CHAPTER III

METHODOLOGY

The study methodology was divided into three parts as follows; landfill site characterization; adsorption and transport of heavy metals in soil and simulation of heavy metal transportation.

3.1 Landfill Site Characterization

This study was divided into three steps as follows:

3.1.1 Preliminary Framework

The objective of this step was to study the existing site conditions to understand soils, geology and hydrogeology in the study area. The previous works were reviewed as well as site visit was surveyed and planned for the next study.

3.1.2 Landfill Site Characterization

The goal of this step was to describe and evaluate the site geology and hydrogeology, including all stratigraphic units encounters the uppermost aquifer and all other potential zones of contaminant transport. The study methodology followed a sequence of five steps as described below (Figure 3.1).

3.1.2.1 Data gathering. Information was sourced out from geological reports, archived materials, aerial photographs and map interpretation.

3.1.2.2 Reconnaissance. Reconnaissance of the landfill site and adjacent areas was done by pacing, so as to plan the location of boreholes for the subsurface investigations.

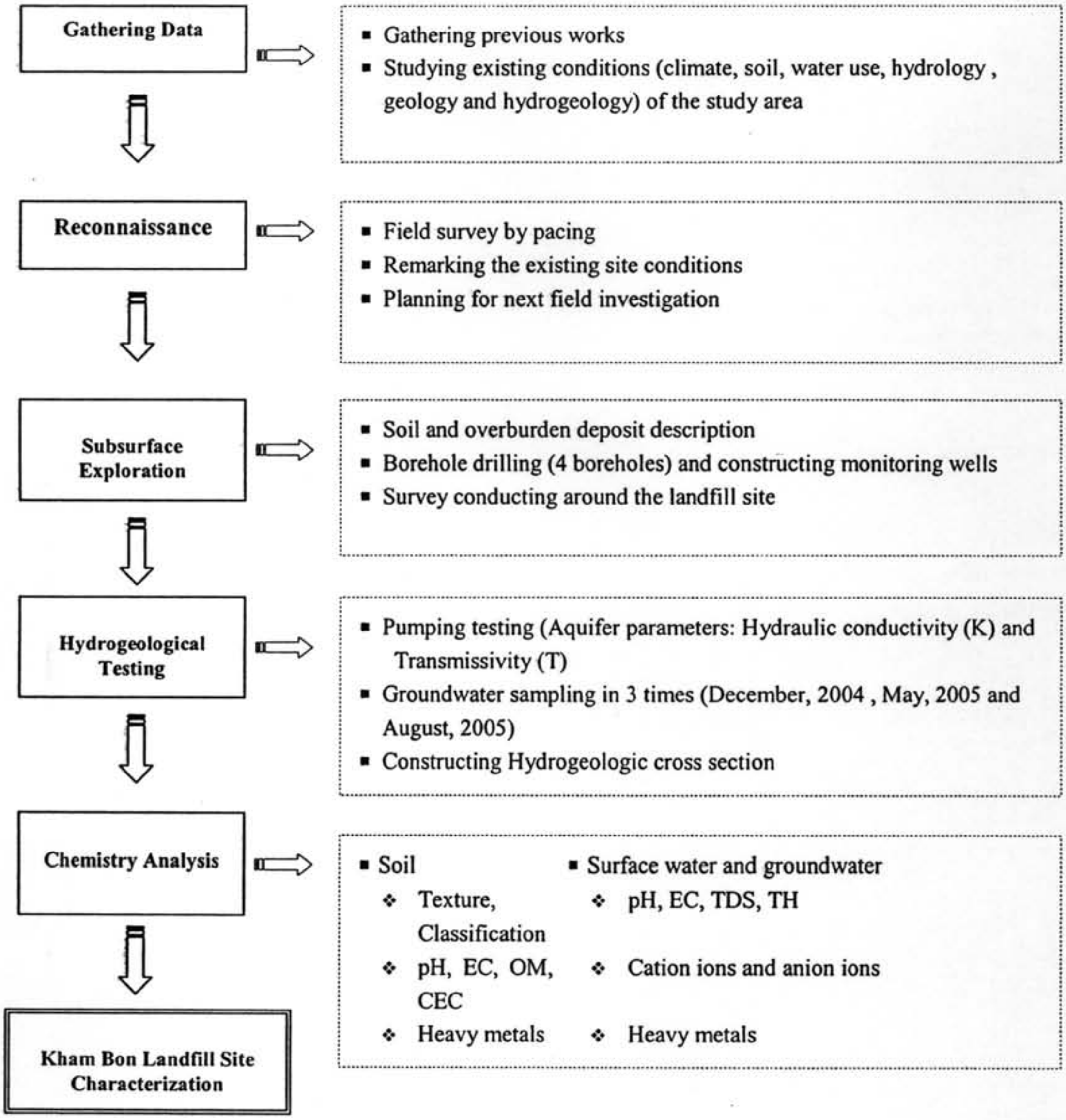

Figure 3.1 Flow diagram of field and laboratory investigation

3.1.2.3 Subsurface investigation. The subsurface investigation was conducted in December 2004. Four boreholes were drilled down to 7 metres depth, to investigate soil profiles, stratigraphy, and the nature of the groundwater. Only 3 groundwater wells (MW-5, MW-6 and MW-7) were constructed and used for monitoring groundwater fluctuation. Moreover, hydrogeochemistry was also performed.

