from this waste. The Mn oxide is generally more sensitive to the redox potential changed than Zn adsorbed on Fe-oxide. Thus, the observed high Mn concentration could be effect of the reduction of Mn oxide by H^+ content in the TCLP extraction solution.

Based on these results, the concentrations of all the heavy metals in these TCLP leachates are below the maximum concentration limit in the TCLP standard. Therefore, disposal of the waste size <25mm and 25-50mm is acceptable. Under the anaerobic condition, however, the leach of reducible fraction of heavy metal such as Mn, Zn and Cd content in these wastes enhances the heavy metal contamination in landfill leachate again.

4.4 Potential practical application of research result

The research results contributed to the MSW management system in Thailand in the following ways.

(1) Plastic waste management

From the results (Table 4.8), the plastic waste was found to be the major composition of 3-5 years old solid waste in the dumpsite. The organic and food waste is degraded from dumpsite in the form of leachate and gas, whereas the remaining organic fraction is present in the form of soil like material which is difficult to be degraded. According to the solid waste composition found in dumpsite, approximately 20-30% w/w of organic matter in the MSW is degraded. In contrary to the organic fraction, approximately 16-28% of accumulated plastic waste was found to be increased in the waste compared to the current MSW composition. The organic waste component in MSW can be degraded and stabilized, whereas the plastic waste is difficult to degrade and tends to accumulate in the dumpsite.

High plastic component in the dumpsite leads to change in physical characteristic of dumpsite. The relatively high composition of plastic with its inherent low density leads to the decrease of solid waste density in dumpsite (Table 4.1). This consequently enhances the distribution of water and gas in the dumpsite affecting the increase of oxidation–reduction potential, solid waste degradation and mobilization of heavy metal in dumpsite especially Cu and Cr adsorbed on solid organic matter or precipitated with sulfide. Moreover, degradation of plastic waste remained in the dumpsite causes the leachate contamination of plasticizer phthalate and Bisphenol A (BPA), which has been identified as endocrine–disruptor substances.

For the above reason, the amount of plastic waste to be disposed into the dumpsite as well as sanitary landfill should be decreased. In addition to reuse and recycling, the segregation/separation of MSW at the source should be encouraged especially in the large municipality which is a major source of plastic waste generation. In addition, the reduction of plastic waste generation can be developed as a national policy.

(2) Household hazardous waste management

From the size distribution, mined waste was found to have household hazardous waste, especially dry cell battery. This is attributed to the lack of proper hazardous waste management system. As the result (Appendix-H, Table H-10), dry cell battery component in the mined waste of dumpsite is about 0.5% w/w of total waste weight. This result is in normal condition compared to the household hazardous waste generation rate in Thailand which is approximately 0.3% w/w of total municipal solid waste. In general dry cell battery consists of heavy metal such as Mn, Zn, Pb, Cd and Hg. It has been reported that concentration of Mn, Zn and Pb content of dry powder contain in battery is about 45%, 21% and 0.03% w/w of dry powder, while the Hg and Cd concentration in the powder is 1.0 mg/kg and 0.06 mg/kg, respectively (Souza and Tenorio,2004). Disposal of this waste into MSW, therefore, can increase the contamination of these metals in dumpsite.

In addition to the relatively high concentration of heavy metals in dry cell battery, leaching potential of these metals in the dumpsite is also high. As discussed in section 4.1, the anaerobic condition and high concentration of dissolved organic compound in the leachate are the two important factors influencing the mobility of Mn and Zn in the dumpsite. In addition, leaching of Mn and Cd from the waste is increased by the ion exchange mechanism with chloride ion content in the leachate. For the reason of high heavy metal concentration and its leaching ability in the dumpsite, source separation of the household hazardous waste should be promoted in order to reduce the concentration of these metals in the waste. Moreover, this decreases risk of heavy metal to the environment.

(3) Leachate treatment

From the leachate analysis result (Table 4.8), the characteristic of leachate accumulated in the dumpsite is relatively lower than the acceptable level. Moreover, the concentration of toxic compounds in leachates was found to have toxic effect on the germination and root elongation of rice. The toxicity test result (Figure 4.10) showed higher toxicity of the runoff leachate from the dumpsite compare to the treated leachate in ponds. This variation of leachate toxicity is because of the difference of toxic compounds concentration in leachate.

Identification of the factors influencing the toxicity of runoff (Section 4.3, Figure 4.11-Figure 4.14), showed that pH, ammonia and heavy metal are the factors influencing toxicity of leachate. The result shows that high pH level of leachate enhances the formation of unionized ammonia which is considered as the toxic form of ammonia. On contrary to the ammonia, the decrease in pH enhances ionization of heavy metal which consequently increases leachate toxicity. From the result (Table 4.8), the presence of 0.67mg/L Cr and 0.16 mg/L of Cu are relatively higher than the allowable concentration of these metals in effluent standard. In addition, the ammonia concentration in leachate was about 620 mg/L. However, there is no concentration limit of ammonia in the effluent standard. But, the allowable ammonia concentration in the natural surface water is limited to 0.5 mg/L. Therefore the pH level, ammonia, and heavy metal concentration in leachate should be controlled to optimal level to reduce the toxicity of leachate in the environment.

(4) Municipal solid waste disposal site selection

In addition to the leachate treatment system, the agricultural area for rice cultivation is highly sensitive to the leachate toxicity. The result (Figure 4.10) of the germination rate and root elongation of rice was found to be very sensitive to the toxicity of leachate. From the result, approximately 50% of germination index (GI) of rice can be decreased by the exposure to the runoff leachate with its concentration at 3.0% v/v. The toxicity of leachate, however, is lower in the leachate ponds (18-24%v/v IC_{50}) due to the reduction of toxic compound concentration. The growth rate and productivity of rice will be affected by the leachate contaminate in the surrounding area. Thus, the cultivation area of rice may be considered as a sensitive area to be affected by the dumpsite and is used as one of criteria for evaluating MSW disposal site.

(5) Dumpsite mining

Presently, more than 60% of the MSW generated in Thailand has been disposed in open dumping area. The remaining fraction is sanitary landfilled, composted, and incinerated. From the above discussions, however, the plastic and soil like material is accumulated in the dumpsite although the degradation of organic matter is complete and acts as a source of organic and inorganic compound as well as heavy metal contamination in leachate, surface water and ground water.

The mining can be implemented in the existing MSW dumpsite. The plastic and soil like material remained in the dumpsite can be removed and separated for recycling. The solid waste separation was performed using trommel screen with screen size of 25mm and 50mm can separate the soil like material and smaller fractions of solid waste size which consequently decreases heavy metal concentration in the waste size >50mm. The characteristic of plastic waste with its relatively low heavy metal concentration (Table 4.14) and high calorific value (36 MJ/kg) indicates the possibility of plastic waste in dumpsite to be recycled as raw material for RDF production. The waste size < 25 mm, which mainly is composed of soil like material, can be reused as compost for soil amendment. Due to the presence of high plastic and non-degradable material component in the waste size 25-50 mm, it is unsuitable to be reused as compost. Thus, it can be returned to the sanitary landfill. The dumpsite can be converted to a sanitary landfill with the proper landfill lining, leachate and gas management system, and reused for MSW disposal. Contamination of leachate in the surface water and ground water can be reduced and reduces the requirement of landfill space for MSW disposal.

As the physical and chemical characteristics of the dumpsite was found to be highly heterogeneous (Table 4.7), this showed varying organic matter degradation rate and solid waste age influencing the toxicity of organic waste and its suitability to be reused as compost. Thus, investigation of dumpsite characteristic is necessary before implementation of dumpsite mining, so as to identify appropriate method of managing waste.

Chapter 5

Conclusion and Recommendations

The objective of this study is to investigate the environmental impact of municipal solid waste dumpsite and the possibility of dumpsite mining for waste recycling. The study comprised of three main parts:

The first part aimed to determine the characteristic of solid waste and leaching ability of heavy metals in solid waste. The solid waste was excavated to characterize its physical and chemical characteristic. The binding forms of heavy metals were determined in solid waste by performing sequential extraction analysis on the solid waste. The leaching potential of heavy metal in the acidic condition was investigated using Toxic Characteristic Leaching Procedure (TCLP). Additionally, the concentration of heavy metals in the dumpsite was determined in the runoff leachate and leachate boreholes.

The second part of study was investigation of the contamination of toxic compounds in the stored leachate in the leachate treatment system and leachate ponds, surface water, and groundwater resources. In addition, the toxicity of leachate was investigated via seed germination and root elongation test of rice (*Oryza sativa* L.), which is considered as a predominant species in the area of study.

Finally, the recycling potential of solid waste in the dumpsite was evaluated. The solid waste composition, size distribution, as well as the physical and chemical characteristics of the reclaimed waste was investigated. Moreover, the phytotoxicity of soil-like material to be recycled as compost was determined. In addition, the TCLP test was performed on the non-recyclable waste fraction that is to be returned to the MSW landfill.

5.1 Conclusions

The conclusions of the research results from this study are presenting below

5.1.1. Characterization of solid waste and leaching potential of heavy metal

(1) The physical and chemical characteristic of solid waste in the dumpsite was found to have no significant difference between the sampling points. The varying moisture content in the vertical profile of dumpsite was found to influence density and biodegradation rate of organic matter in dumpsite.

(2) The concentration of Zn, Cu and Mn in the dumpsite was relatively higher than Cr, Pb, Ni, Cd and Hg, respectively. The binding form of this metal was found to vary at various sampling location reflecting the varying oxidation-reduction condition of the dumpsite. The Mn, Zn and Cd was mainly found in form of Mn/Fe oxide, while Cu and Cr were found to be absorbed on the organic matter or precipitated with sulfide. Most of Pb and Ni content in the dumpsite were found in residual form.

(3) The relatively higher contamination factors (Cf^i) of Zn, Cu and Mn shows higher risk of these metals to be released into the environment, whereas a relatively low contamination factor for Pb and Ni due to the presence of higher insoluble fraction of these metals.

(4) The observed higher leaching rate of Mn, Zn and Cd in the TCLP test indicated the leaching potential of these metal in acidic condition, which is attributed to the high concentration of carbonate precipitated Mn, Zn and Cd in the dumpsite.

5.1.2. Determination of leachate toxicity and toxic compound influences the toxicity of leachate

(1) Biodegradation of organic matter in the dumpsite was found to be in the methanogenic condition. The biodegradation rate and age of solid waste, however, were found to be significantly different among the sampling sites. The influence of the above two factors on the concentration of heavy metals in leachate is seen with the lower heavy metals concentration except Mn in boreholes compared to the runoff leachate. The concentration of heavy metals content in the runoff leachate was found in the following order: Zn> Cr> Cu> Ni> Mn> Pb> Cd> Hg

(2) The reducibility of heavy metal in the anaerobic condition and complexion of heavy metal with the heavy metal chelating agent and dissolved organic matter in the leachate are considered as the major factors influencing heavy metal in leachate. The acid dissolution of carbonate precipitated metal in the dumpsite is expected to be at low level due to the presence of high acid buffer capacity of dumpsite.

(3) The behavior of heavy metal in leachate was found to be different. With exception of Mn, a decrease in the heavy metal concentration as well as organic and inorganic compounds content in runoff leachate in the leachate treatment system and leachate ponds was observed. This is attributed to the difference of speciation of heavy metal in leachate. The Mn content in the runoff leachate was generally present as Mn ion that is relatively stable in the leachate treatment system and ponds.

(4) The contamination of organic and inorganic compound as well as heavy metal in the surface water was noticed near the dumpsite. However, the relatively high contamination of leachate was found in ponds and canal nearby the dumpsite. Moreover, the concentration of organic matter, ammonia and heavy metal especially Cr, Cd, Pb, Ni and Cu was relatively higher than the acceptable level in the surface water and dinking water quality standards. This reveals the potential environmental and human health impact of the dumpsite.

(5) The ground water resource was found to be contaminated with organic matter, ammonia and heavy metal. The concentration of Mn, Pb and Ni exceeds the acceptable level of groundwater quality standard.

(6) The leachate accumulated in the dumpsite was found to be toxic to the germination of rice. The toxicity of leachate however, is different from that of the leachate ponds and runoff leachate. The highest toxicity was found in the runoff leachate, whereas the lowest toxicity was found in the leachate ponds P3.

5.1.3 Recycling potential of solid waste in dumpsite

(1) The plastic waste and soil like material was the major composition of the degraded waste in dumpsite. Approximately 69% of the waste was found to be of size > 50mm, while the smaller fraction of size <25mm and 25-50mm was 18% and 13% w/w, respectively. About 69% of soil like material can be removed from the waste by screening the waste trough trommel screen.

(2) The heavy metal concentration was found to differ among three solid waste sizes. The waste size > 50mm was found to have lower concentration of heavy metal except Cd compared to that of waste size < 25mm and 25-50mm.With exception of Cd, moreover, concentration of all the heavy metal content in the waste size > 50mm was relatively low compared to the estimated heavy metal concentration in the composite waste. Thus this can be concluded by separation of the waste size <25mm and 25-50mm can decrease in the concentration of metals content in the waste size >50mm except for Cd.

(3) The characteristic of solid waste size > 50mm obtained from the trommel screening process was found to be heterogeneous. Although the calorific value of the waste >50mm is high, ash, Cu and Zn concentration in this waste exceeded the maximum limit of the standard quality of waste to be recycled as a substitute fuel. Recycling the plastic waste from the dumpsite as a raw material for RDF production was found to be a suitable way with relatively low concentration of all the heavy metals.

(4) The waste size <25mm was found to have high Cu concentration exceeding the quality standard requirement for compost, whereas potassium concentration is relatively low. However, the toxicity of this waste is low. This can be attributed to the completed organic matter degradation of this waste. Moreover, the humic organic compound in the waste can form a complex with Cu and reduce its bioavailability and toxicity in plant. Thus, the waste size <25m can be reused as the compost material for soil amendment especially for non-edible crop cultivation.

(5) Due to the reason that waste size 25-50mm mainly contains a large amount of non-biodegradable waste, the application of this waste fraction as compost is limited. The TCLP of the waste size 25-50mm shows the relatively higher concentration of Mn and Zn content compared to other metals in the extracted leachate. The concentration of all the heavy metal in this leachate samples, however, is still in the acceptable level for the waste to be disposed in the MSW landfill.

