Evaluation of Rehabilitation and Mining Potential of Municipal Solid Waste Dumpsite

By

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Contents

1. Response of External Examiner Comments

1.1 The reviewer is missing some information about the history of the dumpsite Nonthaburi, like estimate total mass stored there or background information about the former composition.

- **MSW generated in Nonthaburi province : 50-60% w/w of food waste and 12-24 %w/w of plastic**
- **This information is added in the modified final report, page 66.**

1.2 It might be discussed whether 4 times of 150 kg for the characterization of the solid are representative, while 750 tones per day are delivered.

- Determination of recycling potential of waste is focused on the 3-5 years old solid waste
- Low biodegradation of waste at BH1 and BH2
- Four solid waste sampling points nearby BH1 were randomly sampled
- Approximately 150 kg of waste was collected from every 1 depth interval from the surface to 3 m depth
- There are totally 12 samples with 1800 kg of solid waste
- Statistical analysis shows insignificant difference of characteristic and composition of waste among these points

1.3 To test the biodegradability of the material, the method of respiratory or and anaerobic test for gas production would be more adequate than the BOD (for aquatic system).

- Limitation of necessary equipment
- BOD and COD analysis can be done without excavation of solid waste
- BOD/COD ratio of leachate is used as criteria in screening the stability and biodegradability of waste in landfill

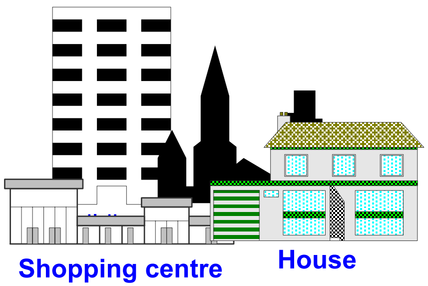
1.4 The author give three tasks to be solve later: economical feasibility, evaluation of adopted dumpsite/ landfill technology and the option of compost. It would have been preferred, if the author would have started at least a discussion on that topics. Or if he would have shown detailed necessary steps to transfer his research into application.

- **Feasibility of adopted dumpsite and landfill has been discussed in section 4.4, page 78-80.**

- **Economic feasibility in pilot scale of dumpsite mining and the option of compost are recommend in future study.**

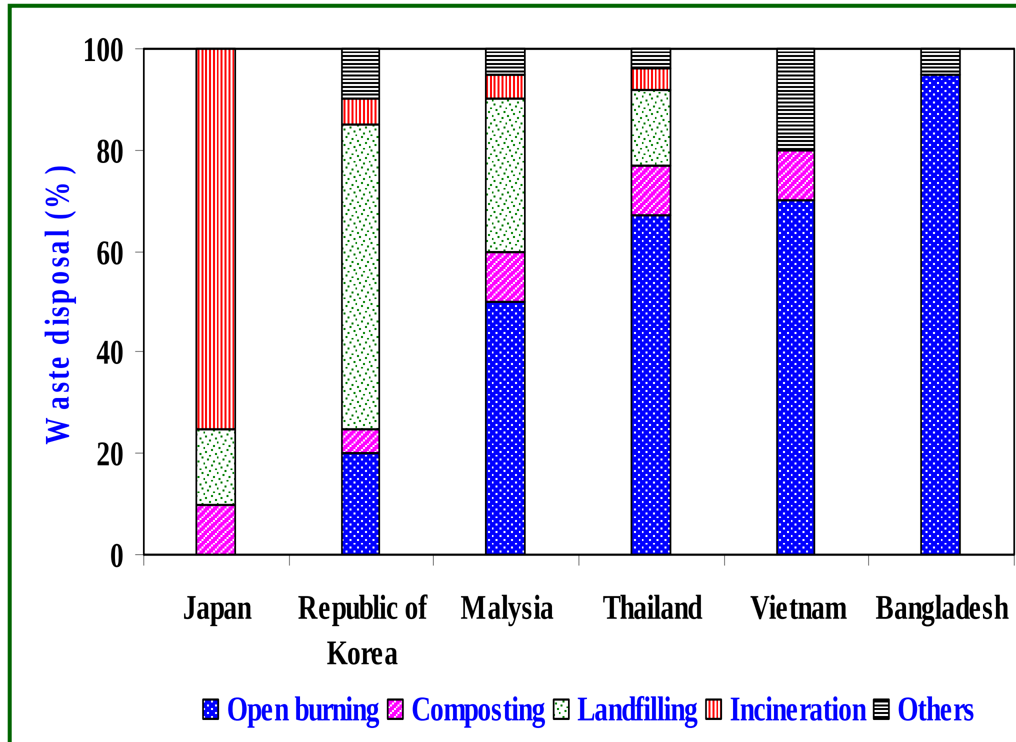
2. Research Background

Municipal solid waste generation



0.5-1.0 kg/capital/day
14 million tons/day

MSW composition:
- Food waste = 50-60%
- Paper = 4.5-11%
- Plastic = 11.6-24%

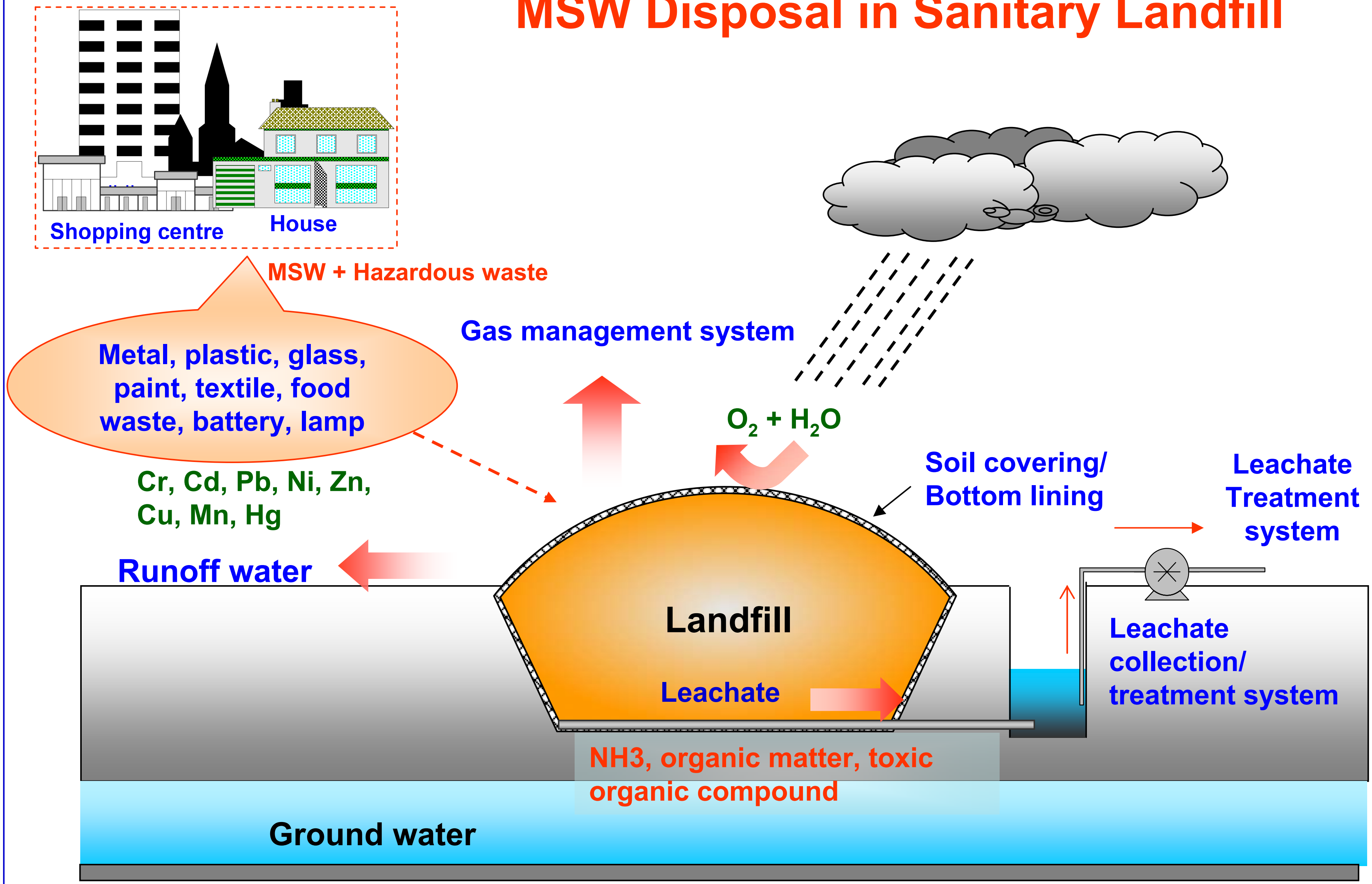


Why open dumping is selected in MSW disposal ?

- ❑ Budget
- ❑ Technology
- ❑ Knowledge

MSW Management

MSW Disposal in Sanitary Landfill



Heavy Metal Accumulation in Solid Waste

Heavy metal (100%)

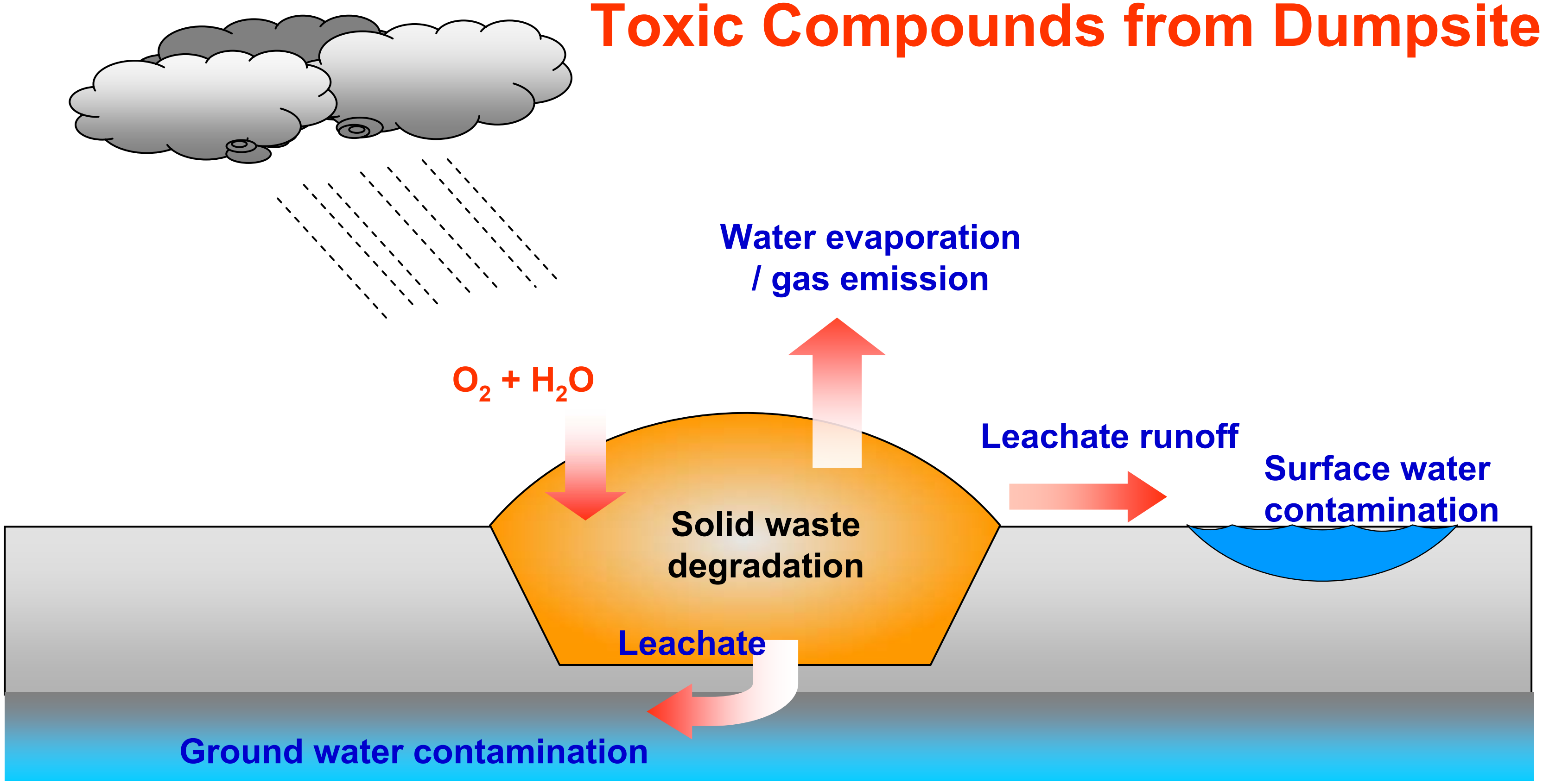
Heavy metal (10% w/w)

90%

1. Ion exchange with negative charge
2. Mn/Fe oxide adsorption
3. Precipitation with carbonate
4. Complexation with solid organic matter/ sulfide precipitation
5. Non solubility property