3.2.1.4 Hydrogeological testing. The hydrogeological testing of the completed wells was by pumping to identify the hydraulic characteristics of the aquifer, including hydraulic conductivity and transmissivity. The hydrogeological cross section was constructed from lithological data and interpretation of drilled cuttings.

3.2.1.5 Soil and water chemistry analysis. In the final step, soil, surface water and groundwater samples from the landfill site and surrounding areas were collected and analyzed for typical parameters that could indicate the influence of the landfill leachate.

3.1.3 Sampling Strategy and Analysis

A sampling strategy was designed on the basis of site history and reconnaissance information. The most important part is to establish the geologic variability/uniformity unit so as to obtain the experimental data needed to achieve the landfill site characterization. Soils, leachate, surface water and groundwater up and down gradient of the landfill site were collected. The first sampling was conducted on 12-13 December, 2004 during the dry, winter season. The second set of samples was collected on 14-15 May, 2005 during the peak dry period. The final samples were taken on 25-26 August, 2005 during the rainy season.

Sampling was undertaken three times per year along the direction of the leachate movement to monitor the seasonal fluctuation in the concentration of contaminants from the landfill. The detailed sampling strategy is composed of soil samplings, water and groundwater samplings which are described as followed:

3.1.3.1 Soil Samplings

From the aerial photograph and topographic map interpretation, 24 locations were selected for soil samplings. The samples were collected at a depth of 15 cm below the ground surface within a radius of 1,500 meters from the landfill site and its surrounding area covering Kham Bon village. The results of this sampling were used to design the detailed sampling strategy.

The second sampling, 38 soil samples were collected. Two samples were collected, one each at depths of 15 cm and 30 cm at each point from a random square

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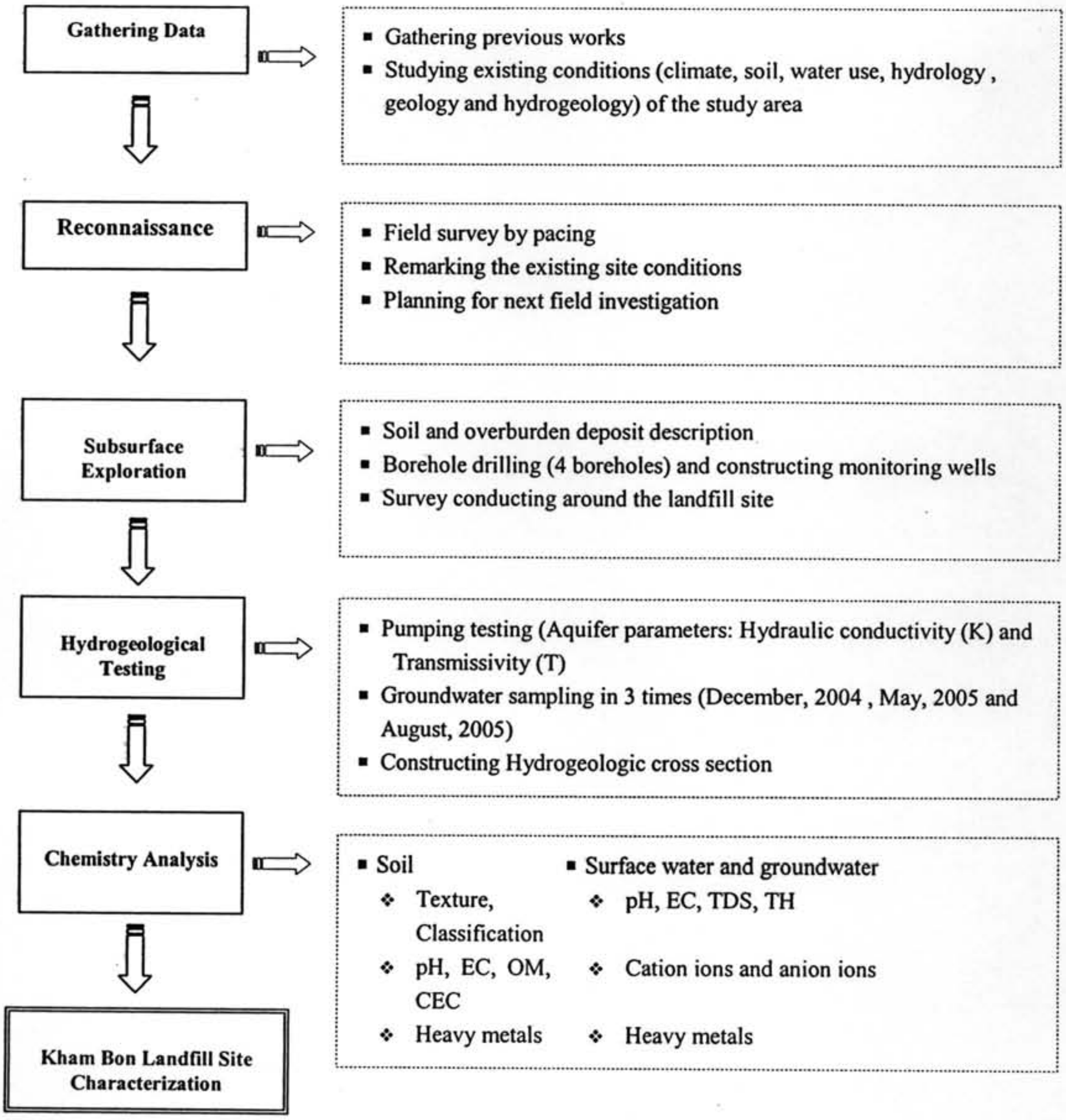