5.2 Recommendations

(1) The observed high contamination of leachate in the surface water and ground water resource in the surrounding area of dumpsite indicates the environmental impact of dumpsite. Therefore, the leachate and solid waste management system within the dumpsite is necessary to be improved in order to mitigate the toxic impact of waste in the dumpsite.

(2) According to the toxicity test result, the pH, ammonia and heavy metal was found to have influence on the toxicity of leachate. Therefore, control on such parameters is highly required to protect the environmental toxic impact from dumpsite.

(3) The observed toxicity test on leachate indicates the possibility of leachate to be toxic to the germination rate and root elongation rate of rice. However, this is insufficient to be used to describe the adverse effect of leachate to the growth rate and productivity of rice. Further research on experiment the toxic effect of leachate to the growth rate and productivity of rice may be done.

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APPENDIX- A

Solid waste sampling and classification

Figure A-1 Nonthaburi MSW dumpsite

Figure A-2 Solid waste sampling

Figure A-3 Solid waste screening by trammel

Figure A-4 Solid waste screening by trommel

APPENDIX- B

Leachate, surface water and groundwater sampling sites

Figure B-1Runoff leachate in dumpsite

Figure B-2 Runoff leachate in the open pipe (L)

Figure B-3 Leachate treatment system (T1, T2)

Figure B-4 Leachate pond in dumpsite (P1-P3)

Figure B-5 Leachate borehole (BH1-BH2)

Figure B-6 Groundwater monitoring well (MW1-MW4)

Figure B-7 Surface water resource (S1)

Figure B-8 Surface water resource (S2)

Figure B-9 Surface water resource (S3)

Figure B-10 Surface water resource (Klong Ha Roi; S8)

APPENDIX-C

Seed germination and root elongation test of rice (*Oryza sativa* L.)

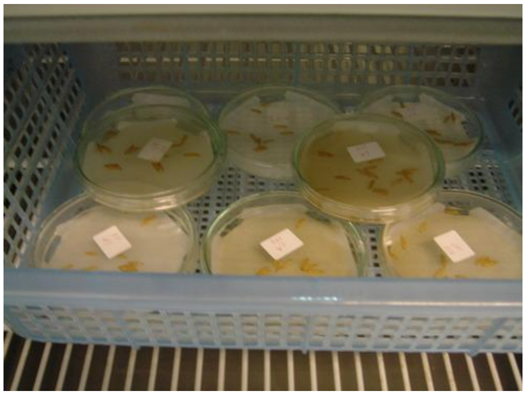


Figure C-1 Seed germination test of leachate

Figure C-2 Incubation of seed during the germination test

Figure C-3 Seed germination and root elongation

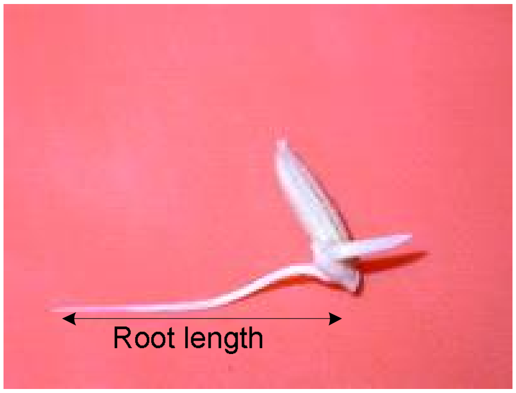


Figure C-4 Root elongation measurement

APPENDIX-D

Physical and chemical characteristics of solid waste in dumpsite

1. physical and chemical characteristic of dumpsite

Table D-1 Solid waste characteristic in Nonthaburi dumpsite

Sampling point	**Depth m**	**Density kg/m^3**	**pH**	**Moisture %w/w**	**VS %w/w**	**TOC %w/w**	**Mn mg/kg**	**Cr mg/kg**	**Cd mg/kg**	**Pb mg/kg**	**Ni mg/kg**	**Zn mg/kg**	**Cu mg/kg**	**Hg µg/kg**
SW1	0-1	250.0	7.3	28.6	52.7	14.3	332.7	142.6	38.1	127.0	94.1	556.7	268.6	202.7
	1-2	337.0	7.7	43.2	20.0	17.1	231.9	57.3	2.0	36.0	52.3	351.0	148.6	319.1
	2-3	270.0	7.6	53.0	35.1	14.0	161.7	85.2	3.7	13.2	28.7	586.5	274.1	407.4
SW2	0-1	260.0	7.2	43.2	24.4	21.8	113.4	79.5	0.9	64.1	24.2	290.9	130.2	429.7
	1-2	410.0	7.5	48.8	50.8	17.1	352.9	90.9	3.1	60.5	47.4	401.3	308.1	264.5
	2-3	370.0	7.5	51.7	41.3	15.1	289.1	88.0	4.0	36.0	38.1	467.0	313.2	284.6
SW3	0-1	285.0	7.3	42.7	30.7	28.1	189.5	59.7	4.2	42.3	52.3	275.4	188.1	292.7
	1-2	410.0	7.3	59.5	30.9	15.3	254.6	58.6	1.3	84.6	51.8	424.1	221.3	428.1
	2-3	302.0	7.9	58.5	35.1	18.3	190.4	186.2	1.0	35.1	45.0	523.7	178.3	331.2
SW4	0-1	238.0	7.3	34.6	52.3	19.9	157.0	59.6	3.4	16.3	83.2	563.8	118.8	513.3
	1-2	412.0	7.9	50.9	63.4	8.9	99.9	76.3	2.7	32.9	38.9	488.1	351.1	301.4
	2-3	225.0	7.9	50.9	46.0	14.9	209.6	65.8	1.7	13.4	25.7	572.3	544.6	433.6
Average	-	314.0	7.5	47.1	40.2	17.1	215.2	87.5	5.50	46.77	48.47	458.4	253.8	350.7

2. Binding forms and contamination factor of heavy metal in the dumpsite

Table D-2 Binding forms and contamination factor of heavy metals content in solid waste

Metal	Point	Concentration (mg/kg)					Cf^i
		F1	F2	F3	F4	F5	
Mn	SW1	7.8	39.7	155.7	15.0	23.8	9.2
	SW2	4.2	10.8	209.6	11.8	15.4	15.4
	SW3	11.7	85.3	60.4	21.3	32.8	5.5
	SW4	11.2	35.0	60.1	31.0	18.1	7.6
Cr	SW1	0.2	0.5	30.8	35.9	27.6	2.4
	SW2	0.2	0.3	32.3	25.2	28.1	2.1
	SW3	0.2	1.1	27.9	54.2	18.1	4.6
	SW4	0.3	0.8	8.2	38.9	18.9	2.6
Cd	SW1	1.3	1.3	9.7	0.8	1.5	9.0
	SW2	0.4	0.3	1.1	0.2	0.7	2.7
	SW3	0.4	0.5	0.4	0.4	0.5	3.7
	SW4	0.5	0.5	0.5	0.2	0.9	2.0
Pb	SW1	0.5	3.1	15.9	1.4	37.9	0.6
	SW2	0.4	2.1	25.0	5.1	21.0	1.5
	SW3	0.9	7.8	13.2	11.1	20.9	1.6
	SW4	0.9	2.0	4.1	3.8	10.1	1.1
Ni	SW1	0.7	1.7	16.0	16.7	23.3	1.5
	SW2	0.7	0.8	12.2	9.9	12.9	1.8
	SW3	1.2	2.6	11.0	15.1	19.7	1.5
	SW4	1.2	2.2	6.8	17.0	22.1	1.2
Zn	SW1	4.9	0.5	417.7	49.5	25.5	18.6
	SW2	1.5	1.1	323.6	39.6	20.6	17.8
	SW3	8.0	119.4	157.6	77.4	45.4	8.0
	SW4	7.8	126.2	175.3	145.6	86.6	5.3
Cu	SW1	1.8	4.6	2.1	176.5	45.4	4.1
	SW2	3.4	4.2	1.7	203.4	37.9	5.6
	SW3	3.0	3.8	0.6	175.8	12.7	14.5
	SW4	2.7	10.1	3.5	281.6	40.3	7.4

F1 = Ion exchanged; F2 = Carbonate; F3 = Mn/Fe oxide; F4= Organic /sulfide;
F5 = Residual

Calculation of contamination factor of heavy metals

$$\text{Contamination factor } (Cf^i) = (F1+F2+F3+F4)/F5 \qquad \text{Equation D-1}$$

3. Toxic characteristic leaching test of heavy metal in dumpsite

Table D-3 Toxic characteristic leaching procedure test of solid waste in dumpsite

Point	Depth (m)	pH	Mn	Cr	Cd	Pb	Ni	Zn	Cu	Hg
			mg/L	Mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	μg/L
SW1	0-1	6.6	1.512	0.008	0.044	0.016	0.038	0.821	0.099	<0.001
	1-2	6.8	1.159	0.020	0.002	0.041	0.061	0.425	0.092	<0.001
	2-3	6.8	1.155	0.003	0.003	0.010	0.043	1.091	0.047	<0.001
SW2	0-1	6.0	0.875	0.063	0.002	0.010	0.070	0.778	0.072	<0.001
	1-2	6.6	1.389	0.009	0.004	0.033	0.033	0.553	0.204	<0.001
	2-3	6.4	1.487	0.006	0.002	0.100	0.016	0.619	0.076	<0.001
SW3	0-1	-	-	-	-	-	-	-	-	-
	1-2	6.4	1.693	0.005	0.002	0.012	0.043	0.567	0.069	<0.001
	2-3	6.5	1.492	0.011	0.002	0.010	0.064	1.041	0.120	<0.001
SW4	0-1	7.0	0.001	0.003	0.002	0.026	0.019	0.377	0.075	<0.001
	1-2	6.9	0.494	0.008	0.005	0.020	0.026	0.565	0.069	<0.001
	2-3	7.0	0.831	0.007	0.003	0.040	0.047	0.237	0.047	<0.001
TCLP standard		-	-	5.0	1.0	5.0	-	-	-	0.2

Calculation of heavy metal leaching rate in the acid condition of dumpsite

$$HR(\%) = \frac{C_L \times L \times 1000 \times 100}{S_W \times C_S} \qquad \text{Equation D-2}$$

Where;

HR = Heavy metal leaching rate (%w/w)
C_L = Heavy metal concentration of extracted leachate (mg/L) (Table D-3)
C_S = Heavy metal concentration of solid waste (mg/kg) (Table D-1)
L = TCLP leachate volume (L); L = 1000 ml
S_W = Solid waste sample size (g); S_W = 50g

Table D-4 Leaching rate of heavy metals in TCLP test

Point	Depth (m)	Leaching rate (%w/w)							
		Mn	Cr	Cd	Pb	Ni	Zn	Cu	Hg
SW1	0-1	9.1	0.1	2.3	0.2	0.8	2.9	0.7	ND
	1-2	10.0	0.7	1.7	2.3	2.3	2.4	1.2	ND
	2-3	14.3	0.1	1.5	1.5	3.0	3.7	0.3	ND
SW2	0-1	15.4	1.6	4.6	0.3	5.8	5.3	1.1	ND
	1-2	7.9	0.2	2.3	1.1	1.4	2.8	1.3	ND
	2-3	10.3	0.1	1.0	5.6	0.8	2.6	0.5	ND
SW3	0-1	-	-	-	-	-	-	-	-
	1-2	13.3	0.2	3.2	0.3	1.6	2.7	0.6	ND
	2-3	15.7	0.1	4.2	0.6	2.8	4.0	1.3	ND
SW4	0-1	0.0	0.1	1.2	3.2	0.5	1.3	1.3	ND
	1-2	9.9	0.2	3.6	1.2	1.3	2.3	0.4	ND
	2-3	7.9	0.2	3.2	6.0	3.6	0.8	0.2	ND

4. Statistical analysis of solid waste characteristic in dumpsite

4.1 Comparison of solid waste characteristic between the sampling points

Table D-5 Test of homogeneity of variances of solid waste characteristic

Parameter	Levene Statistic	df1	df2	Sig.
Density	1.393	3	8	0.314
Moisture	1.105	3	8	0.402
pH	1.055	3	8	0.420
VS	1.456	3	8	0.298
TOC	1.661	3	8	0.252
Mn	1.724	3	8	0.239
Cr	7.248	3	8	0.011[a]
Cd	13.443	3	8	0.002[a]
Pb	5.246	3	8	0.027[a]
Ni	3.055	3	8	0.092
Zn	1.161	3	8	0.383
Cu	2.335	3	8	0.150
Hg	0.188	3	8	0.901

[a] The variance of solid waste characteristic was different significantly at 0.05. The comparison of solid waste characteristic was then performed by using Welch-Test.

For the non different variance parameter (P value ≥ 0.05), the comparison of solid waste characteristics was then performed by using F-test in ANOVA table.

Table D-6 Robust tests of equality of means of solid waste between sampling sites

Parameter		Statistic [a]	df1	df2	Sig.
Cr	Welch	2.675	3	3.935	0.185
Cd	Welch	0.310	3	4.011	0.819
Pb	Welch	2.952	3	4.075	0.159

[a] Asymptotically F distributed.

Table D-7 ANOVA table of solid waste characteristic

Parameter		**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Moisture	Between Groups	224.83	3	74.94	0.866	0.497
	Within Groups	692.43	8	86.55		
	Total	917.26	11			
Density	Between Groups	8024.32	3	2674.77	0.455	0.721
	Within Groups	46980.97	8	5872.62		
	Total	55005.28	11			
pH	Between Groups	0.10	3	0.03	0.433	0.735
	Within Groups	0.63	8	0.08		
	Total	0.74	11			
VS	Between Groups	813.68	3	271.23	2.045	0.186
	Within Groups	1060.86	8	132.61		
	Total	1874.54	11			
TOC	Between Groups	69.33	3	23.11	1.028	0.430
	Within Groups	179.80	8	22.48		
	Total	249.13	11			
Mn	Between Groups	16922.84	3	5640.95	0.830	0.514
	Within Groups	54350.86	8	6793.86		
	Total	71273.70	11			
Ni	Between Groups	727.73	3	242.58	0.450	0.724
	Within Groups	4311.86	8	538.98		
	Total	5039.59	11			
Zn	Between Groups	48640.67	3	16213.56	1.540	0.278
	Within Groups	84251.25	8	10531.41		
	Total	132891.92	11			
Cu	Between Groups	33083.19	3	11027.73	0.713	0.571
	Within Groups	123763.35	8	15470.42		
	Total	156846.54	11			
Hg	Between Groups	19660.84	3	6553.61	0.749	0.553
	Within Groups	69997.04	8	8749.63		
	Total	89657.88	11			

4.2 Comparison of solid waste characteristic between depth intervals of dumpsite

Table D-8 Test of Homogeneity of variances of solid characteristic

Parameter	Levene Statistic	df1	df2	Sig.
Density	1.750	2	9	0.228
Moisture	1.173	2	9	0.353
pH	5.086	2	9	0.033[a]
VS	7.488	2	9	0.012[a]
TOC	1.153	2	9	0.358
Mn	0.420	2	9	0.669
Cr	1.723	2	9	0.233
Cd	7.553	2	9	0.012[a]
Pb	1.711	2	9	0.235
Ni	8.824	2	9	0.008[a]
Zn	22.109	2	9	0.000[a]
Cu	0.918	2	9	0.434
Hg	3.019	2	9	0.099

[a] The variance of solid waste characteristic was different significantly at 0.05. The comparison of solid waste characteristic was then performed by using the Welch-test.