Can be remobilized if environment is changed

Environmental Contamination of Toxic Compounds from Dumpsite



- Oxidation-reduction potential increase
- Biodegradation of organic matter
- Remobilization of heavy metals
- Ground water/surface water contamination

Characteristic of Nonthaburi Dumpsite

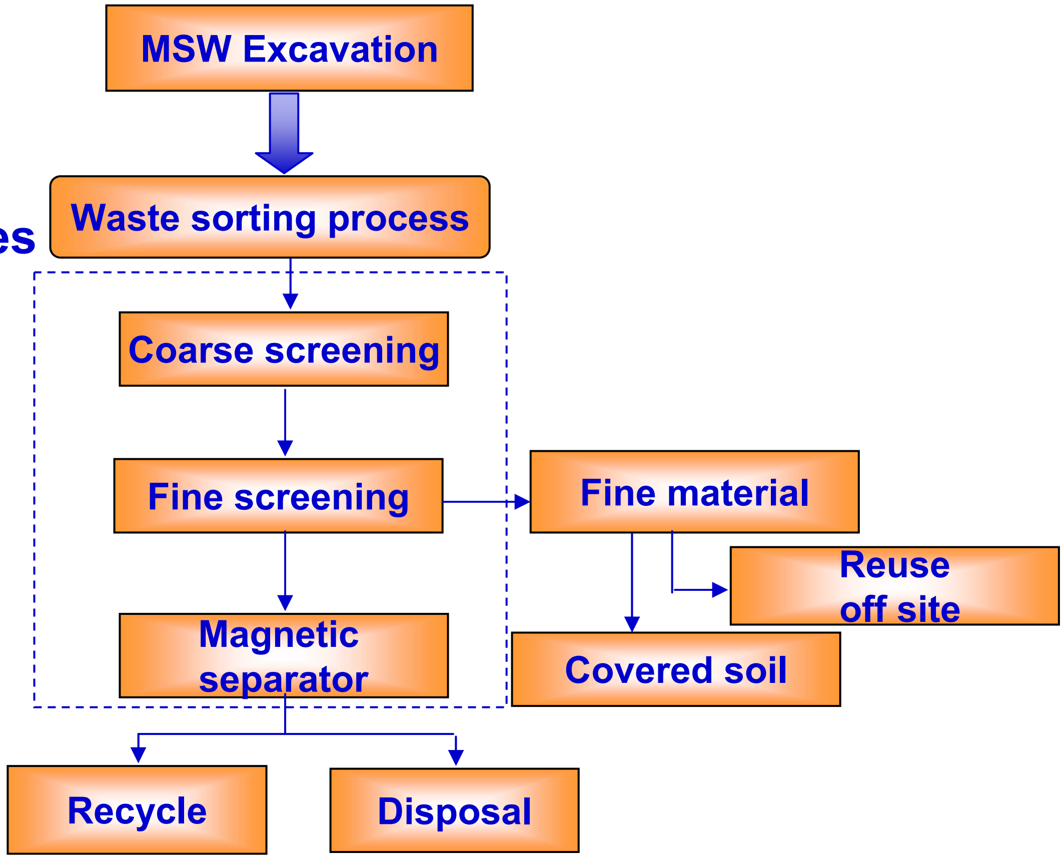
- Total area is about 108,800 m^2
- Approximately 700 tons/day of MSW is disposed without soil covering and leachate collection system at bottom of this site

- Rice (*Oryza sativa* L.) is a dominant specie in surrounding area
- High sensitivity of germination and root elongation of rice to toxic compound

Landfill Mining and Reclamation

Advantage of landfill mining

1) Increase land value of reclaimed site for other uses
2) Reduction of landfill area
3) Elimination of source of contamination
4) Solid waste recycle



Landfill mining process

Source: Figure 2.3, page 20

Waste recycle option

1) Energy recovery
2) Soil recycle as compost
3) Material recovery
4) Others such as Wastewater treatment

Limitation of Landfill Mining

- Quality of recovered material

Energy Recovery	Compost
Moisture	pH
Noncombustible waste	EC
Metals	Metals
Chlorine	Nutrient (N, P, K)
Ash	C/N ratio
Calorific value	Toxicity (Germination Index)

- Landfill gas and odor
- Disposal of hazardous / Non-recyclable waste
- Cost of operation

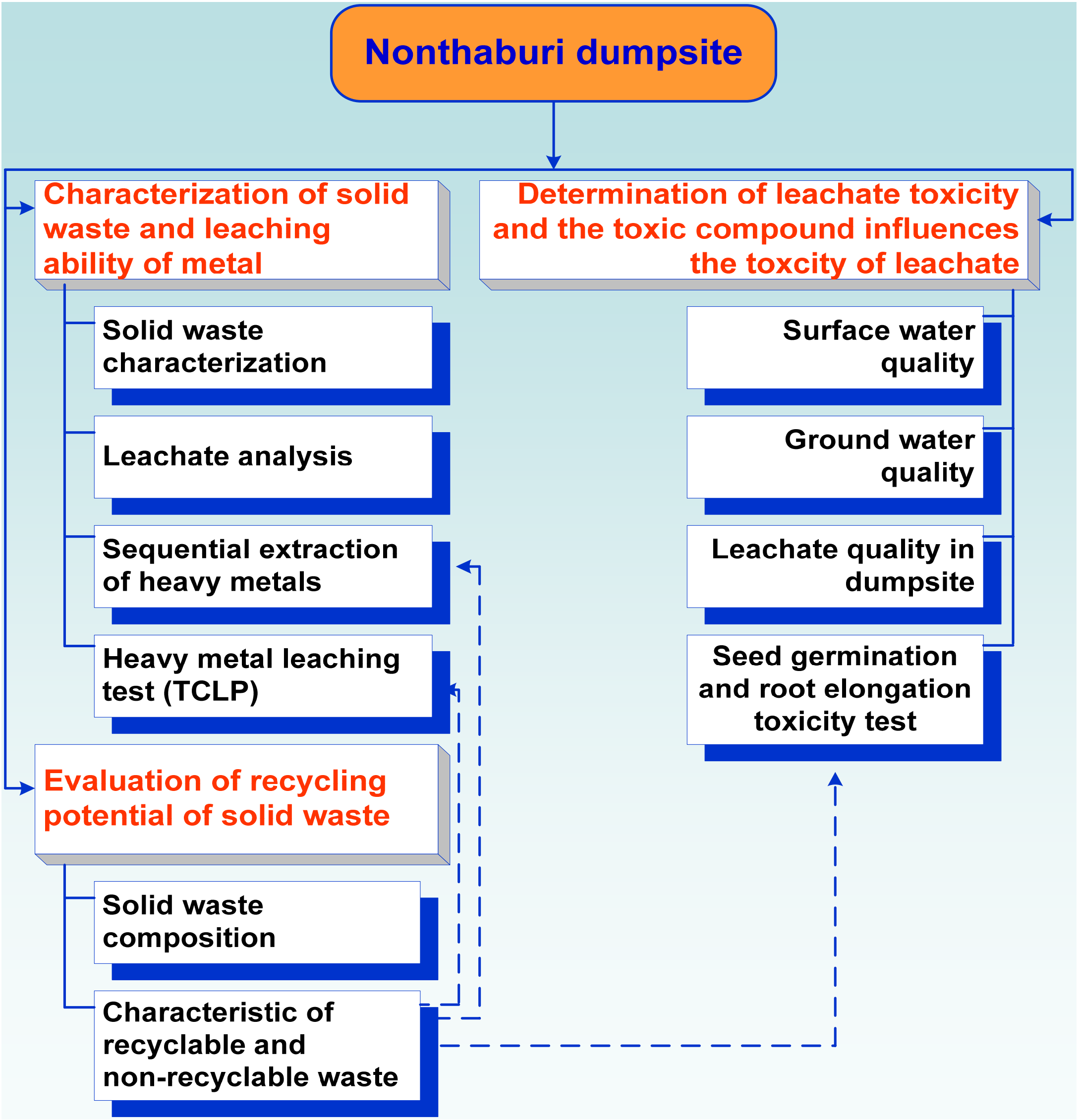
3. Research Objectives

- To determine characteristics of municipal solid waste in a dumpsite and its leaching ability of heavy metals
- To determine the toxicity of leachate to the germination of rice (*Oryza sativa* L.)
- 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

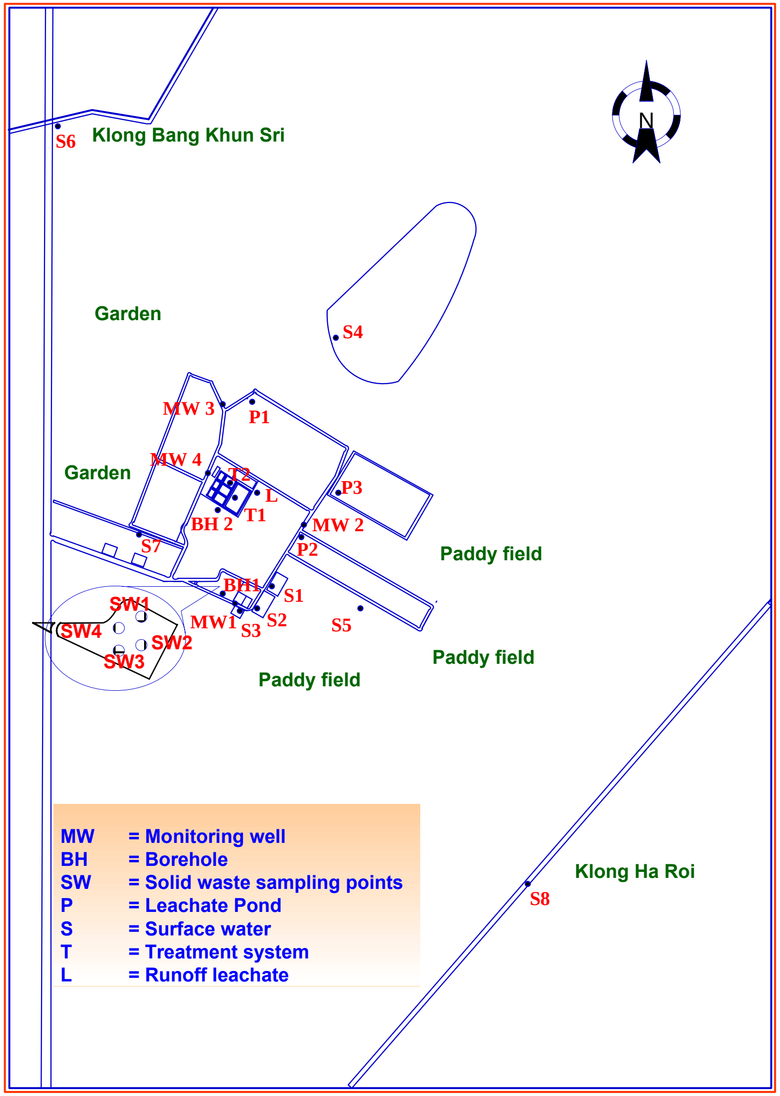
4. Research Methodology

Research Diagram

Source: Figure 3.1 Page 24



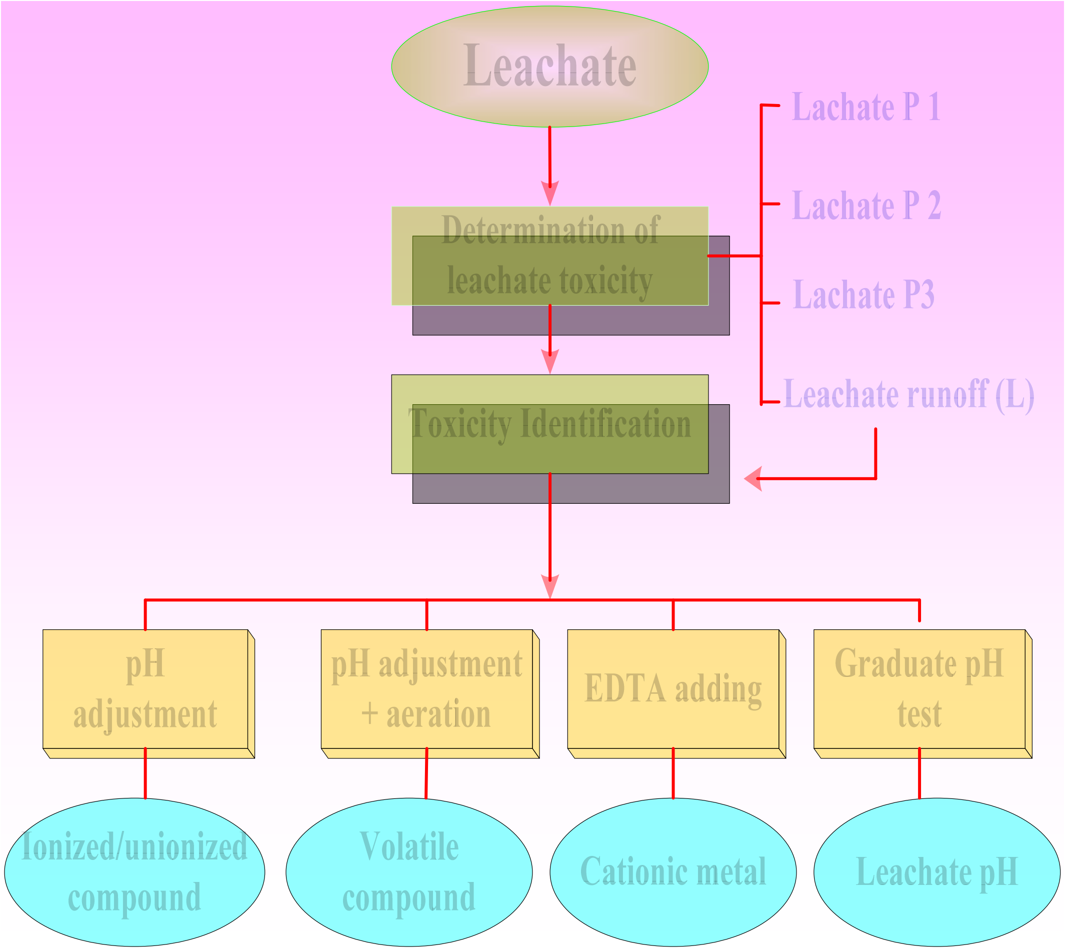
Sampling Location of Solid Waste, Leachate, Surface Water and Groundwater