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The second sampling, 38 soil samples were collected. Two samples were collected, one each at depths of 15 cm and 30 cm at each point from a random square grid on a circle within successive radii of 500 metres, 1,000 metres, 1,500 metres and 2,000 meters away from the landfill. The samples were closely spaced near the landfill site and along the ditch but spaced less closely with increasing distance from the site. Sam Chan village was included in this sampling to study the distribution of heavy metals falling within a radius of 2,000 metres.

For the third sampling, 36 soil locations considerably polluted by leachate were sampled at several depths. This third sampling was designed to obtain the spatial distribution of the contaminant concentrations both laterally and as a function of depth. The sample locations were selected from significant concentration of heavy metals revealed in the site as well as from the surface drainage in the study area. The samples were collected by hand auger from 3 depth intervals below the ground surface: 0 to 30 cm; 30 to 60 cm; and 60 to 90 cm. The zone of 0 to 30 cm depth is regarded as the *disturbed zone I* because within that range, farmers have used ploughs with small ploughshares (≈ 20-25 cm long) for cultivating crops whereas the zone of 30 to 60 cm is regarded as the *disturbed zone II*. This is because farmers have used ploughs with big ploughshares (≈ 45-50 cm long) during cultivation. The depth below 60 cm was determined as the zone of natural or artificially undisturbed soil. These soil samples were analyzed as a composite sample in each depth interval.

The soil samples collected from the landfill site and adjacent area were air-dried and ground to pass through a 2-mm stainless steel sieve to remove gravel and rock, then were homogenized and stored for subsequent analysis. The following physical and chemical properties of the soil samples were determined (Table 3.1): particle size distribution (PSD); pH; electrical conductivity (EC); organic matter (OM) and cation exchange capacity (CEC). The PSD was measured and classified using a Standard US Department of Agriculture soil textural classification triangle (USDA classification). The soil pH was found from a 1:1 H_2O dilution using electrode (pH meter Model HM-5ES). EC was measured by using a conductivity meter (Conduct meter Model CM-78). OM was determined by the wet oxidation method of Walkley and Black (Black, 1965). Finally, the CEC was estimated by the 1 M NH_4OAC method. For background concentration of metal analyses, soil samples were digested in acid following method 3050 B. All digested soil samples were analyzed in a Shimadzu AA 6501F Series Flame Atomic Absorption (FLAA) Spectrophotometer.

The chemical and mineralogical compositions of prepared soil samples were determined by using an Axios XRF spectrophotometer. XRD was performed on soil samples using a Bruker D8 Tools Advance diffractometer with Cu-Ka radiation, 40 kV-40 mA, and scan speed of 0.02 Q/s and 2 seconds per step in the range of 2θ from 2° to 70°. For metal analyses, soil samples were digested in acid following method 3050 B (United States Environment Protection Agency, 1995). All digested soil samples as well as groundwater samples and surface water samples were analyzed in a Shimadzu AA 6501F Series Flame Atomic Absorption (FLAA) Spectrophotometer. The limits of detection at the time of measurements were computed as the concentration equal to three times of the standard deviation (3σ) of a series of the measurement of a procedural blank solution, and the value is shown in Table 3.2.