For the non different variance parameter (P value ≥0.05), the comparison of solid waste characteristic was done by using F-test in ANOVA table.

Table D-9 Robust tests of equality of means of solid waste characteristic

Parameter		Statistic [a]	df1	df2	Sig.
pH	Welch	15.863	2	4.277	0.011[b]
VS	Welch	0.017	2	4.693	0.983
Cd	Welch	0.562	2	4.906	0.603
Ni	Welch	3.360	2	5.227	0.115
Zn	Welch	4.481	2	5.519	0.070

[a] Asymptotically F distributed

[b] Significant different at 0.05

Table D-10 ANOVA table of solid waste characteristics

Parameter		Sum of Squares	df	Mean Square	F	Sig.
Moisture	Between Groups	599.54	2	299.77	8.491	0.008[a]
	Within Groups	317.72	9	35.30		
	Total	917.26	11			
Density	Between Groups	38601.95	2	19300.97	10.590	0.004[a]
	Within Groups	16403.34	9	1822.59		
	Total	55005.28	11			
TOC	Between Groups	95.91	2	47.97	2.817	0.112
	Within Groups	153.22	9	17.02		
	Total	249.13	11			
Mn	Between Groups	2728.37	2	1364.18	0.179	0.839
	Within Groups	68545.34	9	7616.15		
	Total	71273.70	11			
Cr	Between Groups	2552.19	2	1276.10	0.808	0.475
	Within Groups	14205.43	9	1578.38		
	Total	16757.62	11			
Pb	Between Groups	3158.68	2	1579.34	1.589	0.257
	Within Groups	8947.58	9	994.18		
	Total	12106.26	11			
Cu	Between Groups	45754.22	2	22877.11	1.853	0.212
	Within Groups	111092.33	9	12343.59		
	Total	156846.54	11			
Hg	Between Groups	3067.25	2	1533.62	0.159	0.855
	Within Groups	86590.64	9	9621.18		
	Total	89657.88	11			

[a] Significant different at 0.05

APPENDIX - E

Characteristic of leachate, surface water and groundwater in dumpsite

1. Leachate, surface water and groundwater quality

Table E-1 pH level of leachate, surface water and groundwater

Sampling points	**Nov 2005**	**Dec 2005**	**Jan 2006**	**Feb 2006**	**Mar 2006**	**Apr 2006**	**May 2006**	**Jun 2006**	**Average**	**SD**
BH1	-	8.7	8.7	8.9	-	-	-	-	8.8	0.1
BH2	-	8.1	8.1	8.3	8.3	8.3	7.2	7.3	7.9	0.5
P1	8.9	8.8	8.6	8.5	8.6	8.7	8.8	8.7	8.7	0.1
P2	8.7	8.4	8.5	8.6	8.4	8.6	8.8	9.0	8.6	0.2
P3	-	8.1	-	8.5	8.3	8.6	8.7	8.9	8.5	0.3
T1	8.6	8.2	8.2	8.5	8.2	8.4	7.2	8.3	8.2	0.4
T2	8.6	8.2	8.5	8.5	8.4	8.5	8.5	8.5	8.5	0.1
L	8.4	8.4	8.3	8.3	8.4	8.2	8.4	8.5	8.3	0.1
S1	8.6	8.2	8.6	8.8	8.8	8.2	8.5	8.8	8.6	0.3
S2	7.4	8.1	8.5	8.8	8.7	8.9	9.0	9.1	8.6	0.6
S3	7.6	7.9	8.0	8.2	-	-	-	8.0	7.9	0.2
S4	8.8	7.9	7.6	8.1	7.6	7.8	7.7	7.6	7.9	0.4
S5	-	8.2	-	-	-	-	-	-	8.2	-
S6	-	7.8	7.7	8.2	7.3	7.6	7.5	7.2	7.6	0.3
S7	-	-	7.4	8.2	7.8	7.3	7.8	7.1	7.6	0.4
S8	-	-	-	8.2	7.4	7.9	7.7	7.1	7.7	0.4
MW1	-	7.8	7.6	7.3	7.0	7.0	7.0	7.1	7.3	0.3
MW2	-	10.7	8.9	7.6	6.7	6.4	6.6	6.5	7.6	1.6
MW3	-	11.4	11.6	11.8	11.7	7.6	7.7	6.3	9.7	2.4
MW4	-	8.6	-	7.9	7.8	7.3	-	-	7.9	0.5

Table E-2 Conductivity level (mS/cm) of leachate, surface water and groundwater

Sampling points	**Nov 2005**	**Dec 2005**	**Jan 2006**	**Feb 2006**	**Mar 2006**	**Apr 2006**	**May 2006**	**Jun 2006**	**Average**	**SD**
BH1	-	13.3	14.5	14.0	-	-	-	-	13.9	0.6
BH2	-	11.3	12.5	11.1	12.7	12.2	11.9	11.6	11.9	0.6
P1	19.2	23.4	21.1	18.6	17.4	22.9	23.2	24.2	21.2	2.6
P2	15.2	20.1	21.5	19.7	23.1	24.0	23.6	24.3	21.4	3.1
P3	-	14.3	-	19.2	22.2	23.1	23.0	24.7	21.1	3.8
T1	7.2	23.4	18.2	20.1	23.3	24.7	23.3	21.4	20.2	5.6
T2	6.7	9.3	12.5	14.8	20.9	21.6	17.1	19.8	15.3	5.5
L	24.4	33.6	34.2	31.1	31.6	33.9	20.6	17.3	28.3	6.6
S1	7.7	21.2	22.6	22.1	28.5	28.2	27.4	23.3	22.6	6.7
S2	6.3	17.1	17.5	12.2	19.7	21.3	19.8	17.4	16.4	4.9
S3	1.7	3.4	8.2	6.2	-	-	-	14.1	6.7	4.8
S4	4.4	6.4	9.7	6.4	10.4	11.1	11.7	19.8	10.0	4.7
S5	-	5.4	-	-	-	-	-	-	5.4	-
S6	-	0.4	0.9	0.5	0.7	0.7	0.6	0.9	0.7	0.2
S7	-	-	0.9	0.5	0.7	1.4	1.7	3.7	1.5	1.2
S8	-	-	-	0.4	0.5	0.6	0.7	0.8	0.6	0.1
MW1	-	6.0	6.2	6.1	6.8	7.4	7.3	9.9	7.1	1.4
MW2	-	3.2	3.2	3.2	4.9	7.1	7.1	10.4	5.6	2.8
MW3	-	6.7	7.6	6.8	8.2	10.6	10.2	8.6	8.4	1.5
MW4	-	9.9	-	9.7	11.4	16.0	-	-	11.7	2.9

Table E-3 Concentration of TDS (mg/L) in leachate, surface water and groundwater

Sampling points	Nov 2005	Dec 2005	Jan 2006	Mar 2006	Apr 2006	May 2006	Jun 2006	Average	SD
BH1	-	6.4	8.3	-	-	-	-	7.3	1.3
BH2	-	7.2	8.1	8.2	8.3	9.6	11.3	8.8	1.4
P1	15.5	18.4	17.0	15.9	19.1	18.8	18.5	17.6	1.5
P2	11.9	15.2	17.0	18.5	18.4	19.6	18.4	17.0	2.6
P3	-	10.1	-	13.8	18.2	15.7	17.1	15.0	3.2
T1	4.8	5.3	9.4	17.9	17.4	14.9	17.2	12.4	5.8
T2	5.3	8.1	13.2	14.2	16.7	7.7	13.2	11.2	4.2
L	13.9	17.9	19.4	27.8	21.7	19.1	12.6	18.9	5.0
S1	6.1	7.4	18.4	23.6	24.0	21.3	16.1	16.7	7.3
S2	4.9	8.2	13.3	18.4	15.4	21.8	13	13.6	5.7
S3	1.2	3.0	3.6	-	-	-	10.9	4.7	4.3
S4	3.7	4.2	8.0	14.9	8.4	9.4	9.7	8.3	3.8
S5	-	3.4	-	-	-	-	-	3.4	-
S6	-	0.1	0.6	0.5	0.5	0.4	0.5	0.4	0.2
S7	-	-	0.6	0.6	1.0	1.4	1.8	0.8	0.6
S8	-	-	-	0.4	0.4	0.5	0.6	0.3	0.3
MW1	-	3.9	4.0	5.6	6.2	19.1	6.3	6.4	5.8
MW2	-	2.0	2.8	4.1	5.9	6.0	6.3	3.9	1.8
MW3	-	3.7	4.5	5.0	7.9	6.4	7.7	5.0	1.7
MW4	-	5.6	-	7.2	11.7	-	-	8.1	3.1

Table E-4 Concentration of alkalinity (mg/L as $CaCO_3$) in leachate, surface water and groundwater

Sampling points	Nov 2005	Dec 2005	Jan 2006	Feb 2006	Mar 2006	Apr 2006	May 2006	Jun 2006	Average	SD
BH1	-	4978	5830	5811	-	-	-	-	5540	487
BH2	-	1018	1678	1609	1763	1615	1560	1610	1550	244
P1	4591	4826	5005	4661	4788	4450	4500	4700	4690	182
P2	3942	4744	4923	4758	4944	4620	4240	4300	4559	360
P3	-	4703	-	4599	4450	4000	3800	3950	4250	380
T1	2295	2558	2833	6408	8388	6730	7360	7253	5478	2486
T2	2196	4758	4950	3933	5900	5250	4160	4126	4409	1109
L	6325	14905	14823	13310	10413	11780	6960	11000	11189	3252
S1	269	4771	4400	3900	4788	3120	2420	2310	3247	1554
S2	359	3410	3218	2635	2944	5520	2320	2223	2829	1440
S3	70	963	3493	1330	-	-	-	256	1222	1369
S4	75	138	85	151	481	165	108	132	167	131
S5	-	384	-	-	-	-	-	-	384	-
S6	-	710	140	135	819	320	78	80	325	311
S7	-	-	170	162	700	140	204	250	271	214
S8	-	-	-	140	588	120	96	89	207	214
MW1	-	-	839	833	4244	1103	1040	1631	1615	1321
MW2	-	-	165	128	394	710	640	430	411	238
MW3	-	-	495	253	913	1228	940	754	764	347
MW4	-	-	-	485	994	5575	-	-	2351	2803

Table E-5 Concentration of BOD (mg/L) in leachate and surface water

Sampling points	**Nov 2005**	**Dec 2005**	**Jan 2006**	**Feb 2006**	**Mar 2006**	**Apr 2006**	**May 2006**	**Jun 2006**	**Average**	**SD**
BH1	-	375	86	35	-	-	-	-	165	183
BH2	-	33	80	17	30	179	23	115	68	61
P1	210	330	173	137	96	156	161	563	228	152
P2	655	165	255	150	108	224	139	690	298	236
P3	-	470	-	132	120	151	173	338	231	142
T1	585	150	128	217	150	3720	1043	2475	1058	1338
T2	533	1110	240	111	126	247	353	1740	557	577
L	4800	1495	825	863	701	4785	1065	2040	2072	1734
S1	635	750	330	140	72	174	150	141	299	256
S2	173	128	120	75	66	74	165	182	123	47
S3	60	60	215	36	-	-	-	55	85	73
S4	3.7	5.3	2.3	4.2	1.8	3.0	3.6	11.7	4.4	3.1
S5	-	131	-	-	-	-	-	-	131	-
S6	-	5.0	6.5	7.6	3.1	6.0	2.6	3.2	4.8	2.0
S7	-	-	9.7	9.4	4.2	6.0	14.7	20.7	10.8	6.0
S8	-	-	-	5.9	2.7	4.0	2.3	3.4	3.6	1.4

Table E-6 Concentration of COD (mg/L) in leachate, surface water and groundwater

Sampling points	**Nov 2005**	**Dec 2005**	**Jan 2006**	**Feb 2006**	**Mar 2006**	**Apr 2006**	**May 2006**	**Jun 2006**	**Average**	**SD**
BH1	-	1390	1359	2052	-	-	-	-	1600	391
BH2	-	479	594	560	600	432	320	372	480	110
P1	3859	4362	3834	3565	3560	3552	4000	4430	3895	350
P2	3110	3912	4230	4725	3880	3968	4400	4704	4116	527
P3	-	3371	-	3938	3640	3232	3760	4116	3676	335
T1	1382	1949	2610	4684	5040	4800	5480	4939	3861	1608
T2	1248	3413	3834	3316	3560	3696	2640	3410	3140	843
L	7526	7475	9270	8912	9600	8800	7400	7020	8250	997
S1	2131	3727	3906	4311	4840	3872	3300	1901	3499	1020
S2	595	2212	2322	2611	2320	2304	2120	1627	2014	637
S3	192	630	729	974	-	-	-	466	598	292
S4	50	82	91	114	94	98	134	157	102	33
S5	-	565	-	-	-	-	-	-	565	-
S6	-	43	58	39	22	34	26	43	38	12
S7	-	-	63	60	34	48	66	94	61	20
S8	-	-	-	31	16	34	32	35	30	8
MW1	-	177	107	126	118	131	148	194	143	32
MW2	-	63	60	64	151	118	150	171	111	48
MW3	-	106	68	77	87	88	98	106	90	15
MW4	-	160	-	245	296	1456	-	-	539	614