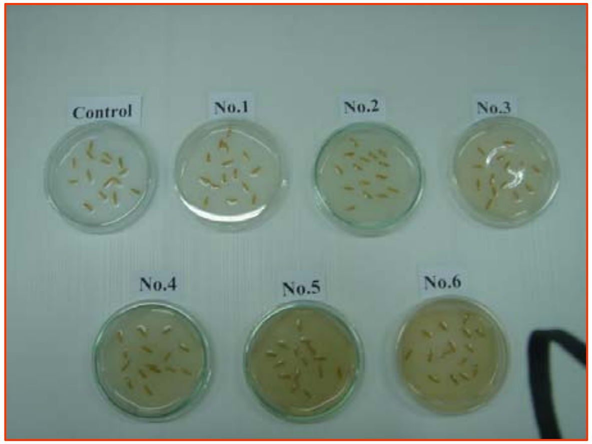
Nonthaburi dumpsite

1. **Leachate sampling**
   - Leachate runoff (L) and borholes (BH1, BH2)
   - Treatment systems (T1, T2) and leachate ponds (P1-P3)
2. **Surface water (S1-S8) and groundwater (MW1-MW4) sampling**
3. **Solid waste sampling (SW1-SW4)**

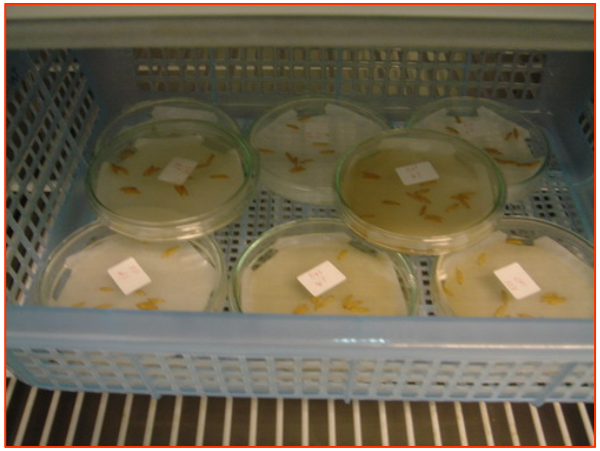
Seed Germination and Root Elongation Toxicity Test of Leachate with *Oryza sativa* L.



Source: Figure 3.4 page 33

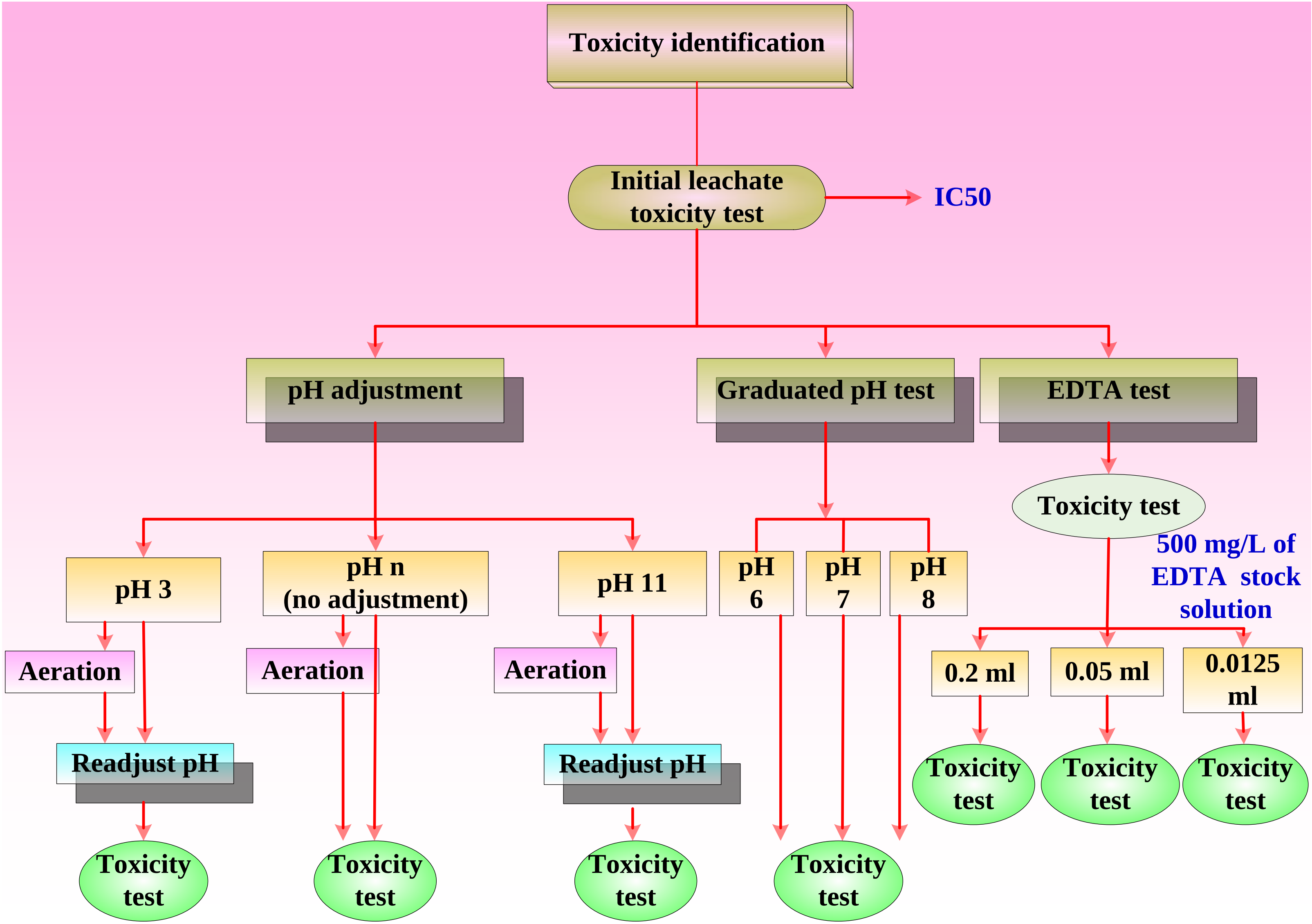


(1) 15 seeds/disc lining with filter paper



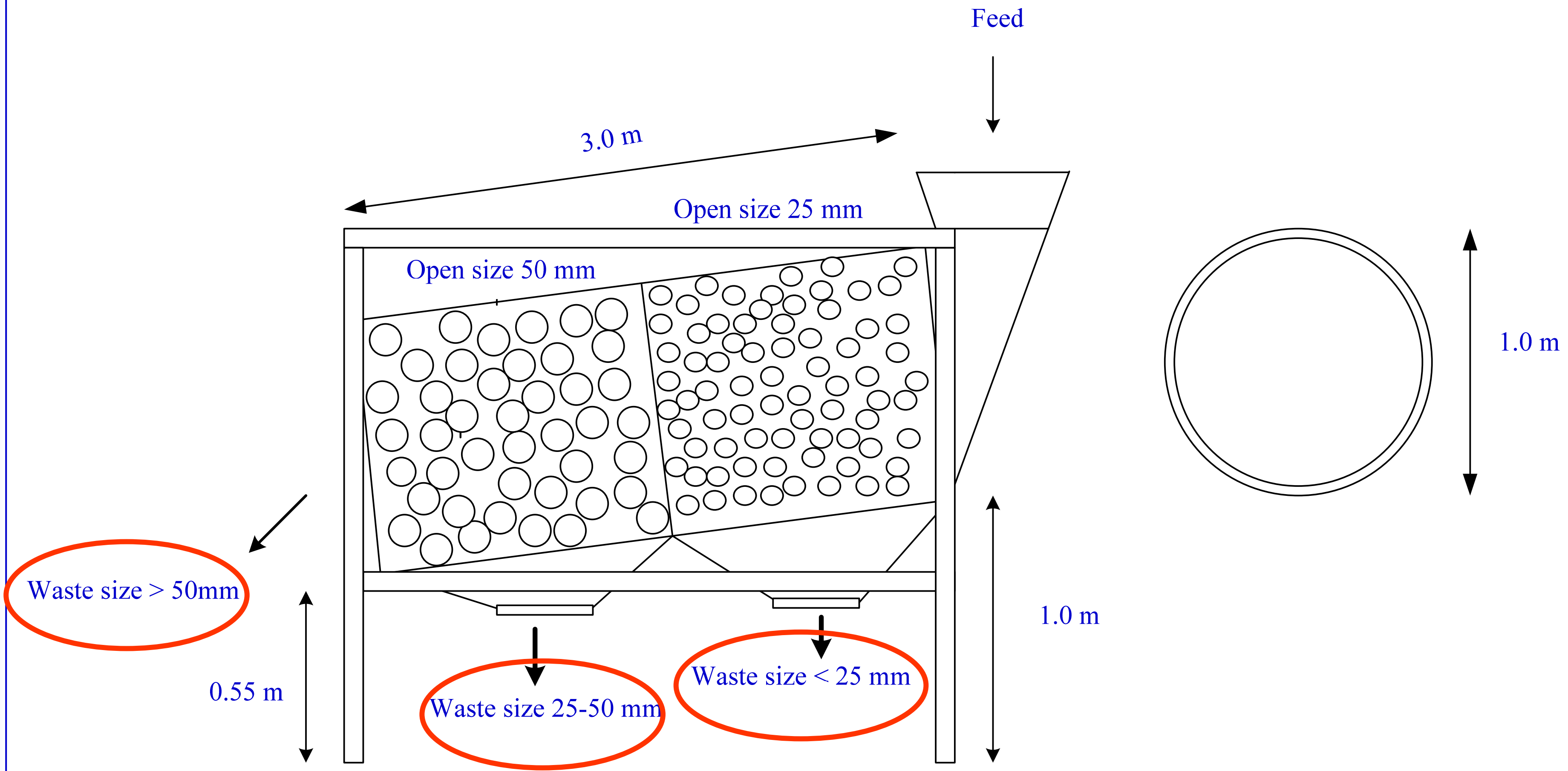
(2) Incubation at 25 °C for 96 h

Toxic Identification of Leachate



Source: Figure 3.5, page 35

Solid Waste Size Distribution



Schematic Diagram of Trommel Screen

Source: Figure 3.6, page 37

5. Results and Discussion: Solid Waste Characteristic and Leaching Potential of Heavy Metal

Characteristics of Waste in Dumpsite

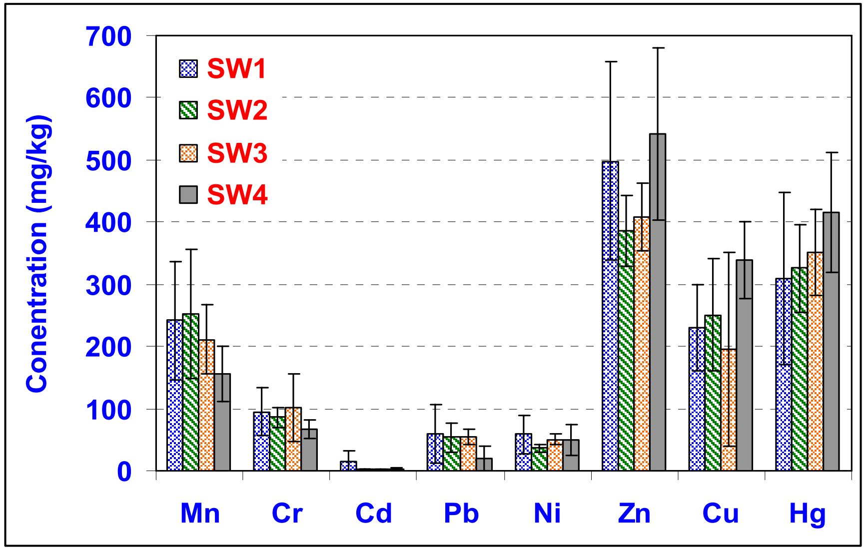
- Relatively low moisture content and density of solid waste at surface layer of dumpsite
- Anaerobic degradation of solid waste occurs at the bottom layer of dumpsite
- The density of solid waste is decreased at 2-3 m depth