Table 3.1 Physico-chemical analyses of soil samples

Properties	Testing	Method
Physical	Classification	USDA
	Natural Moisture Content	Gravimetric method
	Mineral Composition	XRD/XRF
Chemical	Soil pH	Std. Glass Electrode
	Cation Exchange Capacity (CEC)	NH_4OAc 1 N pH 7
	Electrical Conductivity (EC)	Conductivity meter
	Organic Matter Content (OM)	The Walkley-Black wet oxidation

Table 3.2 Detection limit of each metal for AAS analysis

Heavy metals	Detection Limits ($\mu g\ L^{-1}$)
Cd	4
Cr	50
Cu	10
Pb	900
Zn	10
Fe	50
Mn	50

The statistic analysis was performed by using Spearman's rank correlation coefficient, in SPSS 15.0 for Windows Evaluation Version, to test for a significant association between variables. The correlation between soil properties (clay fraction, pH, OM, CEC) and seven metals (Cr, Cd, Cu, Pb, Zn, Fe, and Mn) were calculated. The contour maps were generated by surfer 7.0 from Golden software.

3.1.3.2 Surface Water and Groundwater

The impact of contaminated landfill leachate on surface water and groundwater was also studied. The groundwater samples were collected from the monitoring wells by submersible pump during the winter, summer and rainy seasons. The surface water samples were obtained by direct collection into the 1000-ml polyethylene bottles. Aliquots for trace element analysis were acidified with HNO_3 to pH 2 before filtration through Whatman® No. 42 filter paper. For cations and anions analysis, subsamples of groundwater and surface water samples were filtered at the point of collection using 0.45 μm membrane filters. All samples were stored at a temperature of 4 °C prior to analysis.

For surface water and groundwater samples, the physical and chemical parameters were determined (Table 3.3); such as pH, specific electrical conductivity (EC); total dissolved solids (TDS) and total hardness as well as concentration of major cations (Na^+, K^+, Ca^{2+}, Mg^{2+}) and anions (Cl^-, NO_3^-, HCO_3^-, CO_3^{2-}, SO_4^{2-}). The levels of seven metals: Cd; Cr; Pb; Zn; Cu; Fe and Mn, were also analyzed using AAS analysis.

Table 3.3 Physico-chemical analyses of all liquid samples

Type of Sample	Field Indicator	Laboratory indicator	Cations and Anions	Heavy Metals
Landfill leachate	pH Electrical Conductivity	COD/BOD TDS TOC	Na^+ K^+ Ca^{2+} Mg^{2+} Cl^- NO_3^- SO_4^{2-} PO_4^{3}	Cr Cd Pb Cu Zn Fe Mn
Surface water and groundwater	pH Electrical Conductivity Water table (groundwater)	Hardness TDS Alkalinity	Na^+ K^+ Ca^{2+} Mg^{2+} Cl^- NO_3^- SO_4^{2-} PO_4^{3}	Cr Cd Pb Cu Zn Fe Mn

The physical properties of groundwater and surface water samples were analyzed following the American Public Health Association (APHA) Standard Methods, (1992). For the analysis of dissolved ions, a Dionex DX-100 and a ICS-1000 Ion Chromatograph were used to determine the concentration of cations and anions, respectively.

3.2 Adsorption and Transport of Heavy Metals in Soil

The metal partitioning analyses were conducted according to the EPA procedures (Roy et al., 1991) and ASTM standard (ASTM, 1993). All adsorption experiments were run in triplicate and at the controlled temperature of 25±0.5 °C.

3.2.1 Materials and Reagents

Three subsurface soil samples (0-30 cm depth) collected from the Kham Bon landfill site and adjacent area on the basis of their physical and chemical properties were used in this study. The soil samples were air-dried and ground to pass through a 2-mm stainless steel sieve to remove gravel and rock, then were homogenized and stored in plastic bags for subsequent analysis. For background concentration of metal analyses, soil samples were digested in acid following method 3050 B.

The leachate used for this research was collected from the leachate collection system of the Kham Bon landfill in operation. Sodium azide (NaN_3 0.1% arbitrarily) was used to suppress the biological activity at site and samples were stored at 4 °C. The natural content of heavy metals in the leachate was at very low to low concentration. Therefore, in order to study the speciation of heavy metals in landfill leachate, the leachate was spiked with heavy metals to obtain concentrations ranging from 0.1, 0.2, 0.5, 1.0, 2.0, 5.0, 10.0, 20.0, and 50 mgL^{-1} for all heavy metals. These concentrations were designed from the range availability to be found at any landfill site in Kham Bon.