Table E-7 Concentration of TOC (mg/L) in leachate

Sampling points	**Dec 2005**	**Jan 2006**	**Feb 2006**	**Mar 2006**	**Apr 2006**	**May 2006**	**Jun 2006**	**Average**	**SD**
BH1	709	681	427	-	-	-	-	606	155
BH2	128	230	248	228	147	129	184	185	51
P1	1830	1476	1415	1565	1762	1691	1630	1624	150
P2	1835	1681	1714	1858	1942	1869	1750	1807	94
P3	1176	-	1460	1540	1793	1618	1560	1525	204
T1	695	921	1918	2038	2033	2351	2456	1773	689
T2	1431	1354	1289	1502	1786	1117	1243	1389	215
L	3444	3230	3486	3902	3852	2853	3510	3468	359

Table E-8 Concentration of TKN (mg/L) in leachate

Sampling points	**Nov 2005**	**Dec 2005**	**Jan 2006**	**Feb 2006**	**Mar 2006**	**Apr 2006**	**May 2006**	**Jun 2006**	**Average**	**SD**
BH1	-	889	955	1120	-	-	-	-	988	119.2
BH2	-	333	397	398	372	314	160	352	332	82.3
P1	207	212	386	280	238	274	235	253	261	57.1
P2	400	455	364	319	343	322	238	256	337	71.3
P3	-	721	-	230	224	238	179	203	299	207.7
T1	256	838	795	792	1141	1033	1140	1253	906	316.0
T2	194	243	244	316	672	636	358	325	373	181.2
L	2632	4331	3486	1946	1610	3038	1271	2505	2602	1011.2

Table E-9 Concentration of ammonia (mg/L) in leachate, surface water and groundwater

Sampling points	**Nov 2005**	**Dec 2005**	**Jan 2006**	**Feb 2006**	**Mar 2006**	**Apr 2006**	**May 2006**	**Jun 2006**	**Average**	**SD**
BH1	-	822.3	858.2	1061.2	-	-	-	-	913.9	128.8
BH2	-	328.3	362.6	394.8	392.0	334.6	158.2	345.6	330.9	80.5
P1	50.3	47.5	205.8	151.2	100.8	75.6	58.8	65.4	94.4	56.4
P2	163.5	304.6	217.0	145.6	151.2	106.4	47.6	57.7	149.2	84.1
P3	-	641.3	-	109.2	79.8	44.8	39.2	48.8	160.5	237.0
T1	178.8	744.7	637.0	604.8	1071.0	806.4	982.8	895.4	740.1	278.0
T2	167.7	171.9	138.6	187.6	576.8	408.8	254.8	287.0	274.1	150.2
L	2358.5	3400.8	3059.0	1736.0	1425.2	2354.8	1029.0	2168.0	2191.4	794.3
S1	92.2	336.7	114.8	36.4	16.8	16.8	11.2	15.4	80.0	110.9
S2	43.3	177.4	86.8	36.4	16.8	8.4	3.5	5.5	47.3	59.5
S3	32.1	38.4	45.5	23.8	-	-	-	16.0	31.2	11.7
S4	0.8	0.1	0.3	0.4	0.3	0.4	0.2	0.5	0.4	0.2
S5	-	7.5	-	-	-	-	-	-	7.5	-
S6	-	0.1	0.3	0.1	0.4	0.8	0.4	0.5	0.4	0.2
S7	-	-	0.4	0.4	0.1	0.5	0.4	0.4	0.4	0.1
S8	-	-	-	0.1	0.1	ND	0.3	0.2	0.2	0.1
MW1	-	1.4	2.1	1.0	0.8	3.9	3.1	3.5	2.3	1.3
MW2	-	9.8	9.4	9.9	9.9	9.8	8.7	9.5	9.6	0.4
MW3	-	5.9	5.7	5.7	5.5	6.6	3.1	5.2	5.4	1.1
MW4	-	135.0	-	152.6	219.0	785.4	-	-	323.0	310.4

Table E-10 Concentration of phosphate (mg/L) in leachate and surface water

Sampling points	**Nov 2005**	**Dec 2005**	**Jan 2006**	**Feb 2006**	**Mar 2006**	**Apr 2006**	**May 2006**	**Jun 2006**	**Average**	**SD**
BH1	-	1.59	6.10	9.15	-	-	-	-	5.61	3.80
BH2	-	0.85	1.22	1.62	1.79	1.42	2.75	1.50	1.59	0.59
P1	12.91	6.33	1.50	14.59	16.06	15.04	16.22	15.00	12.21	5.37
P2	12.46	7.04	10.47	17.68	18.78	19.67	19.10	17.00	15.27	4.69
P3	-	5.64	-	11.99	11.95	10.33	11.62	11.80	10.56	2.49
T1	11.25	9.64	25.37	29.59	28.58	19.42	19.82	27.00	21.33	7.68
T2	11.15	7.30	16.50	18.62	13.35	9.58	12.75	10.50	12.47	3.70
L	24.10	8.98	48.50	36.79	28.66	55.83	38.92	36.00	34.72	14.50
S1	4.62	6.05	27.89	12.20	13.29	8.00	6.13	7.80	10.75	7.56
S2	2.18	3.85	4.11	7.56	7.28	7.38	6.26	6.50	5.64	2.00
S3	0.55	0.73	6.83	7.72	-	-	-	5.00	4.17	3.37
S4	0.07	0.09	0.03	0.03	0.02	0.01	0.03	0.07	0.04	0.03
S5	-	0.60	-	-	-	-	-	-	0.60	-
S6	-	0.19	0.09	0.17	0.21	0.07	0.16	0.20	0.16	0.06
S7	-	-	0.69	0.54	0.31	0.35	0.22	0.31	0.40	0.18
S8	-	-	-	0.17	0.28	0.28	0.17	0.19	0.22	0.06

Table E-11 Concentration of nitrate (mg/L) in leachate and surface water

Sampling points	**Nov 2005**	**Dec 2005**	**Jan 2006**	**Feb 2006**	**Mar 2006**	**Apr 2006**	**May 2006**	**Jun 2006**	**Average**	**SD**
BH1	-	-	1.20	3.56	-	-	-	-	2.38	1.67
BH2	-	-	-	ND	0.09	0.74	1.21	1.00	0.61	0.54
P1	2.42	3.06	1.43	1.53	1.27	2.69	ND	0.81	1.65	1.02
P2	1.33	4.95	1.27	2.44	3.87	0.26	ND	2.69	2.10	1.73
P3	-	1.44	-	2.25	4.76	1.73	ND	0.96	1.86	1.61
T1	0.58	4.23	1.21	4.69	5.07	3.80	ND	1.22	2.60	2.04
T2	2.54	1.36	1.91	2.92	1.61	6.49	ND	2.62	2.43	1.88
L	3.71	16.81	5.32	3.12	5.15	7.20	ND	ND	5.16	5.34
S1	12.46	5.15	1.77	2.21	3.17	ND	1.61	1.31	3.46	3.93
S2	7.86	3.82	0.76	0.16	1.81	0.22	0.09	0.94	1.96	2.69
S3	1.27	2.81	0.22	ND	-	-	-	1.55	1.17	1.13
S4	0.74	0.86	0.15	0.14	0.27	0.08	0.18	0.37	0.35	0.30
S5	-	3.10	-	-	-	-	-	-	3.10	-
S6	-	0.56	ND	0.06	0.49	0.10	0.09	0.15	0.21	0.22
S7	-	-	ND	ND	0.17	0.04	ND	0.24	0.08	0.10
S8	-	-	-	ND	0.22	ND	ND	0.21	0.09	0.12

Table E-12 Concentration of Mn (mg/L) in leachate, surface water and groundwater

Sampling points	**Nov 2005**	**Dec 2005**	**Jan 2006**	**Feb 2006**	**Mar 2006**	**Apr 2006**	**May 2006**	**Jun 2006**	**Average**	**SD**
BH1	-	1.362	0.120	0.196	-	-	-	-	0.559	0.696
BH2	-	0.561	0.091	0.154	0.323	0.599	4.222	3.700	1.378	1.781
P1	0.255	0.548	1.102	2.052	1.299	1.302	1.189	1.020	1.096	0.537
P2	0.299	0.580	0.293	0.438	0.371	0.428	0.410	0.356	0.397	0.092
P3	-	5.912	-	1.534	1.282	1.021	0.998	0.815	1.927	1.968
T1	0.337	1.141	0.422	0.808	0.590	0.946	1.151	0.506	0.737	0.320
T2	0.361	0.822	0.461	0.641	0.628	0.857	0.905	0.730	0.675	0.192
L	0.446	0.255	0.285	0.786	0.674	0.483	0.488	0.475	0.486	0.178
S1	0.664	1.188	0.248	0.300	0.152	0.321	0.127	0.073	0.384	0.373
S2	0.962	1.625	0.239	0.207	0.110	0.142	0.134	0.129	0.443	0.556
S3	0.686	1.247	0.456	0.299	-	-	-	1.051	0.748	0.397
S4	1.353	2.237	0.605	0.339	0.232	0.562	0.160	0.179	0.708	0.730
S5	-	1.256	-	-	-	-	-	-	1.256	-
S6	-	0.218	0.432	0.274	0.124	0.308	0.317	0.385	0.294	0.103
S7	-	-	0.208	0.332	0.135	0.456	0.532	0.892	0.426	0.272
S8	-	-	-	0.284	0.137	0.211	0.398	0.501	0.306	0.146
MW1	-	6.264	2.310	5.543	3.551	6.070	6.699	5.697	5.162	1.611
MW2	-	0.122	0.019	0.486	3.892	4.425	5.618	5.151	2.816	2.502
MW3	-	0.046	0.010	0.022	0.026	0.574	1.123	0.048	0.264	0.430
MW4	-	0.163	-	0.079	0.104	0.367	-	-	0.178	0.131

Table E-13 Concentration of Cr (mg/L) in leachate, surface water and groundwater

Sampling points	**Nov 2005**	**Dec 2005**	**Jan 2006**	**Feb 2006**	**Mar 2006**	**Apr 2006**	**May 2006**	**Jun 2006**	**Average**	**SD**
BH1	-	0.272	0.121	0.241	-	-	-	-	0.211	0.080
BH2	-	0.044	0.030	0.043	0.026	0.038	0.027	0.016	0.032	0.010
P1	0.633	1.179	0.481	0.656	0.453	0.630	0.693	0.643	0.671	0.222
P2	0.496	1.271	0.535	0.782	0.626	0.719	0.774	0.720	0.740	0.239
P3	-	0.589	-	0.659	0.612	0.620	0.643	0.550	0.612	0.039
T1	0.22	0.585	0.294	0.743	0.511	0.702	0.468	0.366	0.486	0.187
T2	0.248	0.874	0.408	0.545	0.445	0.692	0.402	0.411	0.503	0.197
L	0.687	1.412	0.808	0.954	1.598	1.289	0.560	0.635	0.993	0.392
S1	0.200	1.108	0.459	0.816	0.408	0.480	0.327	0.141	0.492	0.323
S2	0.097	0.623	0.208	0.341	0.185	0.297	0.250	0.163	0.270	0.162
S3	0.013	0.078	0.040	0.053	-	-	-	0.010	0.039	0.028
S4	0.003	0.005	0.003	<0.003	<0.003	0.003	<0.003	0.003	<0.003	0.002
S5	-	0.070	-	-	-	-	-	-	0.070	-
S6	-	<0.003	0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	0.001
S7	-	-	<0.003	<0.003	<0.003	<0.003	0.045	<0.003	0.008	0.018
S8	-	-	-	<0.003	<0.003	<0.003	0.039	<0.003	0.008	0.017
MW1	-	0.016	<0.003	0.005	<0.003	0.006	0.006	0.003	0.005	0.005
MW2	-	0.012	<0.003	<0.003	<0.003	0.005	0.007	0.005	0.004	0.004
MW3	-	0.004	<0.003	0.005	<0.003	<0.003	<0.003	<0.003	<0.003	0.002
MW4	-	0.019	-	0.017	0.010	0.089	-	-	0.034	0.037

Table E-14 Concentration of Cd (mg/L) in leachate, surface water and groundwater

Sampling points	**Nov 2005**	**Dec 2005**	**Jan 2006**	**Feb 2006**	**Mar 2006**	**Apr 2006**	**May 2006**	**Jun 2006**	**Average**	**SD**
BH1	-	0.002	<0.002	<0.002	-	-	-	-	<0.002	0.001
BH2	-	<0.002	<0.002	<0.002	0.002	<0.002	<0.002	<0.002	<0.002	0.001
P1	0.003	0.005	0.004	0.003	0.004	0.004	0.003	0.004	0.004	0.001
P2	0.003	0.006	0.004	0.004	0.005	0.005	0.003	0.004	0.004	0.001
P3	-	0.006	-	0.003	0.006	0.004	0.002	0.002	0.004	0.002
T1	0.002	0.004	0.003	0.004	0.005	0.005	0.003	0.003	0.004	0.001
T2	0.003	0.006	0.004	0.002	0.004	0.004	0.003	0.004	0.004	0.001
L	0.008	0.011	0.007	0.008	0.013	0.013	0.005	0.004	0.008	0.003
S1	<0.002	0.006	0.003	0.004	0.002	0.003	0.003	0.002	0.003	0.002
S2	0.002	0.005	0.002	0.003	0.002	0.003	0.002	0.002	0.002	0.001
S3	0.004	0.002	<0.002	<0.002	-	-	-	<0.002	<0.002	0.002
S4	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	0.002	<0.002	<0.002	0.001
S5	-	<0.002	-	-	-	-	-	-	<0.002	-
S6	-	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	0.000
S7	-	-	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	0.000
S8	-	-	-	<0.002	<0.002	0.002	0.002	<0.002	<0.002	0.001
MW1	-	<0.002	<0.002	<0.002	<0.002	0.002	<0.002	<0.002	<0.002	0.001
MW2	-	<0.002	0.002	<0.002	<0.002	0.002	<0.002	<0.002	<0.002	0.001
MW3	-	-	<0.002	<0.002	<0.002	<0.002	0.002	<0.002	<0.002	0.000
MW4	-	<0.002	-	<0.002	0.002	0.002	-	-	<0.002	0.001