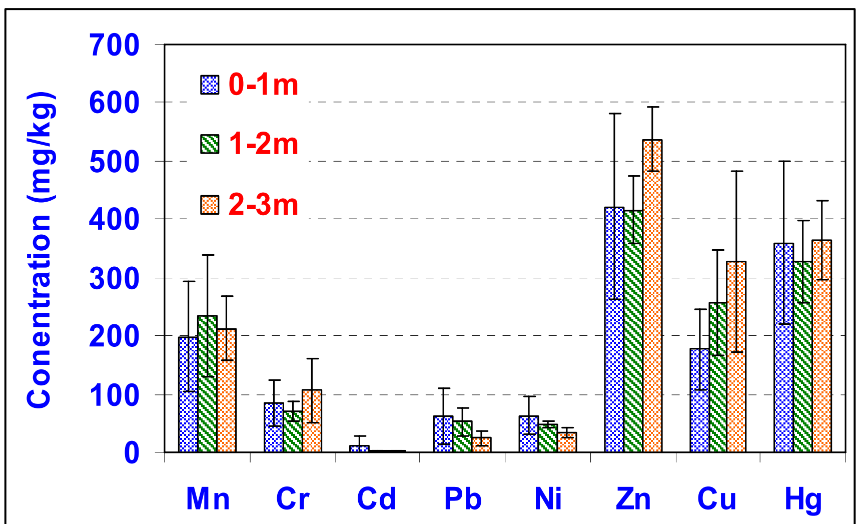
TOC = 21% w/w
Moisture = 37% w/w
pH = 7.3

Anaerobic degradation

pH = 7.7
Moisture = 54% w/w
TOC = 15.6% w/w

Concentrations of Heavy Metals in Dumpsite

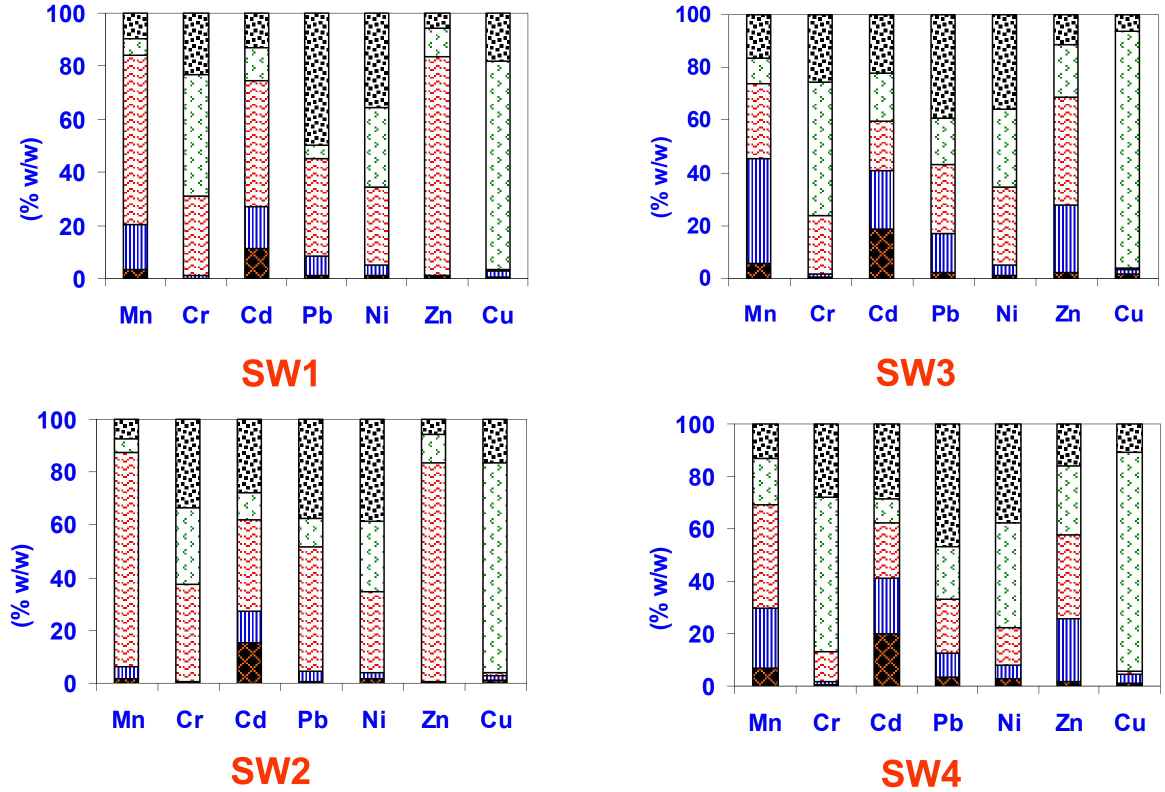


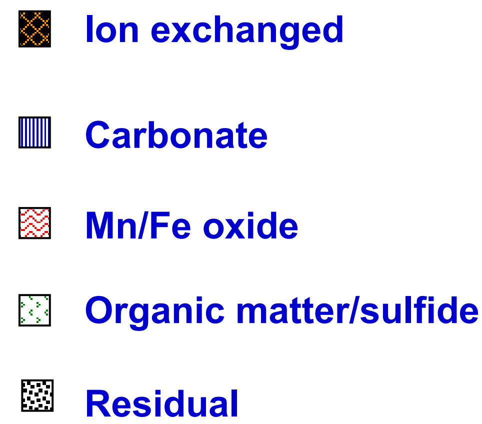


- No difference of heavy metal concentration between sampling sites and depth intervals of dumpsite
- Average heavy metal concentration :Zn> Cu> Mn> Cr> Pb> Ni> Cd> Hg
- High concentration of Zn in MSW

Note: Hg is presented as µg/kg
Source: Figure 4.1 page 43

Heavy Metal Binding Forms





Source: Figure 4.2 page 45

- ✓ **Redox potential of solid waste in dumpsite is variable**
- ✓ **Mn, Zn and Cd are mainly adsorbed on Mn/Fe oxide**
- ✓ **Most of Cu and Cr is absorbed on organic compound and precipitated with sulfide, while Most of fraction of Pb and Ni is in residual form**
- ✓ **Carbonate precipitated heavy metal: Mn> Cd> Zn> Pb> Ni> Cu> Cr**

Contamination Factors of Heavy Metals in Dumpsite

Metals	Contamination factor (C_f^i)			
	SW1	SW2	SW3	SW4
Zn	18.6	17.8	7.9	5.3
Mn	9.5	15.4	5.5	7.6
Cu	4.1	5.6	14.5	7.4
Cd	9.0	2.7	3.7	2.0
Cr	2.4	2.0	4.6	2.6
Ni	1.1	1.8	1.5	1.2
Pb	0.6	1.6	1.6	1.1
$Cf = \sum C_f^i$	45.3	46.9	39.3	27.1

Source: Table 4.5 , Page 47

$$C_f^i = \frac{\text{Mobile fraction}}{\text{Residual fraction}}$$

$$C_f^i = \frac{F1+F2+F3+F4}{F5}$$

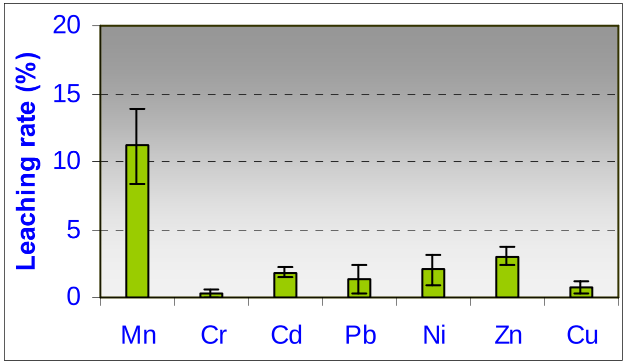
High C_f^i → High leaching ability

- Leaching ability of heavy metal: Zn> Mn > Cu >Cd> Cr> Pb> Ni

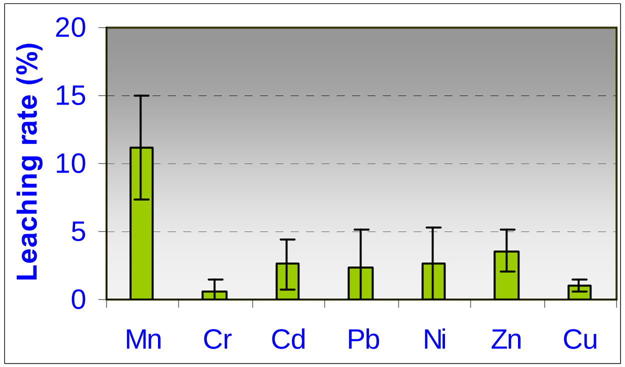
and

SW2 >SW1> SW3> SW4

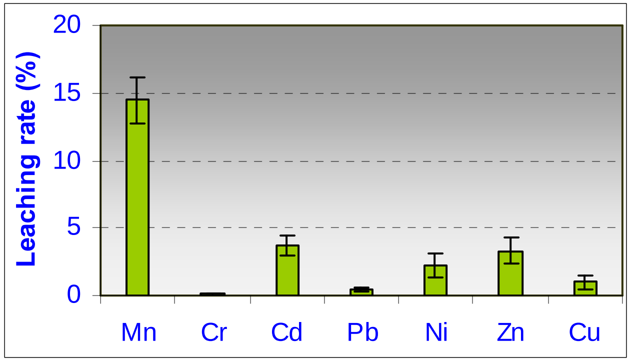
Toxic Characteristic Leaching Potential (TCLP) Test



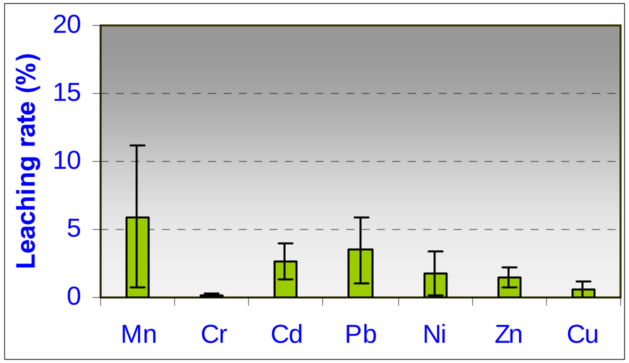
SW1



SW2



SW3



SW4

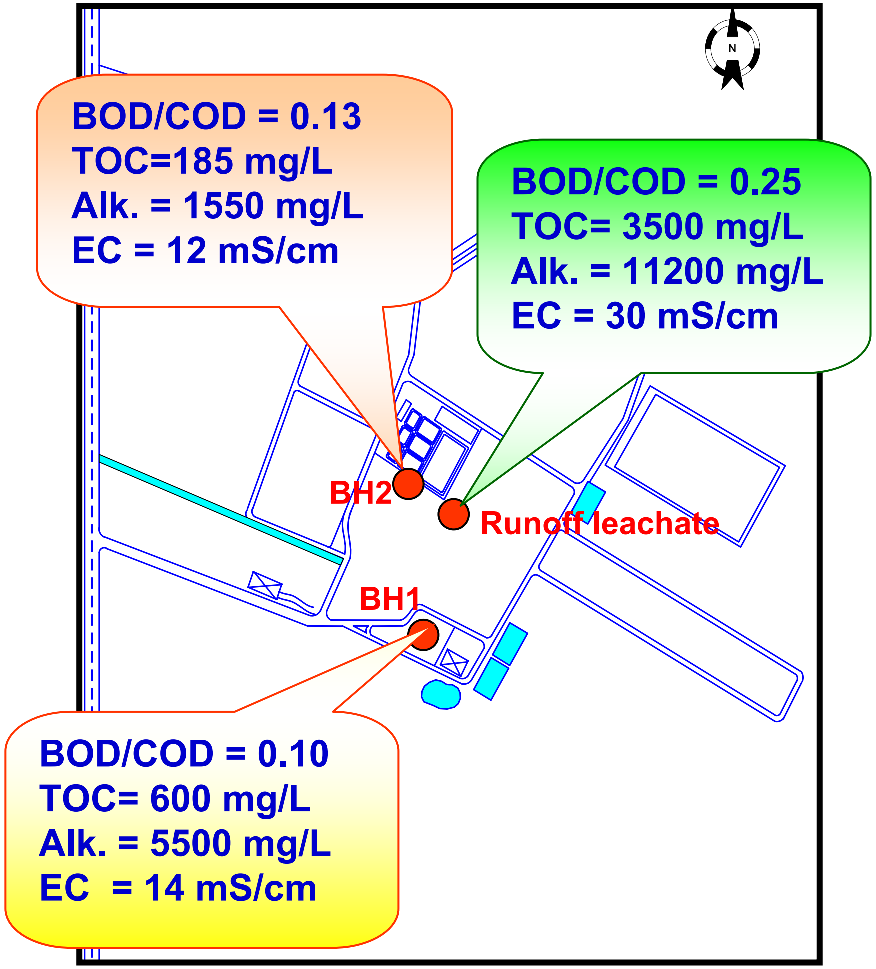
Source: Figure 4.3, page 48

- **Heavy metal leaching rate under acid condition:**

  Mn> Cd, Zn> Ni> Pb> Cu> Cr

- **Acid dissolution of carbonate precipitated metal occurs under acid condition**