Synthetic leachate was prepared as a reference solution to mimic the composition of the actual landfill leachate with respect to the concentration of heavy metals and ionic strength. A 1000 mgL^{-1} stock solution of each heavy metal was prepared from ; $Cu(NO_3)_2 \cdot 3H_2O$; $Cd(NO_3)_2 \cdot 4H_2O$; $N_2O_6Zn \cdot 6H_2O$; $Pb(NO_3)_2$, and

$K_2Cr_2O_7$.Various concentrations of heavy metals were prepared in buffer Tris pH 8.16 to maintain the initial pH of landfill leachate in all experiments. Moreover, 0.01 M $Ca(NO_3)_2$ as background electrolyte and 0.1 % sodium azide were added to each aliquot of these solutions to mimic actual landfill leachate conditions. The background electrolyte solution was used to simulate natural soil conditions where there is often a large excess of Ca ions. The initial and pH values were systematically controlled. Prior to the analysis, each sample was digested with concentrated HNO_3 and HCl (1:1) according to the US EPA 3010 A standard method. In these experiments, de-ionized water taken from a standard laboratory was used throughout as well as analytical grade reagents (Merck™) were used in all cases.

Before use, all glass and plastic equipments used during the sampling, and analysis were soaked in 10% HNO_3 24 hr and carefully rinsed in deionized water.

3.2.2 Batch Adsorption Experiment

3.2.2.1 Preliminary Experiment

The test was done to decide on an equilibration time for the Heavy metals solutions. The soil: solution was prepared following the ratio of soil weight to solution volume as shown in Table 3.4. A series of solid: solution ratio was mixed with leachate solution containing 10 mgL^{-1} of each metal and shaken in an orbital shaker at 200 rpm with different time interval until equilibrium was reached. The pH did not control and only equilibrium pH values were record. At the end of designed time, the soil suspension was centrifuged at 10,000 rpm for 20 min and the supernatant liquid was separated, filtered and the soluble heavy metals determined using Atomic Absorption Spectroscopy (AAS). Before using the spectrophotometer, all samples had to be prepared in a standard way to break down their complex bonds. The standard method, EPA method 3010 A was used for sample preparation. The differences between initial heavy metals concentration and equilibrium heavy metals concentration was assumed to be the amounts sorbed by the Kham Bon landfill soil. Sorption isotherms were fitted to the various isotherm equations and distribution coefficients were calculated. The total amount of heavy metals retained by the soil was calculated by the difference between the initial and final concentration of heavy metals in each solution. The percentage metal removal was plotted against shaking time, and the steady state was obtained.

3.2.2.2 Sorption Experiments

Soil with a solid to solution ratio of 1:30 was equilibrated in polypropylene bottles such that each 30 ml aliquot of actual landfill leachate contained 1 g of soil. The synthetic leachate including 0.01 M $Ca(NO_3)_2$ in Tris buffer contained variable heavy metal concentrations ranging from 0 to 50 mgL^{-1} for each heavy metal (Table 3.5). The initial pH was set at 8.16 using 0.1 M NaOH or 0.1 HNO_3 and the change of pH was monitored. The suspension was shaken on an orbital shaker operated at 200 rpm for 48 hr based on preliminary experiments. The final pH was recorded and the sample was then centrifuged in plastic centrifuge tubes at 10,000 rpm or 10733 x g for 20 minutes and the clear supernatant was collected in polyethylene bottles and then acidified with 1 % nitric acid and stored at 4 °C until metal analysis. Before using the spectrophotometer, all samples had to be prepared in a standard way to break down their complex bonds. The standard method, EPA method 3010A was used for sample preparation. The differences between initial heavy metals concentration and equilibrium heavy metals concentration was assumed to be the amounts sorbed by the Kham Bon landfill soil. Sorption isotherms were fitted to the various isotherm equations and distribution coefficients were calculated.

Table 3.4 Experimental conditions design for preliminary study

Heavy Metals	**The Experimental Design**			
	Soil: Solution Ratio	**Initial Concentration (mg/l)**	**Contact time**	**Shaking Speed (rpm)**
Monometal (Cr, Cd, Pb, Cu, Zn)	1g : 30 ml (1:30)	10	15 min, 30 min, 1,2,4,6,12,18,24,36, 48, 60, 72, 84, 96 hr	200

3.2.2.3 Desorption Experiment

In order to evaluate the reversibility of heavy metals sorbed onto contaminated soil, their desorption characteristics were also determined. Deionized water was assumed as infiltration water to extract heavy metals from contaminated soil. Solid residues remaining in the centrifuge tubes after sorption experiments both in monometal and mixed metals were thoroughly wash with deionized water and the supernatant discarded immediately after 20 minutes of centrifugation (10,000 rpm). Washed residues were treated with 30 ml of deionized water as leaching solution and the slurries were shaken on an orbital shaker for 48 hr. Slurries were centrifuged and their supernatants were taken and analyzed for metal concentrations as described above for the sorption experiment.