Table E-15 Concentration of Pb (mg/L) in leachate, surface water and groundwater

Sampling points	**Nov 2005**	**Dec 2005**	**Jan 2006**	**Feb 2006**	**Mar 2006**	**Apr 2006**	**May 2006**	**Jun 2006**	**Average**	**SD**
BH1	-	0.157	0.013	0.026	-	-	-	-	0.065	0.079
BH2	-	0.193	0.015	0.018	0.017	0.026	0.030	0.023	0.046	0.065
P1	<0.010	<0.010	<0.010	<0.010	0.011	0.005	0.012	<0.010	<0.010	0.005
P2	<0.010	<0.010	<0.010	0.010	0.010	0.013	0.01	0.010	<0.010	0.006
P3	-	0.011	-	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	0.006
T1	0.012	<0.01	<0.01	0.016	0.031	0.024	0.023	0.012	0.015	0.011
T2	<0.010	0.021	0.011	<0.010	0.014	0.010	0.010	<0.010	0.010	0.007
L	0.050	0.100	0.024	0.112	0.113	0.301	0.061	0.064	0.103	0.086
S1	0.017	0.011	0.010	<0.010	<0.010	0.012	<0.010	<0.010	<0.010	0.007
S2	0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	0.004
S3	<0.010	<0.010	<0.010	0.010	-	-	-	<0.010	<0010	0.004
S4	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	0.002
S5	-	<0.010	-	-	-	-	-	-	<0.010	-
S6	-	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	0.001
S7	-	-	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	0.003
S8	-	-	-	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	0.002
MW1	-	0.280	0.018	<0.010	0.025	0.024	0.018	0.015	0.056	0.099
MW2	-	0.088	0.013	0.039	0.035	0.033	0.031	0.037	0.039	0.023
MW3	-	0.080	0.039	0.074	0.033	0.013	0.019	0.041	0.042	0.026
MW4	-	0.118	-	0.012	0.022	0.010	-	-	0.040	0.052

Table E-16 Concentration of Ni (mg/L) in leachate, surface water and groundwater

Sampling points	**Nov 2005**	**Dec 2005**	**Jan 2006**	**Feb 2006**	**Mar 2006**	**Apr 2006**	**May 2006**	**Jun 2006**	**Average**	**SD**
BH1	-	0.186	0.076	0.167	-	-	-	-	0.143	0.059
BH2	-	0.089	0.048	0.094	0.101	0.074	0.027	0.053	0.069	0.027
P1	0.977	0.527	0.229	0.354	0.260	0.324	0.341	0.336	0.418	0.242
P2	0.256	0.542	0.234	0.384	0.328	0.336	0.357	0.333	0.346	0.094
P3	-	0.406	-	0.371	0.352	0.321	0.319	0.276	0.341	0.045
T1	0.114	0.285	0.125	0.379	0.296	0.372	0.311	0.273	0.269	0.100
T2	0.133	0.332	0.171	0.292	0.254	0.362	0.242	0.266	0.256	0.076
L	0.320	0.681	0.422	0.581	0.752	0.573	0.386	0.296	0.501	0.170
S1	0.131	0.545	0.265	0.482	0.247	0.347	0.262	0.150	0.303	0.147
S2	0.088	0.339	0.124	0.256	0.118	0.197	0.175	0.119	0.177	0.085
S3	0.017	0.031	0.028	0.065	-	-	-	0.028	0.034	0.018
S4	0.017	<0.010	<0.010	<0.010	0.092	<0.010	<0.010	<0.010	0.014	0.032
S5	-	0.085	-	-	-	-	-	-	0.085	-
S6	-	0.045	0.019	0.006	0.012	0.011	<0.010	0.010	0.014	0.015
S7	-	-	<0.010	<0.010	<0.010	0.010	0.010	<0.010	<0.010	0.005
S8	-	-	-	<0.010	<0.010	0.010	0.010	0.010	<0.010	0.005
MW1	-	<0.010	0.010	0.033	0.010	0.017	<0.010	0.037	0.016	0.014
MW2	-	<0.010	<0.010	0.015	0.017	0.017	<0.010	0.012	0.010	0.008
MW3	-	<0.010	<0.010	0.015	0.015	0.010	<0.010	0.104	0.021	0.037
MW4	-	0.011	-	0.050	0.056	0.121	-	-	0.059	0.045

Table E-17 Concentration of Zn (mg/L) in leachate, surface water and groundwater

Sampling points	**Nov 2005**	**Dec 2005**	**Jan 2006**	**Feb 2006**	**Mar 2006**	**Apr 2006**	**May 2006**	**Jun 2006**	**Average**	**SD**
BH1	-	0.403	0.221	0.170					0.265	0.123
BH2	-	0.720	0.108	0.082	0.112	0.054	0.185	0.138	0.200	0.233
P1	0.132	0.083	0.112	0.156	0.072	0.078	0.102	0.124	0.107	0.029
P2	0.194	0.063	0.098	0.179	0.103	0.092	0.156	0.101	0.123	0.047
P3	-	0.165		<0.002	0.072	0.046	0.100	0.072	0.076	0.055
T1	0.126	0.078	0.109	0.220	0.257	0.240	0.286	0.305	0.202	0.086
T2	0.157	0.357	0.193	0.010	0.121	0.165	0.140	0.139	0.160	0.096
L	1.003	1.841	1.149	1.109	1.153	2.598	0.969	0.731	1.319	0.607
S1	0.123	0.002	0.049	0.075	0.027	<0.002	<0.002	0.024	0.037	0.043
S2	0.132	<0.002	0.040	0.023	0.006	<0.002	0.052	0.010	0.033	0.044
S3	0.044	<0.002	0.053	<0.002	-	-	-	0.003	0.020	0.026
S4	0.039	<0.002	<0.002	0.006	0.037	<0.002	0.031	<0.002	0.014	0.018
S5	-	<0.002		-	-	-	-	-	<0.002	-
S6	-	<0.002	0.030	<0.002	<0.002	<0.002	0.102	0.025	0.023	0.037
S7	-	-	0.045	0.002	0.004	<0.002	0.021	<0.002	0.012	0.018
S8	-	-	-	<0.002	0.005	<0.002	0.036	<0.002	0.008	0.016
MW1	-	0.682	0.061	0.089	0.046	0.067	0.053	0.074	0.153	0.234
MW2	-	0.338	0.028	0.159	0.132	0.003	0.064	0.109	0.119	0.111
MW3	-	0.175	0.090	0.182	0.124	0.039	0.223	0.342	0.168	0.099
MW4	-	0.530	-	0.118	0.098	0.101	-	-	0.212	0.213

Table E-18 Concentration of Cu (mg/L) in leachate, surface water and groundwater

Sampling points	**Nov 2005**	**Dec 2005**	**Jan 2006**	**Feb 2006**	**Mar 2006**	**Apr 2006**	**May 2006**	**Jun 2006**	**Average**	**SD**
BH1	-	0.046	0.036	0.048	-	-	-	-	0.043	0.006
BH2	-	0.025	0.023	0.007	0.020	<0.003	0.011	<0.003	0.013	0.010
P1	0.045	0.076	0.052	0.072	0.046	0.040	0.046	0.050	0.053	0.013
P2	0.066	0.086	0.061	0.092	0.072	0.058	0.062	0.057	0.069	0.013
P3	-	0.092	-	0.065	0.051	0.017	0.038	0.035	0.050	0.026
T1	0.073	0.034	0.031	0.138	0.117	0.074	0.099	0.051	0.077	0.039
T2	0.039	0.094	0.052	0.058	0.052	0.055	0.046	0.041	0.055	0.017
L	0.185	0.275	0.385	1.109	0.678	1.726	0.348	0.339	0.630	0.532
S1	0.383	0.473	0.126	0.136	0.078	0.148	0.096	0.059	0.187	0.153
S2	0.066	0.163	0.038	0.054	0.020	<0.003	0.021	0.018	0.047	0.051
S3	0.005	<0.003	0.008	0.066	-	-	-	<0.003	0.016	0.028
S4	0.004	<0.003	0.013	0.004	0.003	<0.003	<0.003	<0.003	0.003	0.004
S5	-	<0.003	-	-	-	-	-	-	<0.003	-
S6	-	<0.003	0.112	<0.003	<0.003	<0.003	<0.003	<0.003	0.016	0.042
S7	-	-	0.009	<0.003	<0.003	<0.003	0.006	<0.003	0.003	0.004
S8	-	-	-	<0.003	<0.003	<0.003	0.005	0.003	<0.003	0.002
MW1	-	0.011	0.011	0.017	0.005	<0.003	0.008	<0.003	0.007	0.006
MW2	-	0.050	0.021	0.024	0.027	<0.003	0.015	0.006	0.020	0.016
MW3	-	<0.003	0.016	0.017	0.011	<0.003	0.008	<0.003	0.007	0.007
MW4	-	0.058	-	0.022	0.007	<0.003	-	-	0.021	0.026

Table E-19 Concentration of Hg (μg/L) in leachate, surface water and groundwater

Sampling points	Nov 2005	Dec 2005	Jan 2006	Feb 2006	Mar 2006	Apr 2006	May 2006	Jun 2006	Average	SD
BH1	-	<0.001	<0.001	<0.001	-	-	-	-	<0.001	-
BH2	-	<0.001	<0.001	<0.001	<0.001	0.425	0.299	0.213	0.136	0.176
P1	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.044	0.291	0.042	0.102
P2	<0.001	<0.001	<0.001	<0.001	<0.001	0.165	<0.001	0.204	0.046	0.086
P3	-	<0.001	-	<0.001	<0.001	<0.001	<0.001	0.204	0.034	0.083
T1	<0.001	<0.001	<0.001	<0.001	<0.001	1.067	0.076	0.196	0.167	0.370
T2	<0.001	<0.001	<0.001	<0.001	<0.001	0.096	0.248	0.471	0.102	0.173
L	<0.001	<0.001	<0.001	<0.001	<0.001	1.544	0.674	0.625	0.355	0.563
S1	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.093	0.012	0.033
S2	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.421	0.122	0.068	0.149
S3	<0.001	<0.001	<0.001	<0.001	-	-	-	0.051	0.010	0.023
S4	<0.001	<0.001	<0.001	<0.001	<0.001	0.297	0.439	0.187	0.115	0.173
S5	-	<0.001	-	-	-	-	-	-	<0.001	-
S6	-	<0.001	<0.001	<0.001	<0.001	0.051	0.308	0.178	0.077	0.121
S7	-	-	<0.001	<0.001	<0.001	0.004	0.103	0.079	0.031	0.047
S8	-	-	-	<0.001	<0.001	0.227	0.033	<0.001	0.052	0.099
MW1	-	<0.001	<0.001	<0.001	<0.001	0.507	0.441	0.613	0.223	0.283
MW2	-	<0.001	<0.001	<0.001	<0.001	0.098	0.312	0.247	0.094	0.133
MW3	-	<0.001	<0.001	<0.001	<0.001	0.108	0.160	0.503	0.110	0.185
MW4	-	<0.001	-	<0.001	<0.001	<0.001	-	-	<0.001	-

2. Statistical analysis of leachate and groundwater quality in dumpsite

2.1 Comparison of leachate quality between leachate treatment system and leachate ponds

Table E-20 Test of homogeneity of variances of leachate quality

Parameter	**Levene Statistic**	**df1**	**df2**	**Sig.**
pH	1.194	4	33	0.332
TDS	6.723	4	28	0.001[a]
EC	1.204	4	33	0.328
Alkalinity	20.965	4	33	0.000 [a]
BOD	7.236	4	33	0.000 [a]
TOC	7.871	4	29	0.000 [a]
COD	10.897	4	33	0.000 [a]
NH_4-N	2.575	4	33	0.056
TKN	3.684	4	33	0.014 [a]
NO_3-N	1.376	4	33	0.264
TP	2.989	4	33	0.033 [a]
Mn	5.543	4	33	0.002 [a]
Cr	1.011	4	33	0.416
Cd	1.029	4	33	0.407
Pb	3.669	4	33	0.014 [a]
Ni	2.500	4	33	0.061
Zn	1.742	4	33	0.164
Cu	3.459	4	33	0.018 [a]
Hg	2.082	4	33	0.106

[a] The variance of leachate quality was different significantly at 0.05, The comparison of leachate quality was then performed by using Welch -test

For non significant different parameters, the F-test in the ANOVA table was used to compare leachate quality between the sampling points.

Table E-21 Robust tests of means of leachate quality

Parameter		**Statistic [a]**	**df1**	**df2**	**Sig.**
TDS	Welch	4.304	4	12.555	0.021[b]
Alkalinity	Welch	1.831	4	14.639	0.177
BOD	Welch	1.284	4	15.970	0.318
TOC	Welch	6.505	4	13.539	0.004[b]
COD	Welch	2.046	4	16.057	0.136
TKN	Welch	8.035	4	14.732	0.001[b]
TP	Welch	3.798	4	16.401	0.023[b]
Mn	Welch	7.397	4	14.044	0.002[b]
Pb	Welch	2.489	4	15.887	0.085
Cu	Welch	2.060	4	15.410	0.136

[a] Asymptotically F distributed; [b] Significant different at 0.05

Table E-22 ANOVA table of leachate quality

Parameter		**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
pH	Between Groups	1.13	4	0.28	3.900	0.011[a]
	Within Groups	2.40	33	0.07		
	Total	3.53	37			
EC	Between Groups	208.89	4	52.22	2.785	0.043[a]
	Within Groups	618.79	33	18.75		
	Total	827.67	37			
NH_4-N	Between Groups	2188060.40	4	547015.09	17.168	0.000[a]
	Within Groups	1051492.30	33	31863.40		
	Total	3239552.70	37			
NO_3-N	Between Groups	4.77	4	1.19	0.414	0.798
	Within Groups	95.22	33	2.89		
	Total	99.99	37			
Cr	Between Groups	0.38	4	0.09	2.453	0.065
	Within Groups	1.27	33	0.04		
	Total	1.65	37			
Cd	Between Groups	0.00	4	0.00	0.288	0.883
	Within Groups	0.00	33	0.00		
	Total	0.00	37			
Ni	Between Groups	0.14	4	0.03	1.913	0.132
	Within Groups	0.59	33	0.02		
	Total	0.73	37			
Zn	Between Groups	0.07	4	0.017	3.745	0.013[a]
	Within Groups	0.15	33	0.005		
	Total	0.22	37			
Hg	Between Groups	0.10	4	0.025	0.612	0.657
	Within Groups	1.33	33	0.040		
	Total	1.43	37			

[a] Significant different at 0.05

2.2 Comparison of groundwater quality

Table E-23 Test of homogeneity of variances of groundwater quality

Parameter	Levene Statistic	df1	df2	Sig.
pH	14.016	3	21	0.000[a]
TDS	11.066	3	18	0.000[a]
EC	2.119	3	21	0.128
Alkalinity	7.788	3	14	0.003[a]
COD	15.064	3	21	0.000[a]
NH_4-N	16.617	3	21	0.000[a]
Mn	17.072	3	21	0.000[a]
Cr	12.683	3	21	0.000[a]
Cd	0.875	3	20	0.471
Pb	2.116	3	21	0.129
Ni	2.060	3	21	0.136
Zn	1.071	3	21	0.383
Cu	2.626	3	20	0.079
Hg	8.732	3	21	0.001[a]

[a] The variance of groundwater quality was different significantly at 0.05, The comparison of groundwater quality was the performed by using Welch - test

For non significant different parameters, the F- test in ANOVA was used to determine the difference of groundwater between the sampling points.