Characteristics of Leachate Runoff and Borholes



Source: Table 4.7, page 49

- Biodegradation of waste is in the methanogenic phase
- Acid buffer capacity of dumpsite is relatively high and is sufficient for acid attenuation
- Biodegradation rate of solid waste in dumpsite is heterogeneously: Leachate runoff > BH2 > BH1
- Waste deposits at BH1 and BH2 can be excavated for recycling as compost

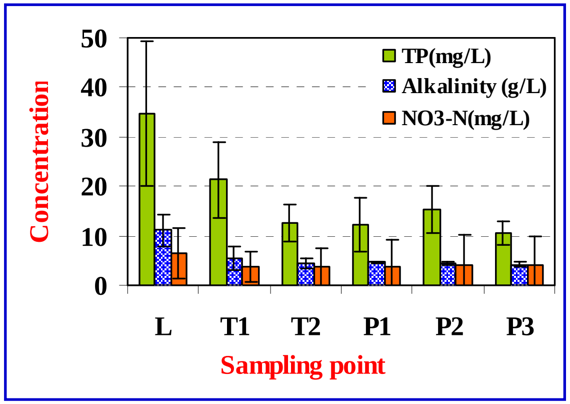
Heavy Metal leaching into the Leachate

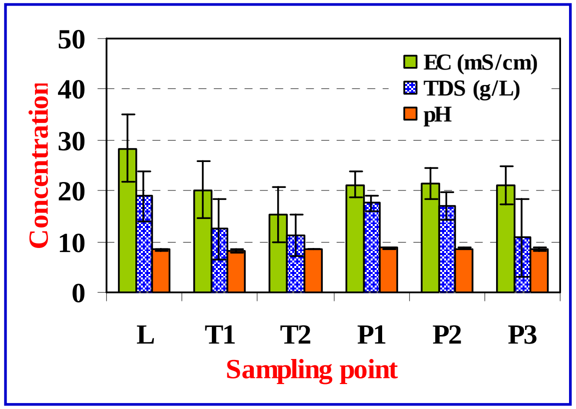
Metals	Leachate runoff	BH1	BH2
Mn (mg/L)	0.49	0.56	1.38
Cr (mg/L)	0.99	0.21	0.03
Cd (mg/L)	0.01	0.001	0.001
Pb (mg/L)	0.10	0.07	0.05
Ni (mg/L)	0.50	0.14	0.07
Zn (mg/L)	1.32	0.27	0.20
Cu (mg/L)	0.63	0.04	0.01
Hg (µg/L)	0.95	<0.001	0.31

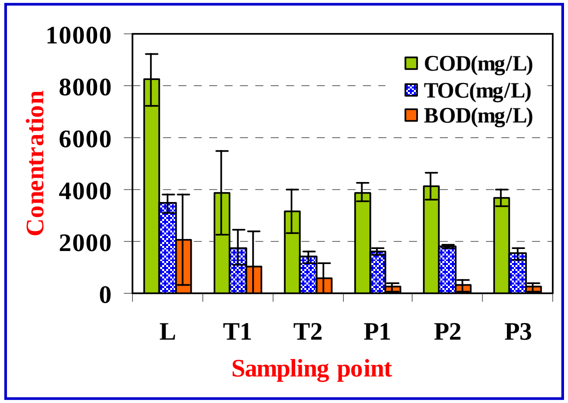
Source: Table 4.7, page 49

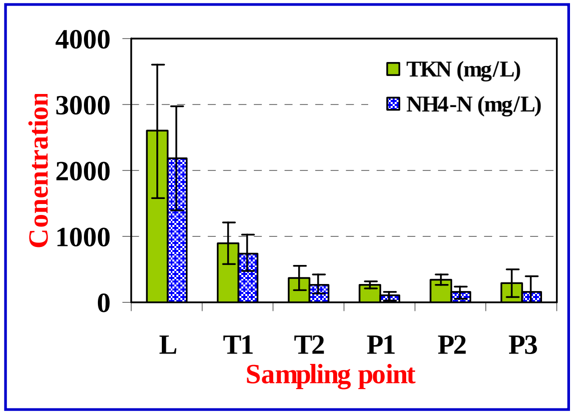
- Heavy metals concentration decreases in the old solid waste ages (BH1, BH2)
- High leaching ability of Mn under anaerobic condition of dumpsite
- High concentration of TOC in leachate runoff increases leach of Cu, Cr and Ni from dumpsite

5. Results and Discussion: Leachate Toxicity and Toxic Compound Influences the Toxicity of Leachate







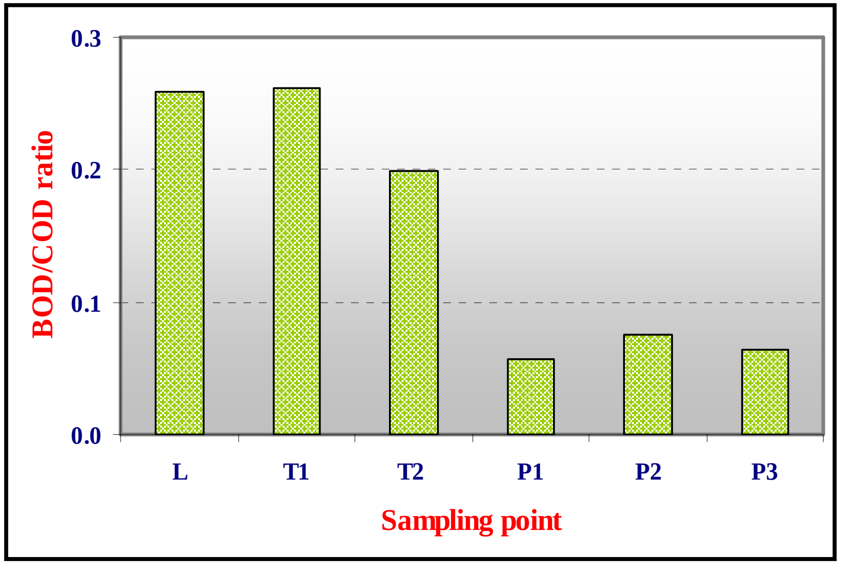


Variation of Leachate Quality in Dumpsite

Source: Figure 4.4, page 51

- Concentration of organic and inorganic compounds decrease significantly in the treatment system (T1, T2)
- Leachate quality is different significantly among these sampling sites (Ammonia, TKN, TP, TDS, TOC, pH and EC)

Average BOD/COD ration of leachate



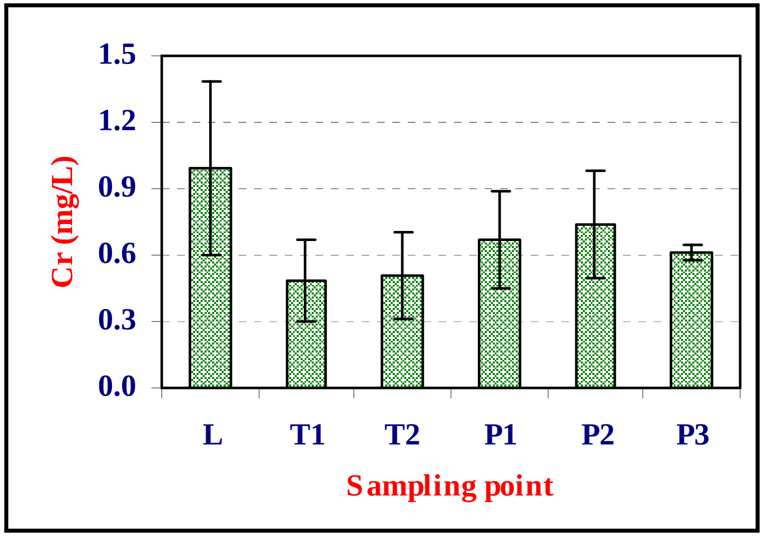
Source: Figure 4.5, page 52

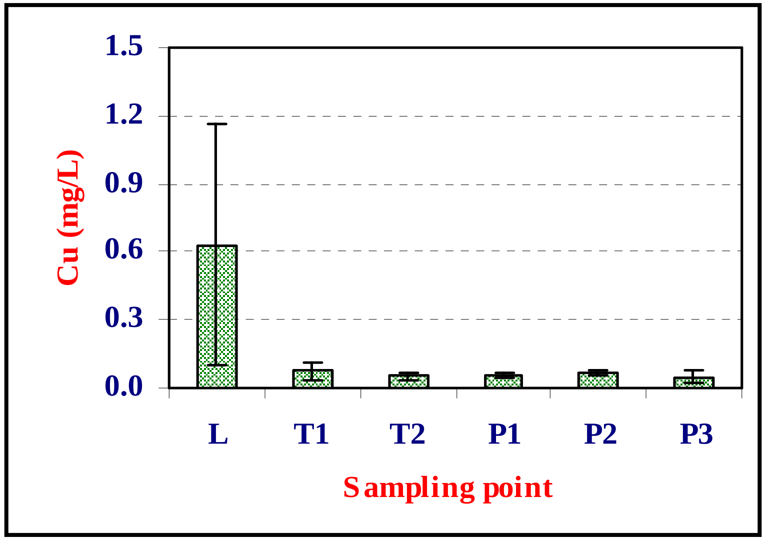
- Relatively low biodegradability of organic matter in pond P1-P3
- BOD, COD, TKN, Cr and Cu exceed the effluent standard

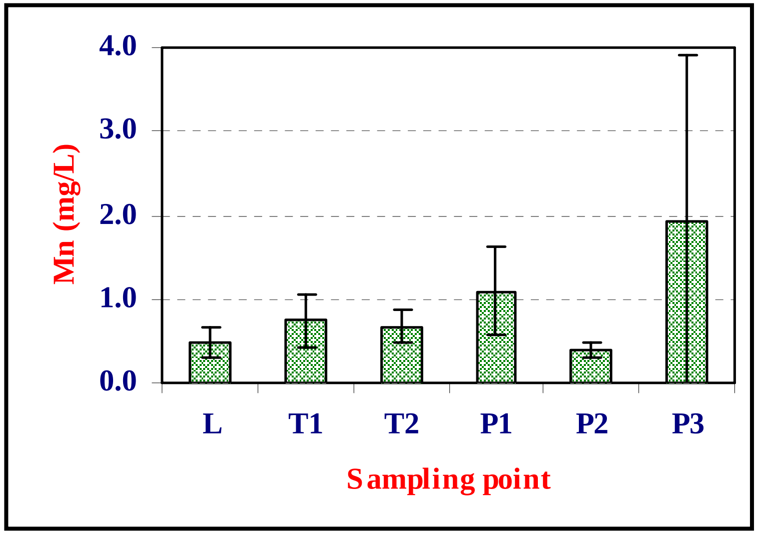
Average Leachate Quality in Dumpsite

Parameter	Leachate quality	Effluent Standard
pH	8.5	5.5-9.0
BOD (mg/L)	740	20
COD (mg/L)	4490	120-400
NH_4-N (mg/L)	620	-
TKN (mg/L)	800	100-200
Mn (mg/L)	0.886	5.0
Cr (mg/L)	0.667	0.25, 0.75
Cd (mg/L)	0.004	0.2
Pb (mg/L)	0.025	1.0
Ni (mg/L)	0.355	5.0
Zn (mg/L)	0.331	2.0
Cu (mg/L)	0.156	0.03
Hg (μg/L)	0.124	5.0