Table 3.5 Experimental conditions design for sorption study

Heavy Metals	The Experimental Design			
	Soil: Solution Ratio	Concentration (mg/l)	Contact time	Shaking Speed (rpm)
Monometal (Cr, Cd, Pb, Cu, Zn) Actual leachate/ Synthetic leachate	1g : 30 ml	0.1,0.2,0.5,1,2,5,10, 20,50	48 hr	200
Mixed metal (Cr, Cd, Pb, Cu, Zn) Actual leachate/ Synthetic leachate	1g : 30 ml	0.1,0.2,0.5,1,2,5,10, 20,50	48 hr	200

3.2.2.4 Sequential extraction of sorbed metals

After the end of batch experiment, the isotherm of metal and mixed metals was obtained. As a consequence, the study of the portioning profiles in accordance with the affinity sequences of heavy metals was deduced from the initial slope of isotherms. The same conditions as batch test was set corresponding to the high affinity zone (Figure 3.2) which obtained by intersecting the tangents arising from the origin and from the plateau of the isotherms. Suspension was centrifuged for 10 minutes at 10,000 rpm and the supernatant was discarded. The residue sample was washed with deionized water to remove the dissolved metals trapped in the soil sample. The washing was disposed and the remaining residue was air-dried and stored for heavy metals distribution using the sequential extraction procedure.

The Selective Sequential Extraction (SSE) Method was used to extract heavy metals from natural soil and the sorbed metal at the high affinity zone which obtained from adsorption isotherm (Table 3.6). It can be divided in to five stages as follows (Tessier et al., 1979).

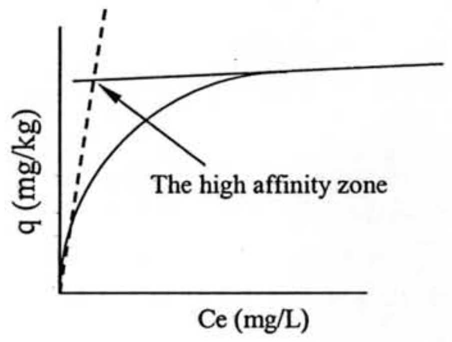

Figure 3. 2 The high affinity zone obtained from initial isotherm

Table 3.6 Sequential extraction procedure for speciation of heavy metals

Fraction	Partition	Reagents
I	Exchangeable	1.0 M $MgCl_2$
II	Carbonate-bound	1.0 M NaOAc
III	Fe-Mn oxides-bound	0.04 M $NH_2OH.HCl$ in 25 % acetic acid (vol/vol)
IV	Organic-bound	*i.* 0.02 M HNO_3 + 30 % H_2O_2 (vol/vol) *ii.* 30 % H_2O_2 *iii.* 3.2 M NH_4OAc in 20 % HNO_3 (vol/vol)
V	Residual	▪ HF ▪ $HClO_4$ ▪ 12 M HCL

1. ***Exchangeable*** **:** This stage is designed to release heavy metals retained via cation exchange mechanisms. Soil extracted with 8 ml of pH 7, unbuffered, 1.0 M $MgCl_2$ with continuous agitation for 1 h at 25 °C.

2. ***Carbonate*** : The purpose of this stage is to release metals which precipitated with carbonate. Residue from exchangeable extracted with 8 ml of pH 5, 1.0 M NaOAc with continuous agitation for 5 h at 25 °C

3. ***Fe-Mn Oxides*** : The goal of this stage is to extract all metals precipitate or adsorbed on the oxides or hydroxide or the amorphous hydroxides. Residue from carbonate extracted with 20 ml of 0.04 M $NH_2OH.HCl$ in 25 % acetic acid (vol/vol) for 6 h at 96 °C with occasional agitation.

4. ***Organics*** : Heavy metals bounded to organic constituents in soil via complexation, adsorption and chelation are investigated by this stage. Residue from Fe-Mn oxides extracted with 3 ml of 0.02 M HNO_3 + 5 ml of pH 2, 30 % H_2O_2 (vol/vol) for 2 h at 85 °C with occasional agitation, an additional 3 ml of pH 2, 30 % H_2O_2 for 3 h at 85 °C with occasional agitation, and then 5 ml of 3.2 M NH_4OAc in 20 % HNO_3 (vol/vol) with continuous agitation for 30 min. at 25 °C.

5. ***Residual*** : Metals that are bound to the soils solids via specific adsorption in soil mineral lattice was extracted by digestion. Residue from organics was decomposed over heat with 10 ml of concentrated HF + 2 ml concentrated $HClO_4$ to near dryness, further 10 ml HF + 1 ml $HClO_4$ to near dryness, an additional 1 ml of $HClO_4$ to white fumes, and the remaining material taken up in 12 M HCl and diluted to 25 ml.