Table E-24 Robust tests of equality of means of groundwater characteristic

Parameter		Statistic [a]	df1	df2	Sig.
pH	Welch	3.341	3	8.976	0.070[b]
TDS	Welch	1.082	3	8.003	0.410
COD	Welch	5.338	3	8.284	0.025[b]
Alkalinity	Welch	1.838	3	5.665	0.246
NH_4-N	Welch	78.432	3	8.279	0.000[b]
Mn	Welch	21.875	3	10.861	0.000[b]
Cr	Welch	1.741	3	8.277	0.233
Hg [c]	Welch	.	.	.	.

[a] Asymptotically F distributed; [b] Significant different at 0.05

[c] Robust tests cannot be performed for Hg because at least one group has zero variance.

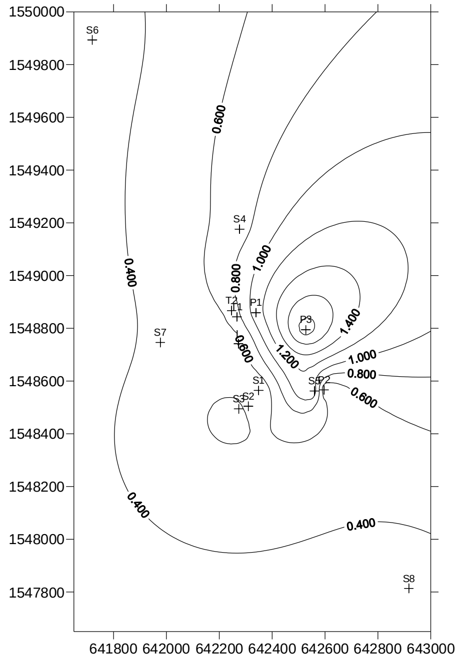
Table E-24 ANOVA table of groundwater quality

Parameter		**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
EC	Between Groups	102.48	3	34.161	7.461	0.001[a]
	Within Groups	96.16	21	4.579		
	Total	198.64	24			
Cu	Between Groups	0.001	3	0.000	1.606	0.220
	Within Groups	0.004	20	0.000		
	Total	0.005	23			
Zn	Between Groups	0.023	3	0.008	0.271	0.846
	Within Groups	0.596	21	0.028		
	Total	0.619	24			
Ni	Between Groups	0.007	3	0.002	3.041	0.052
	Within Groups	0.016	21	0.001		
	Total	0.023	24			
Pb	Between Groups	0.001	3	0.000	0.103	0.958
	Within Groups	0.074	21	0.004		
	Total	0.075	24			
Cd	Between Groups	0.000	3	0.000	0.060	0.980
	Within Groups	0.000	20	0.000		
	Total	0.000	23			

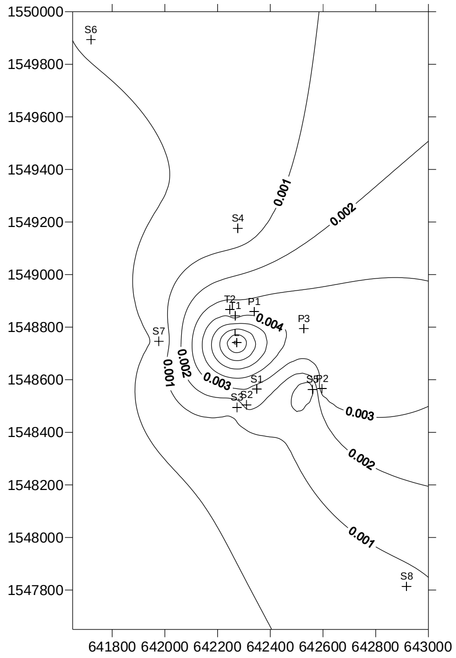
[a] Significant different at 0.05

APPENDIX-F

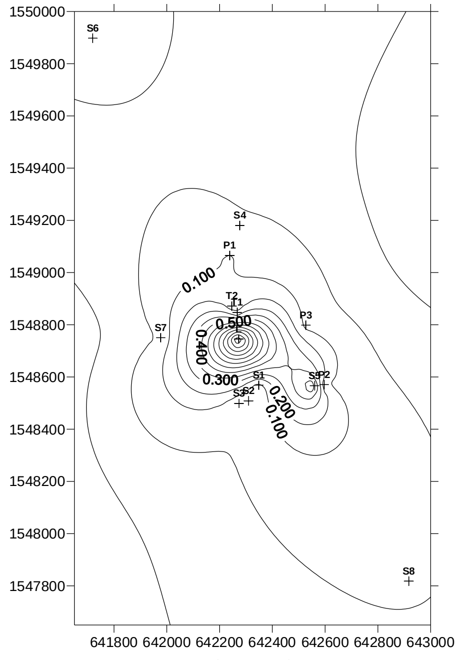
Variation of heavy metals concentration in leachate and surface water



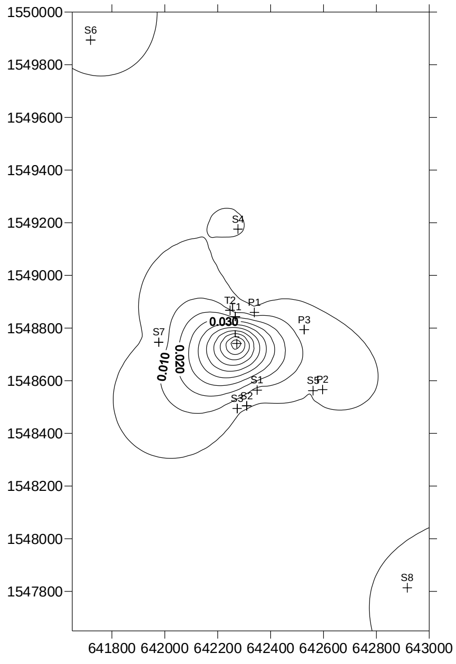
Mn (mg/L)



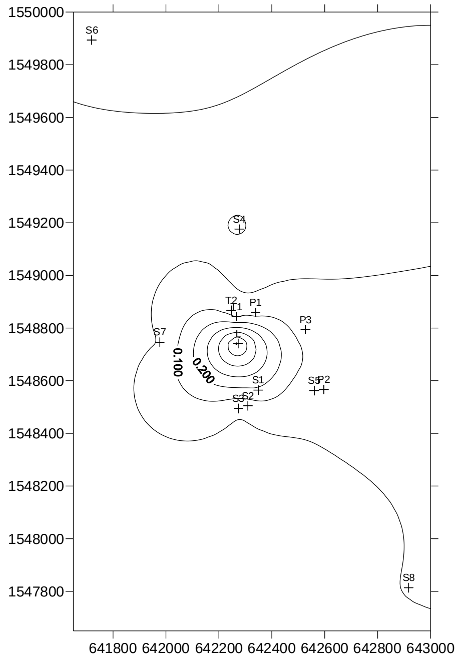
Cd (mg/L)



Zn (mg/L)



Pb (mg/L)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642200
642400
642600
642800
643000
S6
S4
T2
T1
P1
P3
S7
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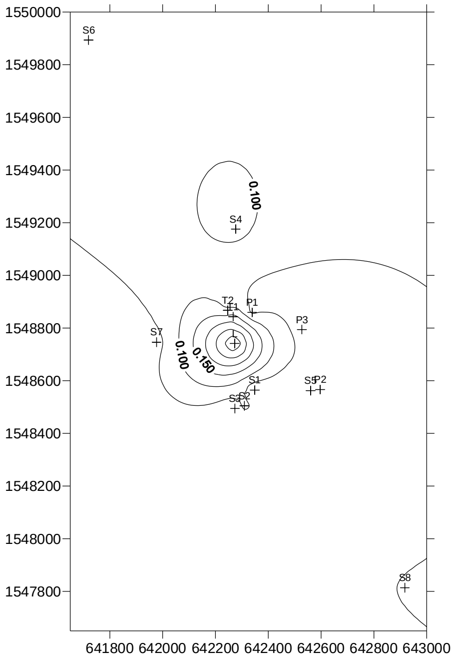
0.200
S1
S5
P2
S3
S2
S8

Cu (mg/L)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S4
T2
T1
P1
P3
S7
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S1
S5
P2
S3
S2
S8

Hg (µg/L)

Appendix-G

Seed germination test of leachate

Table G-1 Seed germination test of leachate in pond P1

Concentration(%v/v)	**April 2006**			**May 2006**		
	RRG (%)	**SGR (%)**	**GI (%)**	**RRG (%)**	**SGR (%)**	**GI (%)**
0	100	100	100	100	100	100
10	121	100	121	84	88	74
20	57	58	33	60	76	46
30	18	27	5	15	21	3
40	9	12	1	11	21	2
50	1	2	0	1	2	0
60	5	12	1	0	3	0

Table G-2 Seed germination test of leachate in pond P1

Concentration (%v/v)	**April 2006**			**May 2006**		
	RRG (%)	**SGR (%)**	**GI (%)**	**RRG (%)**	**SGR (%)**	**GI (%)**
0	100	100	100	100	100	100
10	102	90	92	91	86	78
20	53	65	35	31	43	13
30	28	33	9	22	29	6
40	9	17	2	1	0	0
50	2	8	0	0	0	0
60	0	0	0	0	0	0

Table G-3 Seed germination test of leachate in pond P3

Concentration (%v/v)	**April 2006**			**May 2006**		
	RRG (%)	**SGR (%)**	**GI (%)**	**RRG (%)**	**SGR (%)**	**GI (%)**
0	100	100	100	100	100	100
10	101	100	101	126	100	126
20	73	90	66	83	88	73
30	49	63	31	46	74	34
40	17	27	4	33	57	19
50	10	13	1	6	4	0
60	4	0	0	4	12	1

Table G-4 Seed germination test of runoff leachate (L)

April 2006				May 2006			
Concentration (%v/v)	**RRG (%)**	**SGR (%)**	**GI (%)**	**Concentration (%v/v)**	**RRG (%)**	**SGR (%)**	**GI (%)**
0	100	100	100	0	100	100	100
2.0	56	90	50	1.0	95	96	91
4.0	44	85	38	2.0	82	100	82
6.0	25	54	14	4.0	74	84	62
8.0	6	10	1	6.0	43	63	27
10.0	1	0	0	8.0	24	53	13
12.0	0	0	0	10.0	10	21	2

Table G-5 Median inhibiting concentration of leachate (IC_{50} v/v)

Leachate sample	April 2006			May 2006			Average		
	RRG (%)	**RSG (%)**	**GI (%)**	**RRG (%)**	**RSG (%)**	**GI (%)**	**RRG (%)**	**RSG (%)**	**GI (%)**
P1	21.5	22.2	17.3	20.1	24.0	19.0	20.8	23.1	18.1
P2	21.4	23.3	17.0	17.2	18.7	13.5	19.3	21.0	15.2
P3	26.9	31.7	22.9	30.0	36.8	25.3	28.5	34.3	24.1
L	2.8	5.7	2.0	5.0	7.3	4.1	3.9	6.5	3.0

Table G-6 Seed germination test of leachate in the pH adjustment test

Concentration (%v/v)	pHn			pH3			pH11		
	RRG (%)	**SGR (%)**	**GI (%)**	**RRG (%)**	**SGR (%)**	**GI (%)**	**RRG (%)**	**SGR (%)**	**GI (%)**
0	100	100	100	100	100	100	100	100	100.0
0.75	108	100	108	75	86	65	72	90	64.6
1.5	84	80	68	68	86	59	69	84	57.9
3.0	64	86	55	65	86	56	49	76	37.5
6.0	27	61	16	57	69	39	48	66	31.9
12.0	7	18	1	44	60	27	33	58	19.2

Table G-7 Seed germination test of leachate in the pH adjustment and aeration test

Concentration (%v/v)	pH n			pH3			pH11		
	RRG (%)	**SGR (%)**	**GI (%)**	**RRG (%)**	**SGR (%)**	**GI (%)**	**RRG (%)**	**SGR (%)**	**GI (%)**
0	100	100	100	100	100	100	100	100	100
0.75	95	83	79	77	95	73	116	89	103
1.5	75	82	62	69	97	67	151	98	148
3.0	81	83	67	55	88	48	126	100	126
6.0	67	88	59	51	93	47	117	93	109
12.0	30	50	15	47	89	42	82	95	77

Table G-8 Seed germination test of leachate in the EDTA adding test

Concentration (%v/v)	**0.0125 ml EDTA[a]**			**0.05 ml EDTA[a]**			**0.2ml EDTA[a]**		
	RRG (%)	**SGR (%)**	**GI (%)**	**RRG (%)**	**SGR (%)**	**GI (%)**	**RRG (%)**	**SGR (%)**	**GI (%)**
0	100	100	100	100	100	100	100	100	100
0.75	111	102	113	100	102	102	113	107	121
1.5	82	96	79	97	93	90	89	102	90
3.0	77	96	74	72	89	64	72	100	72
6.0	49	91	45	59	96	57	69	102	70
12.0	33	88	29	26	80	21	30	75	23

[a] 500 mg/L EDTA

Table G-9 Seed germination test of leachate in the graduated pH test

Concentration (%v/v)	**pH6**			**pH7**			**pH8**		
	RRG (%)	**SGR (%)**	**GI (%)**	**RRG (%)**	**SGR (%)**	**GI (%)**	**RRG (%)**	**SGR (%)**	**GI (%)**
0	100	100	100	100	100	100	100	100	100
0.75	82	102	84	90	89	80	77	92	70
1.5	68	89	60	81	93	75	94	97	92
3.0	55	96	53	60	86	51	83	100	83
6.0	41	81	34	46	75	34	55	92	51
12.0	23	51	12	27	66	18	28	70	19

Table G-10 Median inhibiting concentration (IC_{50}) of GI of leachate toxicity in various leachate treatments