Variation of Heavy Metal Concentration in Dumpsite





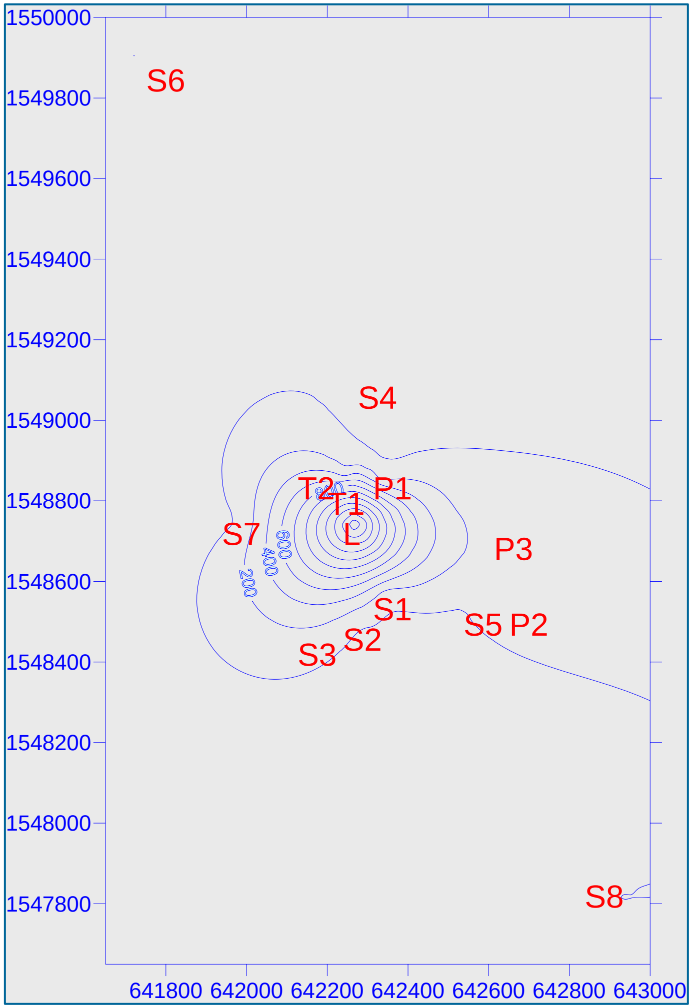


- Except for Mn, concentration of heavy metal decreased in T1,T2 and P1- P3
- Zn and Cu are in particulate and colloid, whereas Mn is expected to be in free ion form

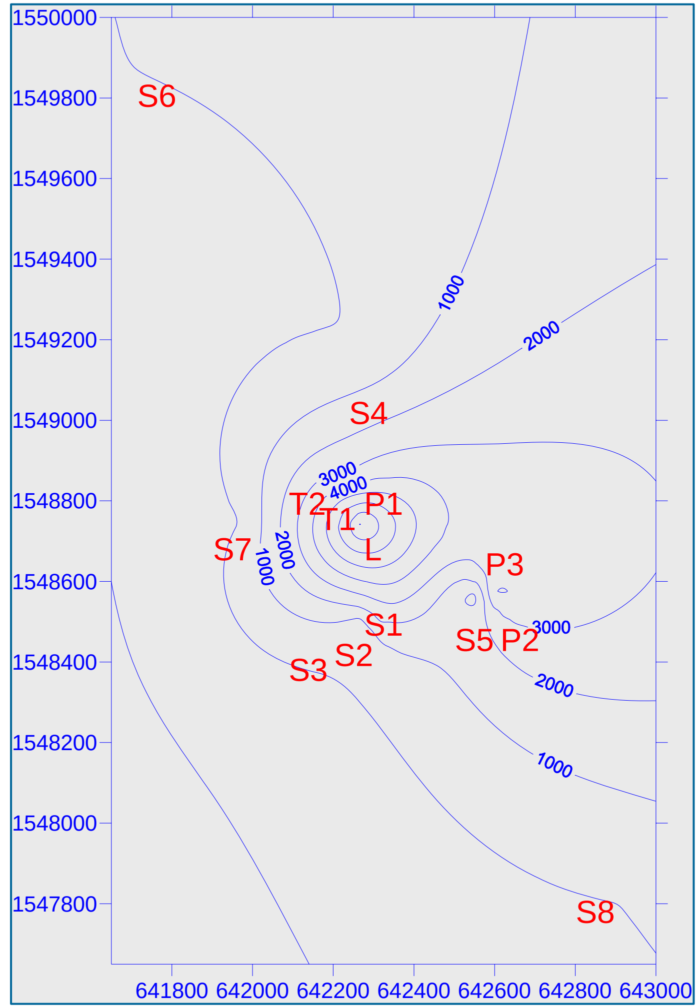
Surface Water Quality

Parameter	Surface Water	Surface Water Quality Standard	Drinking Water Quality Standard	
			USEPA	WHO
pH	8.0	5.0-9.0	6.5-8.5	6.5-9.5
BOD (mg/L)	83	4.0	-	-
NH_4-N (mg/L)	21	0.5	-	-
Mn (mg/L)	0.570	1.0	0.05	0.4
Cr (mg/L)	0.111	0.05	0.1	0.05
Cd (mg/L)	<0.002	0.005, 0.05	0.005	0.003
Pb (mg/L)	<0.01	0.05	ND	0.01
Ni (mg/L)	0.080	0.1	-	0.07
Zn (mg/L)	0.018	1.0	5.0	-
Cu (mg/L)	0.034	0.1	1.3	2.0
Hg (µg/L)	0.046	2.0	2.0	6.0

- Organic matter, ammonia, Mn, Cr and Ni exceed the surface water or drinking water quality standard
- However, high contamination of leachate was found in small ponds nearby the dumpsite



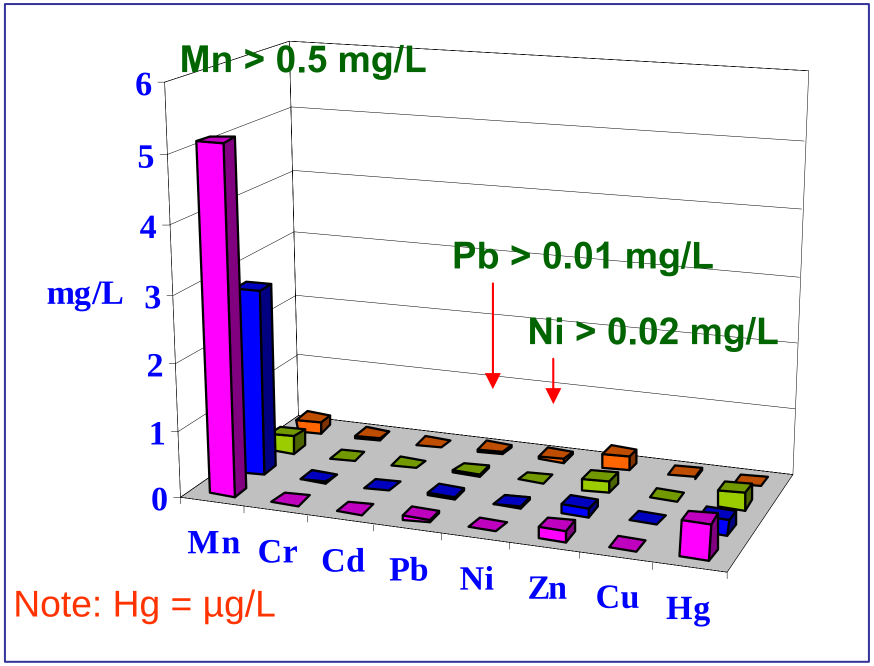
NH_3-N (mg/L)

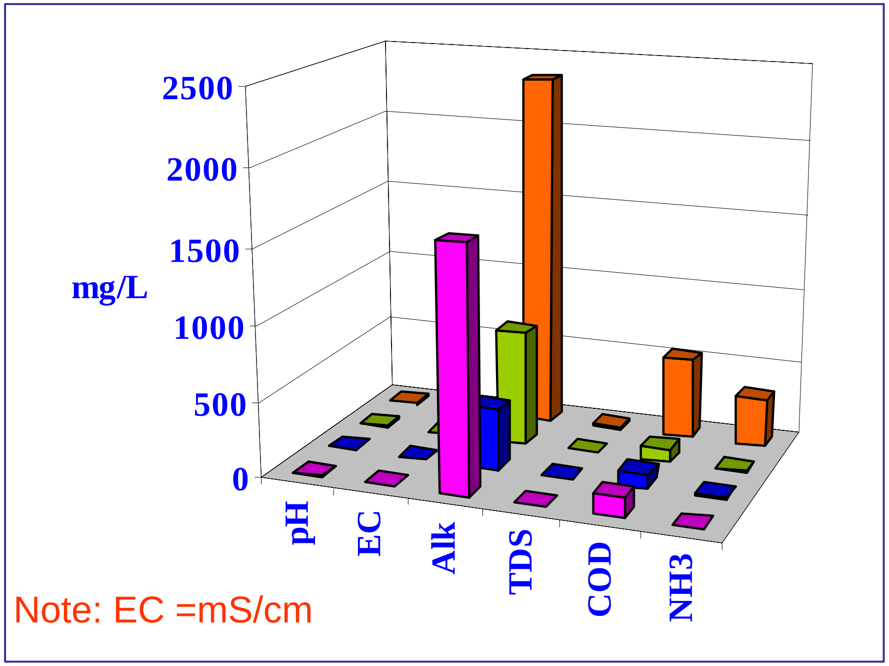


COD (mg/L)

Concentration of ammonia and organic compound (COD) in leachate and surface water resource

Groundwater Quality

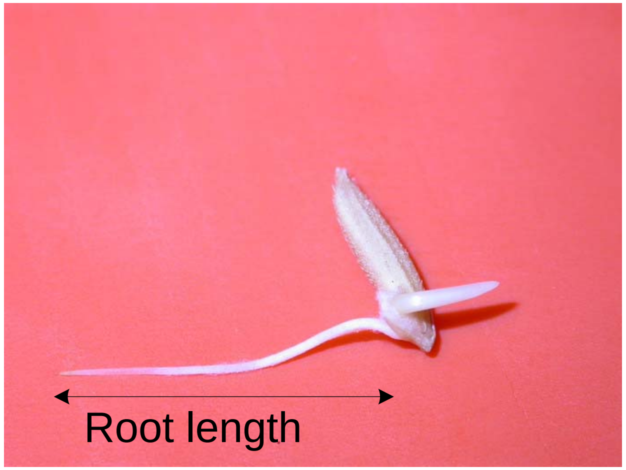




MW1 MW2 MW3 MW4

- High leachate contamination in groundwater was found at MW4
- Mn, Pb and Ni concentration exceeds the ground water and drinking water quality standard
- Leach of Mn from soil increases Mn concentration in groundwater

Toxic effect of leachate to germination and root elongation of rice



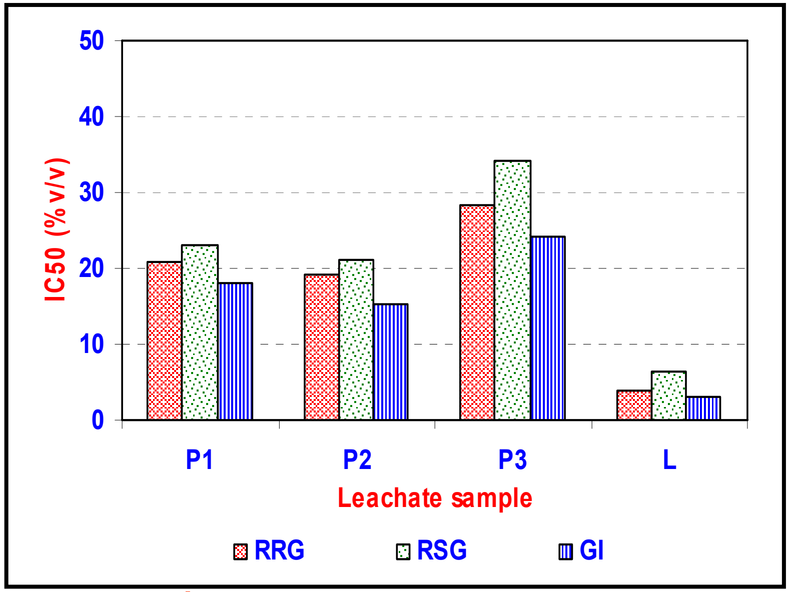
1. Relative seed germination (SGR) =

$$\frac{\text{No. of seed germinated in leachate}}{\text{No. of seed germinated in control}} \times 100$$

2. Relative root growth (RRG) =

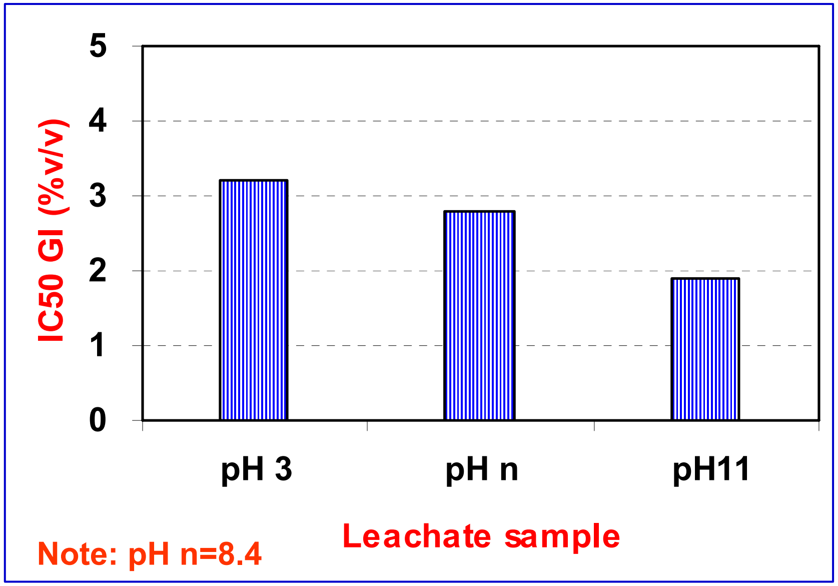
$$\frac{\text{Average root length in leachate}}{\text{Average root length in control}} \times 100$$