Before starting next stage of each extraction, the slurry was centrifuged at 10,000 rpm for 20 minutes. The supernatant was collected in plastic bottle and acidified with 1 % nitric acid as well as stored at 4 °C until metal analysis. Moreover, the residue was then washed with 8 ml of Deionized water by centrifuging at 10,000 rpm for 20 minutes. The second supernatant was discarded and the residue was treated following next step. Metal analyses were performed by using a Shimadzu AA 6501F Series Flame Atomic Absorption (FLAA) Spectrophotometer.

3.2.3 Column Experiment

The column was conducted to study the behavior of heavy metals transport in landfill leachate. Only KBS-2 (sand) and KBS-3 (silty loam sand) were chosen to study heavy metals transported through soil within landfill area. The column was made from Plexiglas, with diameter of 5 cm and a height of 10 cm. Plexiglas columns was uniformly packed with air-dry soil at bulk density (Figure 3.3). Columns were operated in up flow mode to prevent preferential flow (Thornton et al., 2000). The column was slowly saturated with deionized water with the aid of a peristaltic pump. The cell was then leached with a continuously supplies heavy metals solution (actual leachate and synthetic leachate) in 10 mgL^{-1} of monometal or mixed metals. The effluent leachate from the column was then collected in different time interval. After reaches equilibrium breakthrough curve, desorption experiment was conducted by flushing with deionized water to assume infiltration of water in the field. The standard method, EPA method 3010 A was used for sample preparation. The Cr, Cd, Pb, Cu and Zn concentrations in the influent and effluent solutions were determined using AAS. For tracer analysis, potassium bromide (KBr) was used as nonreactive substance to determine dispersion coefficient of all KBS-2 and KBS-3 soil samples. The assemblage and conditions of tested column is shown in Figure 3.3 and Table 3.7 respectively.

The dispersion coefficient, effective porosity and retardation factor were obtained from column experiment. The obtained data was used to simulate the heavy metals transport in subsurface by using HYDRUS 2D model.