Toxicity unit	**IC_{50}GI (% v/v)**
pH3	3.2
pH n	2.8
pH11	1.9
pH3 + aeration	3.8
pH n + aeration	4.2
pH11 + aeration	12.7[a]
0.2 ml EDTA	7.4
0.05 ml EDTA	5.7
0.0125 ml EDTA	5.7
pH6	2.9
pH7	2.9
pH8	5.4

[a] The IC_{50}GI was received from the toxicity test in Table G-11

Table G-11 Toxicity test of the pH 11 adjustment and aeration test

Concentration (%v/v)	pH11 + aeration		
	RRG (%)	SGR (%)	GI (%)
0	100	100	100
10	69	102	70
20	20	60	12
30	10	33	3
40	1	4	0
50	0	0	0

APPENDIX-H

Solid waste composition in dumpsite

1. Composition of solid waste in dumpsite

Table H-1 Composition of solid waste in different sampling sites and depth interval of the dumpsite

Composition (%w/w)	**SW1**			**SW2**			**SW3**			**SW4**			**Mean**
	0-1 m	**1-2 m**	**2-3 m**	**0-1 m**	**1-2 m**	**2-3 m**	**0-1 m**	**1-2 m**	**2-3 m**	**0-1 m**	**1-2 m**	**2-3 m**	
Plastic	37.9	48.4	51.4	35.7	29.3	39.8	38.8	43.4	64.6	37.8	20.0	51.3	41.5
Textile	12.4	16.1	7.2	11.9	8.8	5.8	9.9	14.2	6.9	11.1	6.1	11.4	10.2
Wood	9.0	6.5	25.2	13.1	4.4	10.5	3.3	18.6	6.9	2.2	2.4	6.3	9.0
Paper	ND	ND	ND	6.0	ND	ND	ND	ND	ND	2.2	ND	ND	0.7
Rubber	1.1	ND	ND	1.2	1.7	5.8	ND	1.8	0.7	ND	ND	ND	1.0
Foam	1.1	ND	ND	2.4	1.1	1.2	1.7	1.8	0.7	1.1	ND	0.6	1.0
Ceramic /stone	2.3	ND	1.8	2.4	1.7	ND	1.7	ND	0.7	ND	ND	ND	0.9
Glass	ND	1.6	1.8	3.6	4.4	ND	1.7	ND	1.4	ND	3.6	3.8	1.8
Metal	2.3	1.6	7.2	3.6	3.3	1.2	8.3	1.8	5.6	ND	ND	1.3	3.0
Soil	33.9	25.8	5.4	20.2	45.3	35.7	34.7	18.6	12.5	45.6	67.9	25.3	30.9
Battery	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100

2. Statistical analysis of solid waste composition

2.1 Comparison of solid waste composition between sampling points on dumpsite

Table H-2 Test of homogeneity of variances of solid waste composition

Composition	Levene Statistic	df1	df2	Sig.
Plastic	1.443	3	8	0.301
Textile	0.206	3	8	0.889
Wood	3.176	3	8	0.085
Paper	12.552	3	8	0.002[a]
Rubber	8.095	3	8	0.008[a]
Foam	0.272	3	8	0.844
Ceramic/stone	3.226	3	8	0.082
Glass	2.641	3	8	0.121
Metal	2.281	3	8	0.156
Soil	0.356	3	8	0.787

[a] The variance of paper and rubber composition was different significantly between the sampling points at 0.05. The comparison of waste composition was then performed by using Welch-Test. However, this test cannot be performed because at least one group of paper and rubber has zero variance.

For non different variance parameters (P value ≥ 0.05), the comparison of solid waste composition was tested by using F-Test in ANOVA table.

Table H-3 ANOVA table of the solid waste composition

Composition		Sum of Squares	df	Mean Square	F	Sig.
Plastic	Between Groups	432.25	3	144.08	1.121	0.396
	Within Groups	1028.18	8	128.52		
	Total	1460.43	11			
Textile	Between Groups	15.63	3	5.21	0.404	0.754
	Within Groups	103.24	8	12.91		
	Total	118.870	11			
Wood	Between Groups	150.37	3	50.12	1.042	0.425
	Within Groups	384.68	8	48.09		
	Total	535.05	11			
Foam	Between Groups	3.20	3	1.07	2.669	0.119
	Within Groups	3.20	8	0.40		
	Total	6.40	11			

Table H-3 ANOVA table of the solid waste composition (Continued)

Composition		Sum of Squares	df	Mean Square	F	Sig.
Ceramic/stone	Between Groups	3.76	3	1.25	1.350	0.325
	Within Groups	7.43	8	0.93		
	Total	11.20	11			
Glass	Between Groups	6.68	3	2.23	0.750	0.552
	Within Groups	23.73	8	2.97		
	Total	30.40	11			
Metal	Between Groups	36.46	3	12.15	2.185	0.168
	Within Groups	44.49	8	5.56		
	Total	80.96	11			
Soil	Between Groups	1227.61	3	409.20	1.702	0.243
	Within Groups	1923.28	8	240.41		
	Total	3150.89	11			

2.2 Comparison of solid waste composition between depth intervals of dumpsite

Table H-4 Test of homogeneity of variances of solid waste composition

Composition	Levene Statistic	df1	df2	Sig.
Plastic	4.232	2	9	0.051
Textile	7.386	2	9	0.013[a]
Wood	0.405	2	9	0.679
Paper	6.985	2	9	0.015[a]
Rubber	3.756	2	9	0.065
Foam	1.849	2	9	0.212
Ceramic/stone	0.150	2	9	0.863
Glass	0.426	2	9	0.665
Metal	1.811	2	9	0.218
Soil	1.994	2	9	0.192

[a] The textile and paper composition in solid waste was different significantly between depth intervals at 0.05. The comparison of textile and paper composition was then performed by using Welch - table.

For the non significant variance parameter (P-value ≥ 0.05), the comparison of solid waste composition test was test by using F- Test in ANOVA table.

Table H-5 Robust tests of equality of means of solid waste composition between depth intervals of dumpsite

Compositions		**Statistic [a]**	**df1**	**df2**	**Sig.**
Textile	Welch	2.999	2	4.806	0.143
Paper [b]	Welch	.	.	.	.

[a] Asymptotically F distributed.

[b] Robust tests of equality of means cannot be performed for paper because at least one group has zero variance.

Table H-6 ANOVA table in the analysis of solid waste composition

Composition		**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Plastic	Between Groups	639.70	2	319.85	3.507	0.075
	Within Groups	820.73	9	91.19		
	Total	1460.43	11			
Wood	Between Groups	63.43	2	31.72	0.605	0.567
	Within Groups	471.62	9	52.40		
	Total	535.05	11			
Rubber	Between Groups	2.34	2	1.17	0.377	0.697
	Within Groups	27.96	9	3.11		
	Total	30.30	11			
Foam	Between Groups	2.18	2	1.09	2.323	0.154
	Within Groups	4.22	9	0.47		
	Total	6.40	11			
Ceramic/stone	Between Groups	3.16	2	1.58	1.771	0.225
	Within Groups	8.04	9	0.89		
	Total	11.20	11			
Glass	Between Groups	2.35	2	1.17	0.376	0.697
	Within Groups	28.06	9	3.12		
	Total	30.40	11			
Metal	Between Groups	10.95	2	5.48	0.704	0.520
	Within Groups	70.01	9	7.78		
	Total	80.96	11			
Soil	Between Groups	817.68	2	408.84	1.577	0.259
	Within Groups	2333.21	9	259.25		
	Total	3150.89	11			

3. Solid waste size distribution

3.1. Solid waste size distribution

Table H-7 Size distribution of solid waste

Experiment No.	Waste <25mm (%w/w)	Waste 25-50mm (%w/w)	Waste >50mm (%w/w)	Total (%w/w)
1	24	15	61	100
2	18	14	68	100
3	13	17	70	100
4	20	14	66	100
5	25	13	62	100
6	17	13	70	100
7	19	14	68	100
8	13	9	78	100
9	22	12	66	100
10	14	11	75	100
11	16	14	70	100
12	14	14	72	100
Average	18	13	69	100

Table H-8 Composition of waste size >50mm

Composition (%w/w)	**Experiment No.**												
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**Mean**
Plastic	46.3	32.1	38.2	21.7	43.6	40.6	35.6	32.1	32.4	26.0	26.7	36.2	34.3
Textile	14.0	10.1	6.1	7.0	19.8	12.5	10.0	5.4	9.4	14.7	8.9	8.6	10.5
Wood	11.9	6.0	8.8	13.0	8.1	8.8	11.1	10.9	11.8	14.7	11.1	12.3	10.7
Paper	0.7	4.2	6.9	4.3	2.3	5.0	2.2	2.2	15.3	4.0	2.2	2.5	4.3
Rubber	6.3	10.1	3.9	8.7	5.8	10.0	7.8	3.3	ND	1.3	2.2	9.8	5.8
Foam	0.7	0.6	0.8	1.7	0.6	1.3	2.2	2.2	1.2	1.3	1.1	1.2	1.2
Ceramic/stone	ND	1.8	3.3	3.5	1.2	1.3	5.6	3.3	2.4	4.0	7.8	2.5	3.0
Glass	3.5	7.1	6.9	4.3	5.8	5.0	14.4	8.7	7.1	8.0	13.3	6.1	7.5
Metal	4.2	14.3	9.4	5.2	5.8	7.5	6.7	8.7	10.6	6.7	7.8	12.3	8.3
Soil	12.3	11.9	15.7	30.4	7.0	8.1	4.4	23.4	10.0	19.3	18.9	6.1	14.0
Battery	ND	1.8	ND	ND	ND	ND	ND	ND	ND	ND	ND	2.5	0.4
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table H-9 Composition of solid waste size 25-50 mm

Composition (%w/w)	**Experiment No.**							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**Mean**
Plastic	21.4	18.4	7.1	13.6	16.4	11.2	13.6	14.5
Textile	5.9	3.8	1.3	2.2	2.2	2.2	3.8	3.0
Wood	5.5	3.7	2.5	4.5	9.9	3.0	2.2	4.5
Paper	1.2	1.7	5.3	4.4	5.2	1.1	0.7	2.8
Rubber	0.6	0.2	0.7	0.8	0.9	1.8	0.8	0.8
Foam	0.4	0.5	0.3	0.8	1.5	1.5	0.8	0.8
Ceramic/ Stone	12.8	5.4	12.5	4.3	8.3	11.9	9.0	9.2
Glass	10.5	23.4	14.7	6.2	3.3	11.2	3.0	10.3
Metal	10.9	6.3	6.9	4.3	4.8	2.3	1.7	5.3
Soil	28.9	34.8	47.1	57.7	45.6	52.8	64.1	47.3
Battery	2.0	1.9	1.6	1.1	1.9	0.9	0.3	1.4
Total	100	100	100	100	100	100	100	100.0

2. Calculation of solid waste recovery rate

Solid waste recovered in waste size > 50 (Kg) → (A)

- Mean of waste size > 50mm = 69% w/w
- Mean of the composition of waste size > 50 mm (Table H-8)

Recovery of waste = 0.69 x Mean of the composition of waste size > 50mm

Solid waste recovered in waste size 25-50 (Kg)→ (B)

- Mean of waste size 25-50 mm = 18% w/w
- Mean of the composition of waste size 25-50mm (Table H-9)

Recovery of waste = 0.18 x Mean of the composition of waste size 25-50mm

Solid waste recovered in waste size < 25mm (kg)→(C)

- Mean value of waste size < 25mm = 13% w/w
- Mean value of the composition of waste size < 25mm = 100% of soil

Recovery of waste = 0.13 x 100

Total waste weight = (A) + (B) + (C)

Table H-10 Solid waste recovery rates in different solid waste sizes

Waste type	**Waste weight (kg)**			
	size > 50 mm (A)	**size 25-50 mm (B)**	**size < 25mm (C)**	**Total (D)**
Plastic	23.7	2.6	ND	26.3
Textile	7.3	0.5	ND	7.8
Wood	7.4	0.8	ND	8.2
Paper	3.0	0.5	ND	3.5
Rubber	4.0	0.2	ND	4.1
Foam	0.9	0.1	ND	1.0
Ceramic/stone	2.1	1.7	ND	3.7
Glass	5.2	1.9	ND	7.1
Metal	5.7	1.0	ND	6.7
Soil	9.6	8.5	13.0	31.1
Battery	0.2	0.3	ND	0.5
Total	69.0	18.0	13.0	100

ND= non-detectable

Determination of percent recovery rate of solid waste in each waste size

According to the result present in Table H-10

(a) Percent recovery rate of waste size > 50mm = (Ax100)/D
(b) Percent recovery rate of waste size 25-50mm = (Bx100)/D
(c) Percent recovery rate of waste size <25mm = (Cx100)/D

Total = (a) + (b) + (c) = 100

Table H-11 Percent recovery rate of solid waste in different solid waste sizes

Waste type	**Recovery rate (% w/w)**			
	size > 50 mm	**size 25-50 mm**	**size < 25mm**	**Total**
Plastic	90	10	ND	100
Textile	93	7	ND	100
Wood	90	10	ND	100
Paper	86	14	ND	100
Rubber	96	4	ND	100
Foam	85	15	ND	100
Ceramic/stone	56	44	ND	100
Glass	74	26	ND	100
Metal	86	14	ND	100
Soil	31	27	42	100
Battery	49	51	ND	100

ND= non-detectable

APPENDIX-I

Characteristics of solid waste reclaimed from dumpsite

1. Characteristic of the reclaimed waste from the dumpsite

Table I-1Characteristic of waste size > 50mm

Experiment No	Recovery (%)	Ash	CV	Mn	Cr	Cd	Pb	Ni	Zn	Cu	Hg
		%	MJ/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	µg/kg
1	68	34.13	36.67	242.4	58.4	9.1	38.2	18.8	2593.6	1040.4	1086.0
2	78	27.62	34.80	83.6	25.8	28.0	13.8	6.2	387.3	70.6	764.7
3	66	55.69	41.85	98.2	45.1	2.7	16.5	5.7	289.7	4876.4	1641.1
4	75	16.05	27.87	147.1	41.1	0.7	11.3	19.6	341.6	142.2	617.7
5	70	28.70	38.05	206.5	50.4	0.4	6.1	30.6	336.5	152.0	737.1
Average	-	32.4	35.8	155.6	44.1	8.2	17.2	16.2	789.7	1256.3	969.3