3. Germination index (GI) = $\frac{\text{SGR x RRG}}{100}$



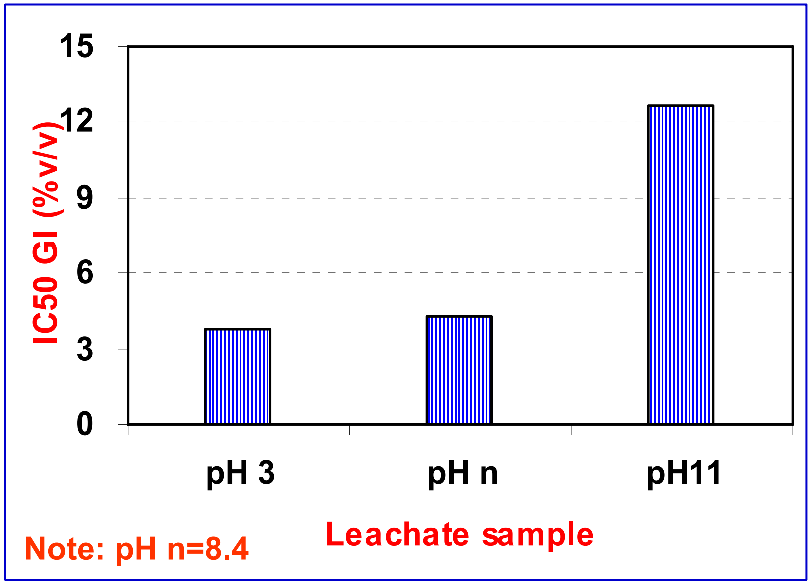
Source: Figure 4.1, page 61

- Germination rate, root elongation rate of rice can be inhibited by leachate
- Toxicity of leachate :
  Leachate runoff> P2,P1> P3



(a) pH adjustment test

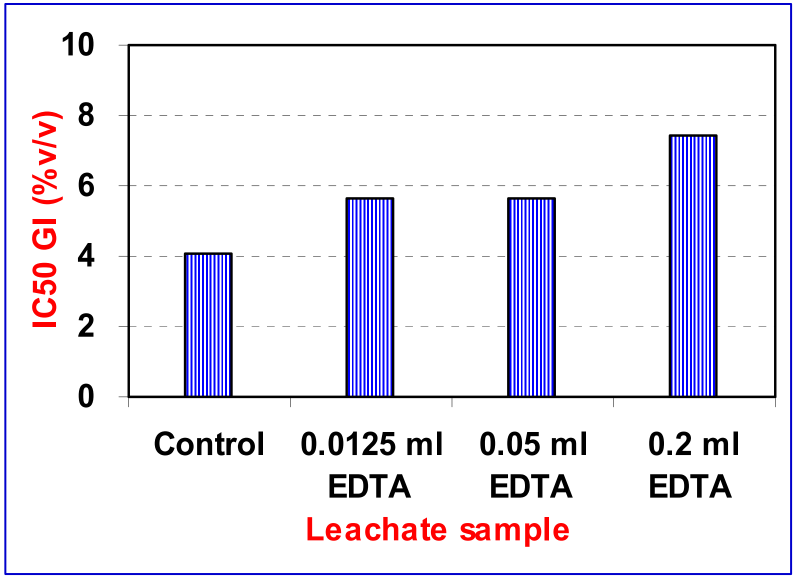
Source: Figure 4.11, page 62



(b) pH adjustment and aeration test

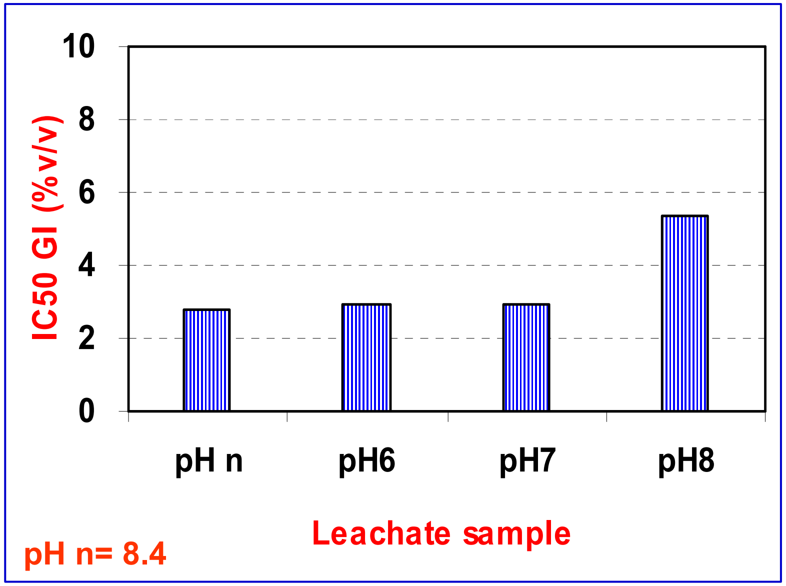
Source: Figure 4.12, page 63

- **Ionization of toxic compound affects the toxicity level of leachate**
- **Leachate toxicity increases at pH 11 and decreases at pH 3**
- **Toxicity of leachate is decreased in pH 11 to be aerated**
- **Unionized ammonia is toxic to germination and root elongation of rice**



EDTA toxicity test

Source: Figure 4.13, page 63



Graduated pH test

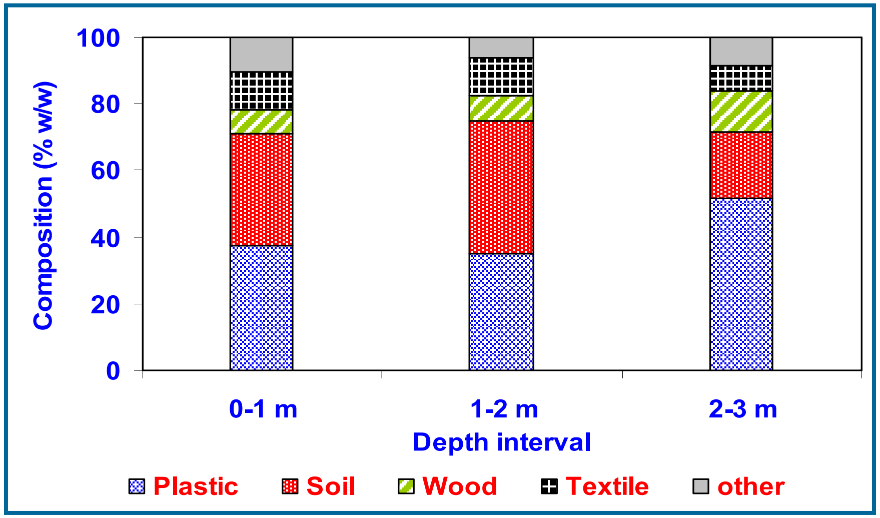
Source: Figure 4.14, page 64

- **High molecular weight EDTA reduces the bioavailability of heavy metal in plants**
- **Heavy metal content in leachate is able to inhibit the germination of rice**
- **The toxicity of leachate can also be affected from the pH change**

5. Results and Discussion: Recycling Potential of Solid Waste in Dumpsite

Waste Type	Composition % (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
Soil like material	21.7	33.7	21.9	46.3
Others	6.9	13.2	9.3	4.2

Source: Table 4.12, page 65



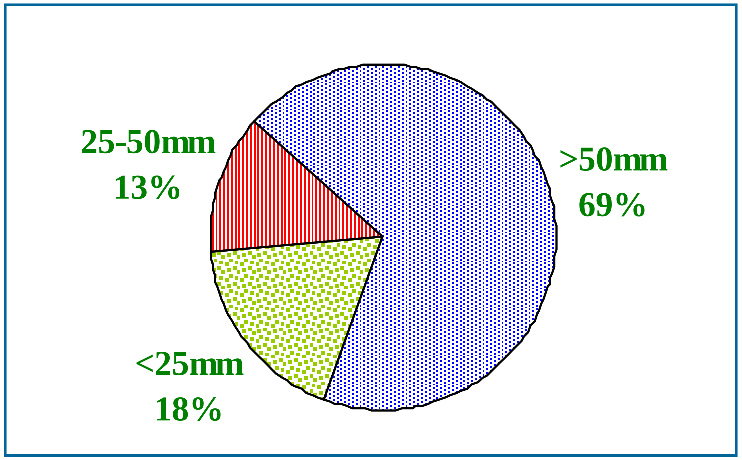
Source: Figure 4.15, page 66

Composition of Waste in Dumpsite

- Average 40% of plastic and 31% w/w of soil are the major composition of the excavated waste
- Approximate 16-28% of plastic was increased in dumpsite
- High plastic composition at 2-3m depth due to older solid waste age and higher biodegradation rate of waste

Size Distribution of Waste in Solid Waste Separating

Solid waste separation



Waste size distribution

Size < 25mm

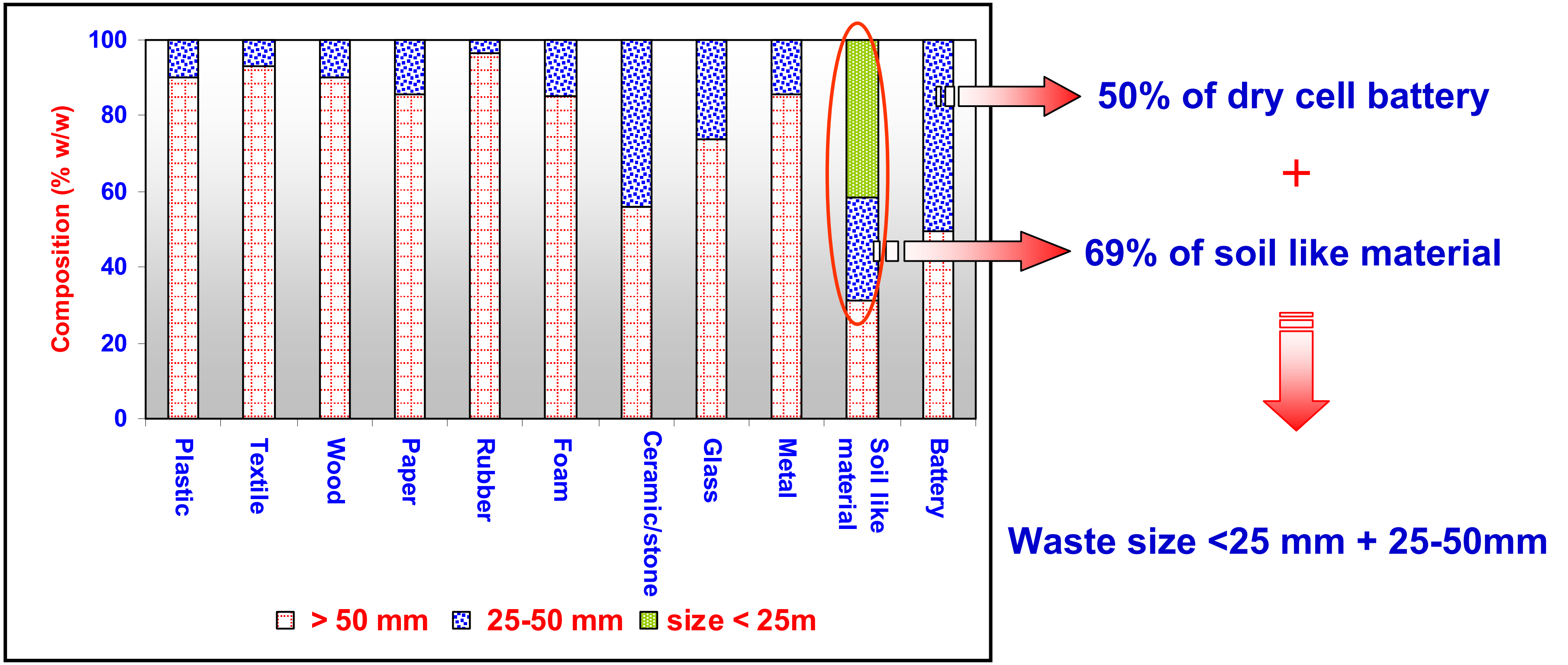
Size 25-50mm

(14% plastic, 47% soil)

Size > 50mm

(34% plastic, 14% soil)

Size Distribution of Waste in Solid Waste Separation



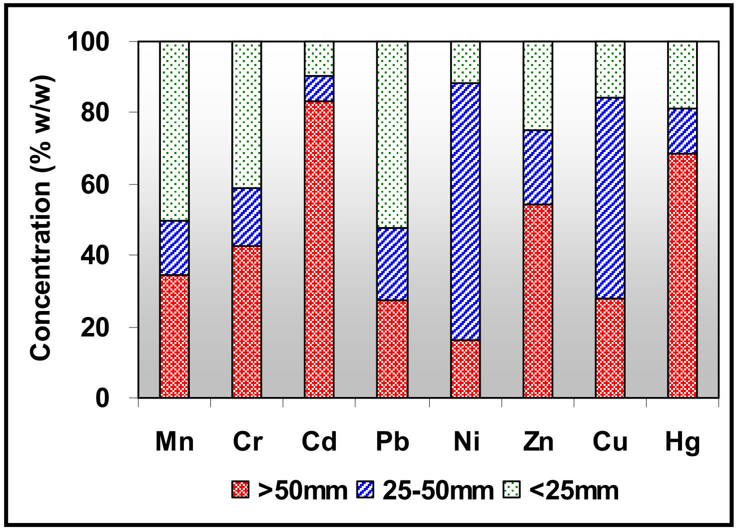
Source: Table 4.18, page 69

- Most of fraction of plastic, textile, wood, rubber was left in the waste size > 50mm
- Approximate 90% plastic can be recovered in the waste size > 50mm

Heavy Metal Content in Various Waste Size

Waste size	Mn	Cr	Cd	Pb	Ni	Zn	Cu	Hg
	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	µg/kg
< 25 mm	947	167	4	130	50	1500	2245	1080
25-50mm	370	96	4	70	390	2070	12350	1060
>50mm	156	44	8	20	16	790	1260	970
Composite	310	70	7	45	70	1000	3000	975

Source: Adapted from Figure 4.19 ,page 70



Source: Figure 4.20, page 71

Heavy metal concentration in composite waste $= \frac{\sum_i CijPi}{\sum_i Pi}$

- **Except for Cd, separate out of waste size < 25mm and 25-50mm can reduces concentration of the heavy metal in waste size > 50mm**
- **Amount of Cd, Zn and Hg is mostly in waste size >50mm**

Waste Size > 50 mm Recycle as Fuel

Waste size	Calorific value	Ash	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
>50mm	36	33	156	44	8	17	16	790	1260	970
Plastic	-	30	107	43	2	43	21	313	151	297
EURITS[a]	15	5	200	200	10	200	200	500	200	2000

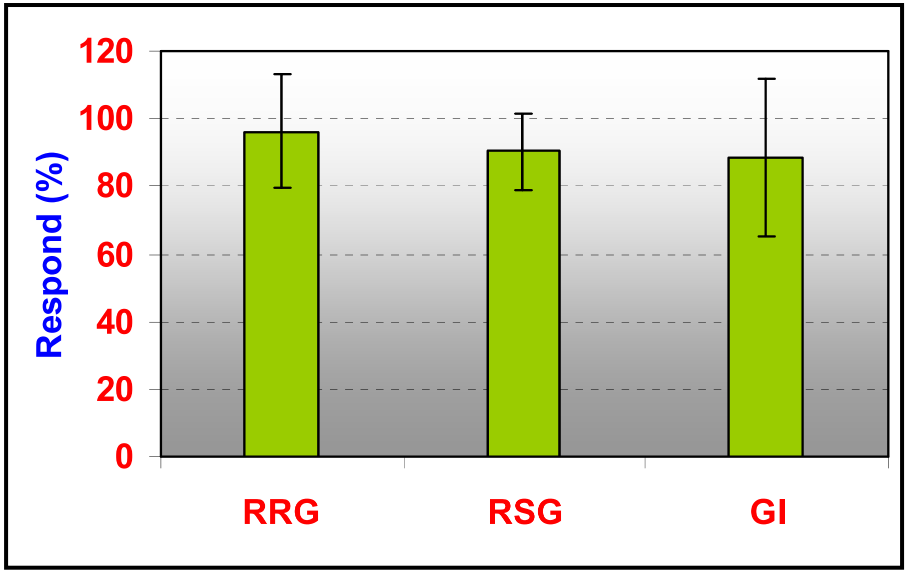
[a] Quality standard of the waste recycled in the cement plant
Source: Adaptation from Table 4.13 and Table 4.14, page 74

- **Waste size > 50mm is unsuitable to be recycled as fuel directly**
- **Recycle the plastic waste from this waste as fuel is suitable**
- **However, ash content in the plastic waste is still high**

Waste Size < 25mm Recycle as Compost

Parameter	Waste < 25mm	Compost standard
pH	7.7	5.5-8.5
EC (mS/cm)	2.6	≤ 3.5
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	-
Cr (mg/kg)	167	≤ 300
Cd (mg/kg)	4.2	≤ 5.0
Pb (mg/kg)	130	≤ 500
Ni (mg/kg)	50	-
Zn (mg/kg)	1500	-
Cu (mg/kg)	2245	≤ 500
Hg (µg/kg)	1080	≤ 2000

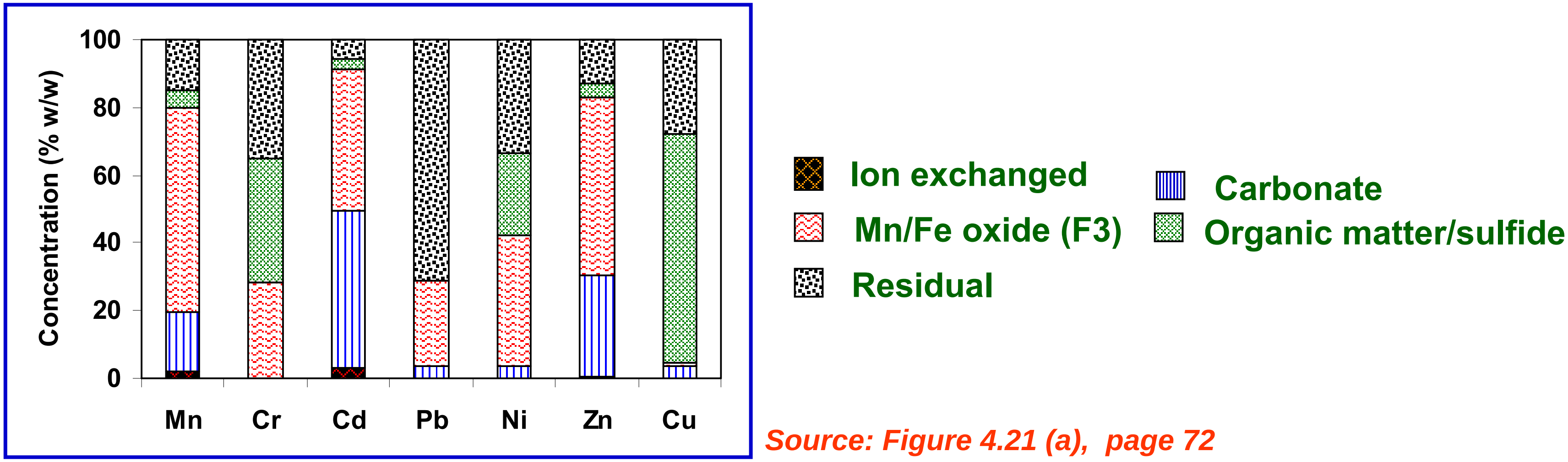
Source: Table 4.15; page 75



Source: Figure 4.22 page 75

- Degradation of organic matter is complete
- Cu concentration exceed the limited concentration in the compost standard, while N and K are relatively low
- However, toxicity of soil is relatively low (GI> 80%)

Binding Form of Heavy metal in Waste size <25 mm



Source: Figure 4.21 (a), page 72

Waste size < 25mm

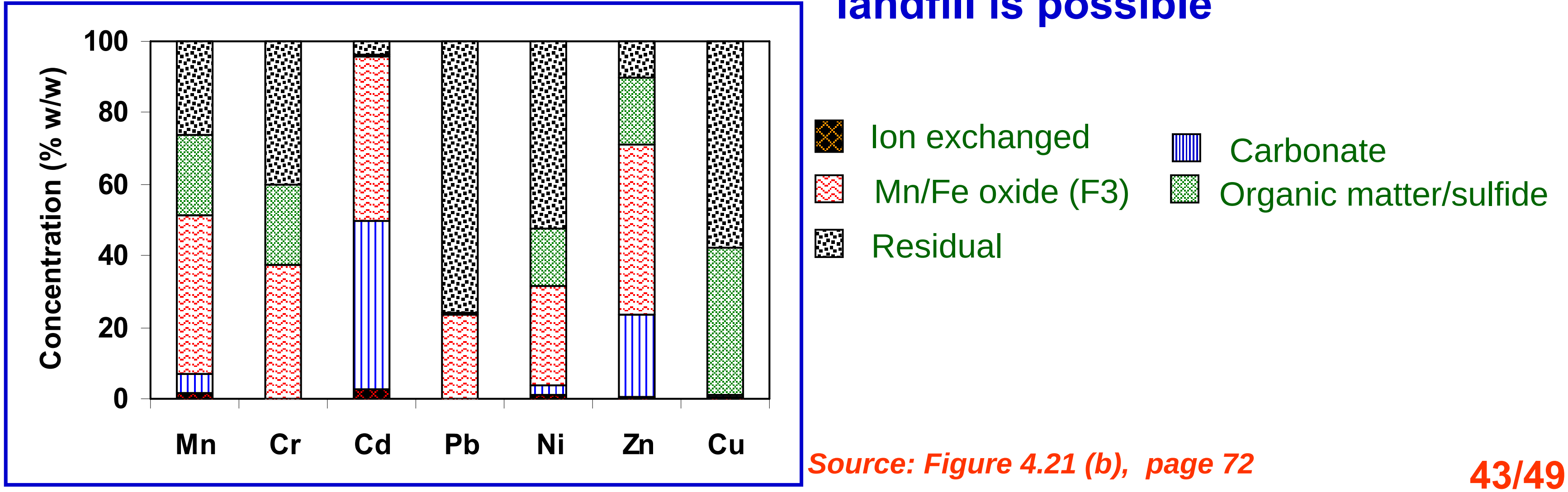
- Cu and Cr in waste size < 25mm are adsorbed on organic matter which reduces the bioavailability and toxicity of these metal in plant
- Residual fraction of metal in waste size < 25mm: Pb> Ni, Cr> Cu> Mn, Zn>Cd
- Cd is mainly precipitated with carbonate compound
- Mn, Zn and Ni are mainly adsorbed on Mn/Fe oxide

Leaching Potential of Metal from Waste Size 25-50 mm

Metal	25- 50 mm	U.S. TCLP standard
Mn (mg/L)	0.514	-
Cr (mg/L)	0.006	5.0
Cd (mg/L)	0.001	1.0
Pb (mg/L)	0.011	5.0
Ni (mg/L)	0.043	-
Zn (mg/L)	0.283	-
Cu (mg/L)	0.055	-
Hg (mg/L)	<0.001	0.2

Source: Table 4.16, page 77

- Higher concentration of Mn and Zn due to its high concentration, acid solubility and reduction reaction of Mn/Fe oxide
- Leaching of heavy metal from these wastes is in acceptable level
- Disposal of this waste into the MSW landfill is possible



Source: Figure 4.21 (b), page 72

6.Conclusions and Recommendation

Conclusion

- Variation of solid waste characteristic was found in dumpsite
- Zn, Cu and Mn was found to have higher concentration and leaching potential than other metal
- Variation of age & biodegradation rate of waste affects the leaching of heavy metal from dumpsite
- Reducibility property of metal and organic compound increase mobility of heavy metals in dumpsite

- High contamination of leachate in surface water and ground water resource nearby the dumpsite
- pH, heavy metal and unionized ammonia are important toxicants in leachate to the germination of rice
- Recycling the plastic as raw material for RDF production and waste size < 25mm as compost are possible
- Non biodegradable waste size 25-50 mm can be disposed into MSW landfill

Recommendations

- Leachate and solid waste management system in dumpsite need to be improved
- pH , ammonia, and heavy metal content in leachate should be control to protect the environmental toxic impact from dumpsite
- Source separation of solid waste at source should be encouraged to reduce the amount of plastic and heavy metal disposal
- Agricultural area may be used as criteria in site selection of landfill establishment
- Future research on the toxic effect of leachate to growth rate and productivity of rice
- Economical evaluation of dumpsite mining should be done before implementing dumpsite mining

7. Contribution to MSW Management

- **Determination of solid waste composition in dumpsite shows tendency of plastic and household hazardous waste to be accumulated in dumpsite**
- **The high concentration of Zn, Cu and Mn with its high leaching mobility is considered as a cause of contamination of these metals in the environment**
- **Moreover, investigation of dumpsite shows potential toxic impact of pH, ammonia and heavy metals content in leachate from dumpsite**
- **Excavation of the stabilized dumpsite to recycle plastic as fuel and reuse soil as compost can be done to reduce the environmental impact from dumpsite**
- **The trommel screen with open size of 25 and 50mm can be used in solid waste separation.**

8. International Publication

Publication Paper

Prechthai, T., Parkpian, P., Visvanathan, C. (2008). Assessment of heavy metal contamination and its mobilization in municipal solid waste dumping site, *Journal of Hazardous Material*, 156, 86-94.

Prechthai, T., Padmasri, M. and Visvanathan, C. Recycling potential of mined municipal solid waste from an open dumpsite, *Journal of Resource Conservation and Recycling.* (In final revision).

Conference

Prechthai, T., Visvanathan, C. and Cheimchaisri C. (2006). RDF production potential of municipal solid waste. In proceeding of the 2 th Joint International Conference on Sustainable Energy and Environment (SEE2006), Bangkok.

Thank you for your attention