Table I-2 Characteristic of waste size 25-50mm

Experiment No	Recovery (%)	VS	TOC	N	P	K	Mn	Cr	Cd	Pb	Ni	Zn	Cu	Hg
		%	%	%	%	%	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	µg/kg
1	14	56.00	11.03	0.70	0.19	0.26	385.3	67.2	6.4	20.6	43.1	362.2	56136.4	655.9
2	9	62.50	10.58	0.67	0.61	0.22	399.8	92.1	2.1	50.9	322.6	6687.2	2304.4	1479.5
3	12	64.40	14.71	0.34	0.67	0.25	233.9	131.7	4.2	77.4	303.7	573.7	900.2	1143.8
4	11	66.20	18.88	1.01	0.56	0.18	190.4	72.0	2.6	68.8	16.4	829.9	183.0	663.4
5	14	50.30	16.25	0.95	0.52	0.28	631.0	115.6	5.2	138.9	1256.8	1630.8	2238.7	1368.8
Average	-	59.88	14.29	0.73	0.51	0.24	368.1	95.7	4.1	71.3	388.5	2016.7	12352.5	1062.3

Table I-3 Characteristic of waste size <25mm

Experiment No	Recovery (%)	VS	TOC	N	P	K	Mn	Cr	Cd	Pb	Ni	Zn	Cu	Hg
		%	%	%	%	%	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	µg/kg
1	18	33.0	13.6	0.8	0.5	0.2	496.8	125.3	4.3	96.1	24.3	844.0	386.7	886.4
2	13	43.8	11.5	0.9	0.7	0.3	573.3	115.4	3.5	92.5	50.1	1087.1	426.9	888.0
3	22	43.7	12.4	0.8	0.9	0.3	460.1	257.1	3.4	151.7	53.9	1081.3	8974.8	1139.7
4	14	47.0	19.7	1.3	0.9	0.3	369.8	150.3	3.3	120.3	43.4	1005.8	304.8	918.7
5	16	42.1	13.3	0.9	0.6	0.2	2835.8	184.8	6.6	200.0	67.2	3465.2	1131.9	1567.8
Average	-	41.9	14.1	0.9	0.7	0.2	947.1	166.6	4.2	132.1	47.8	1496.7	2245.0	1080.1

Table I-4 Concentration of heavy metals content in plastic waste

	Ash	Mn	Cr	Cd	Pb	Ni	Zn	Cu	Hg
Sample No.	%	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	µg/kg
1	35	134.9	38.5	1.7	62.7	24.5	255.2	492.6	241.6
2	48	10.1	4.3	1.2	7.4	3.6	51.8	11.7	133.1
3	17	8.3	5.8	0.1	5.2	4.8	29.5	8.6	113.9
4	29	96.7	50.7	2.4	47.6	22.5	479.4	129.7	353.8
5	18	275.8	62.0	1.7	130.3	39.0	414.3	236.9	872.7
6	47	156.9	162.2	0.6	29.0	23.0	276.3	95.1	142.7
7	11	5.0	3.8	ND	1.0	1.4	14.6	4.8	82.7
8	32	158.1	39.6	1.4	58.3	35.0	435.6	208.9	435.1
9	28	216.4	72.8	6.9	96.1	64.3	590.7	214.0	-
10	27	45.7	6.5	0.1	4.7	5.3	744.5	19.7	-
11	38	54.1	34.4	0.7	18.0	11.2	129.5	58.5	-
12	34	124.6	39.7	2.7	49.9	19.6	338.5	325.3	-
Average	30	107.2	43.4	1.6	42.5	21.2	313.3	150.5	296.9

2. Calculation of heavy metals concentration in the composite waste

Concentration of heavy metal (j) in composite waste $= \frac{\sum_i CijPi}{\sum_i Pi}$

Where

i = Solid waste size > 50mm, 25-50mm and < 25mm;

Pi = Percentage of waste size (i), $\sum_i Pi = 100$

Cij = Concentration of heavy metal (j) in the waste i^{th} fraction

Based on the heavy metal analysis (Table I-1 to Table I-3), the concentration of heavy metal in the waste size <25mm, 25-50mm and > 50mm was found to have much variation. The concentration of heavy metal in the composite waste was calculated from each batch of experiment as presented in Table I-5

Table I-5 Heavy metal distribution in various solid waste size

Waste size (i)	**Experiment No**	**Heavy metal (j) (mg/Kg)**							
		Mn	**Cr**	**Cd**	**Pb**	**Ni**	**Zn**	**Cu**	**Hg**
50mm= (C_{50j} x P_{50})/100	1	164.8	39.7	6.2	26.0	12.8	1763.6	707.5	738.5
	2	65.2	20.1	21.8	10.8	4.9	302.1	55.1	596.4
	3	64.8	29.7	1.8	10.9	3.8	191.2	3218.4	1083.2
	4	95.6	26.7	0.4	7.3	12.7	222.1	92.5	401.5
	5	144.5	35.3	0.3	4.3	21.4	235.6	106.4	515.9
	Average	**107.0**	**30.3**	**6.1**	**11.8**	**11.1**	**542.9**	**836.0**	**667.1**
25-50mm = ($C_{25\text{-}50\,j}$ x $P_{25\text{-}50}$)/100	1	53.9	9.4	0.9	2.9	6.0	50.7	7859.1	91.8
	2	36.0	8.3	0.2	4.6	29.0	601.8	207.4	133.2
	3	28.1	15.8	0.5	9.3	36.4	68.8	108.0	137.3
	4	20.9	7.9	0.3	7.6	1.8	91.3	20.1	73.0
	5	88.3	16.2	0.7	19.5	176.0	228.3	313.4	191.6
	Average	**45.5**	**11.5**	**0.5**	**8.8**	**49.9**	**208.2**	**1701.6**	**125.4**
<25mm= ($C_{<25j}$ x $P_{<25}$)/100	1	94.4	23.8	0.8	18.3	4.6	160.4	73.5	168.4
	2	74.5	15.0	0.5	12.0	6.5	141.3	55.5	115.4
	3	101.2	56.6	0.7	33.4	11.9	237.9	1974.4	250.7
	4	51.8	21.0	0.5	16.8	6.1	140.8	42.7	128.6
	5	453.7	29.6	1.1	32.0	10.8	554.4	181.1	250.9
	Average	**155.1**	**29.2**	**0.7**	**22.5**	**8.0**	**247.0**	**465.4**	**182.8**
Composite $= \frac{\sum_i CijPi}{\sum_i Pi}$	1	313.2	72.9	7.9	47.1	23.4	1974.7	8640.1	998.7
	2	175.8	43.4	22.5	27.4	40.4	1045.2	318.0	845.0
	3	194.1	102.1	3.1	53.5	52.1	497.9	5300.9	1471.1
	4	168.3	55.7	1.2	31.8	20.6	454.2	155.3	603.1
	5	686.6	81.0	2.0	55.7	208.1	1018.3	600.9	958.4
	Average	**307.6**	**71.0**	**7.3**	**43.1**	**68.9**	**998.1**	**3003.0**	**975.3**

Table I-6 Binding forms of heavy metals content in waste size < 25mm

Metal	**Sample No.**	**F1 (%w/w)**	**F2 (%w/w)**	**F3 (%w/w)**	**F4 (%w/w)**	**F5 (%w/w)**
Mn	1	1.9	23.1	52.6	4.1	18.3
	2	2.4	15.1	65.6	6.3	10.6
	3	1.7	13.8	63.5	4.9	16.1
	Average	**2.0**	**17.3**	**60.6**	**5.1**	**15.0**
Cr	1	0.0	0.0	20.8	35.4	43.8
	2	0.0	0.0	32.0	42.1	25.9
	3	0.0	0.0	32.0	31.8	36.2
	Average	**0.0**	**0.0**	**28.3**	**36.4**	**35.3**
Cd	1	2.7	51.9	29.9	5.9	9.6
	2	3.0	32.8	58.4	3.5	2.3
	3	4.0	53.9	37.5	0.0	4.6
	Average	**3.2**	**46.2**	**41.9**	**3.1**	**5.5**
Pb	1	0.0	7.4	27.0	0.0	65.6
	2	0.0	0.5	24.2	0.0	75.2
	3	0.0	3.0	25.1	0.0	71.9
	Average	**0.0**	**3.6**	**25.4**	**0.0**	**70.9**
Ni	1	0.0	3.9	31.8	20.3	43.9
	2	0.3	5.0	47.0	30.0	17.6
	3	0.1	2.2	36.1	22.3	39.3
	Average	**0.1**	**3.7**	**38.3**	**24.2**	**33.6**
Zn	1	0.6	28.5	47.7	4.1	19.0
	2	1.0	29.3	57.2	5.1	7.5
	3	0.7	31.9	51.8	3.2	12.4
	Average	**0.8**	**29.9**	**52.2**	**4.1**	**13.0**
Cu	1	0.2	3.6	1.8	69.6	24.8
	2	0.1	1.7	0.4	60.0	37.8
	3	0.2	4.4	0.8	73.7	20.9
	Average	**0.2**	**3.3**	**1.0**	**67.8**	**27.8**

F1 = ion exchanged; F2 = Carbonate; F3= Mn/Fe oxide; F4 = Organic /Sulfide; F5 = Residual

Table I-7 Binding forms of heavy metals content in waste size 25-50mm

Metal	**Sample No.**	**F1 (%w/w)**	**F2 (%w/w)**	**F3 (%w/w)**	**F4 (%w/w)**	**F5 (%w/w)**
Mn	1	2.0	10.3	44.8	5.2	37.8
	2	1.2	4.4	47.8	13.9	32.7
	3	2.3	0.0	41.5	47.4	8.7
	Average	**1.8**	**4.9**	**44.7**	**22.1**	**26.4**
Cr	1	0.0	0.0	12.0	13.2	74.8
	2	0.1	0.0	34.3	29.0	36.5
	3	0.0	0.0	65.5	24.8	9.7
	Average	**0.1**	**0.0**	**37.3**	**22.3**	**40.4**
Cd	1	3.4	53.6	42.9	0.0	0.0
	2	3.9	48.2	47.0	0.8	0.1
	3	1.4	39.1	47.8	0.0	11.6
	Average	**2.9**	**47.0**	**45.9**	**0.3**	**3.9**
Pb	1	0.0	0.3	17.8	0.4	81.4
	2	0.3	0.0	28.9	0.0	70.8
	3	0.0	0.0	23.9	0.4	75.7
	Average	**0.1**	**0.1**	**23.5**	**0.3**	**76.0**
Ni	1	0.6	4.2	40.5	20.9	33.8
	2	2.8	3.4	18.6	16.7	58.4
	3	0.2	0.3	23.4	11.8	64.2
	Average	**1.2**	**2.6**	**27.5**	**16.5**	**52.2**
Zn	1	0.6	39.9	45.1	2.8	11.6
	2	1.1	23.9	51.9	12.2	10.9
	3	0.6	4.1	45.9	41.3	8.1
	Average	**0.7**	**22.7**	**47.6**	**18.8**	**10.2**
Cu	1	0.0	0.3	0.2	7.8	91.8
	2	0.0	0.4	0.1	21.3	78.2
	3	2.1	0.0	0.4	93.6	4.0
	Average	**0.7**	**0.2**	**0.2**	**40.9**	**58.0**

F1 = ion exchanged; F2 = Carbonate; F3= Mn/Fe oxide; F4 = Organic /Sulfide; F5 = Residual

Table I-8 Seed germination test of waste size < 25mm

Experiment No.	**RRG (%)**	**RSG (%)**	**GI (%)**
1	102	100	102
2	64	69	44
3	100	86	86
4	115	98	113
5	100	94	94
6	97	94	91
Average	96.3	90.2	88.4

RRG = Relative root elongation; RSG = Relative seed germination; GI=Germination index

Table I-9 Characteristic of extracted water in toxicity test of waste size <25mm

Sample No.	**EC**	**pH**	**Mn**	**Cr**	**Cd**	**Pb**	**Ni**	**Zn**	**Cu**
	mS/cm		**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**
1	2.5	7.3	0.280	0.004	< 0.001	0.003	0.045	0.104	0.129
2	4.0	7.5	0.357	0.008	< 0.001	0.004	0.074	0.199	0.208
3	3.0	7.6	0.147	0.011	< 0.001	0.007	0.107	0.183	0.229
4	2.4	8.2	0.235	0.028	< 0.001	0.020	0.095	0.586	0.405
5	2.1	8.0	0.199	0.011	< 0.001	0.011	0.062	0.272	0.609
6	1.7	7.7	0.150	0.016	< 0.001	0.013	0.107	0.198	0.273
Average	2.6	7.7	0.228	0.013	<0.001	0.010	0.082	0.257	0.309

Table I-10 Characteristic of the TCLP leachate of waste size < 25mm

Sample No.	**pH**	**Mn**	**Cr**	**Cd**	**Pb**	**Ni**	**Zn**	**Cu**	**Hg**
		mg/L	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**µg/L**
1	7.04	0.441	0.004	0.002	<0.01	0.011	0.186	0.030	<0.001
2	7.06	0.399	0.007	0.001	0.029	0.023	0.423	0.066	<0.001
3	7.13	0.749	0.002	<0.001	0.017	0.014	0.478	0.065	<0.001
4	7.07	0.487	0.004	0.002	0.022	0.018	0.203	0.039	<0.001
5	7.02	0.823	0.005	0.003	0.025	0.030	0.739	0.169	<0.001
6	6.98	1.174	0.003	0.004	0.020	0.758	0.542	0.053	<0.001
Average	7.05	0.679	0.004	0.002	0.017	0.142	0.428	0.070	<0.001

Table I-11Characteristic of the TCLP leachate of waste size 25-50 mm

Sample No.	**pH**	**Mn**	**Cr**	**Cd**	**Pb**	**Ni**	**Zn**	**Cu**	**Hg**
		mg/L	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**µg/L**
1	7.12	0.399	0.005	0.001	0.015	0.081	0.510	0.166	<0.001
2	7.08	0.906	0.004	0.001	0.015	0.040	0.295	0.033	<0.001
3	7.15	0.596	0.005	0.001	0.018	0.060	0.248	0.035	0.001
4	7.16	0.144	0.004	0.001	0.010	0.052	0.232	0.014	0.001
5	7.14	0.224	0.014	0.001	<0.01	0.010	0.238	0.046	0.001
6	6.50	0.816	0.004	0.002	<0.01	0.014	0.176	0.037	<0.001
Average	7.03	0.514	0.006	0.001	0.011	0.043	0.283	0.055	<0.001