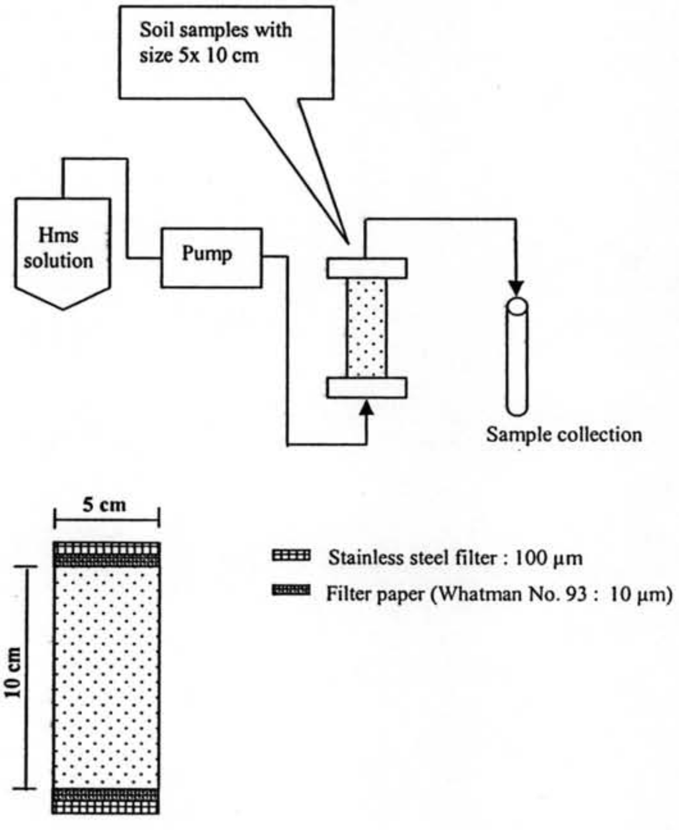

Figure 3.3 Column design

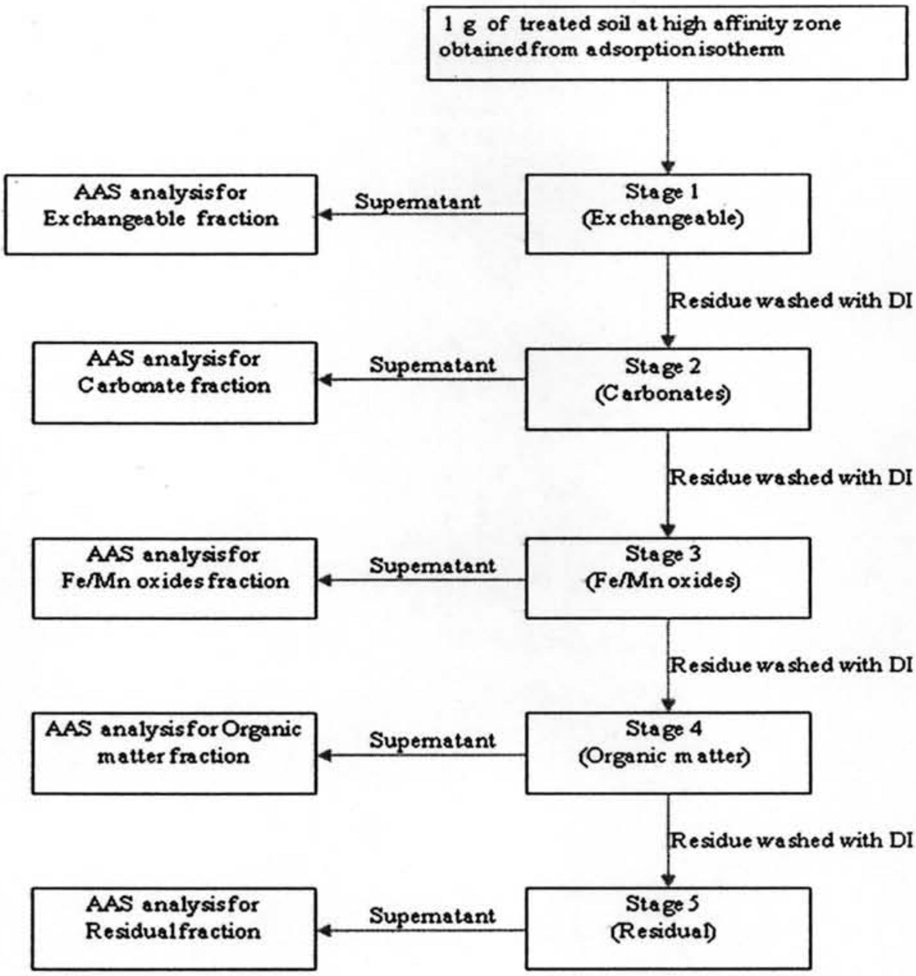

Figure 3.4 Schematic drawing of selective sequencing extraction method

Table 3.7 Experimental conditions for column study

Heavy Metals	Experimental Design		Data Achievements
	Initial Concentration (mg/l)	pH	
Tracer (KBr)	10	-	-Dispersion Coefficient
Monometal (Actual leachate / Synthetic leachate)	10	8.16	-Dispersion Coefficient - Effective porosity - Retardation Factor
Mixed Metals (Actual leachate/ Synthetic leachate)	10	8.16	-Dispersion Coefficient - Effective porosity - Retardation Factor

3.3 Simulation of heavy metal transportation

3.3.1 Visual HELP

Different parameters used are presented in Tables 3.7 to 3.8. Moreover, the procedure of the Visual HELP model simulation is shown in Figure 3.5.

3.3.1.1 Weather Data

Twenty four years (1981-2004) of daily precipitation, temperature, sunshine hours, relative humidity, and wind speed data of Khon Kaen obtained from the Meteorological Department of Thailand were prepared in a format to be used as the input parameters for the model. Annual average precipitation and temperature in the area were estimated to be 1,750 mm and 26.5 °C respectively. The average measured wind speed was 16.43 km per hour for the same duration. From the records of daily sunshine hours, relative humidity and temperature, daily solar radiation values were calculated using relation of extraterrestrial radiation to sunshine duration data in local area (Manandhar, 2000; Akpabio and Etuk, 2002). Average quarterly relative humidity of 0.73, 0.77, 0.83 and 0.81 was obtained from calculated from ten years of relative humidity records. The maximum leaf area index is taken as zero for the study as there was no presence of vegetation.

3.3.1.2 Evapotranspiration Parameters

The evapotranspiration parameters based upon the latitude and longitude of the site, starting and ending of the growing season, maximum leaf area index, wind speed and quarterly relative humidity are mostly taken from the database of the model. For the Kham Bon landfill site, the maximum leaf area index was taken as zero for simulation as there is no vegetation in the site.

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Table 3.8 Input parameters for Visual HELP Model Application in Kham Bon Landfill

Data Input (1981-2004)			Real Data	Empirical data	Default data
Weather	Precipitation	Daily precipitation data	*		
	Solar radiation	Daily sunshine hour data	*		
		Daily solar radiation		*	
	Temperature	Daily temperature data	*		
	Evapotranspiration	Evaporative zone depth	*		
		Maximum leaf area index	*		
		Quarterly relative humidity	*	*	
		Average wind speed	*	*	
Soil	Soil properties	Total porosity	*		
		Field capacity	*		
		Wilting point	*		
		Saturated hydraulic conductivity of top soil	*		
		Barrier soil and gravel	*		
Waste	Waste properties	Total porosity			*
		Field capacity			*
		Wilting point			*
		Saturated hydraulic conductivity of top soil			*
Landfill Design	Landfill profile	Obtained from Kham Bon landfill	*		

3.3.1.3 Soil and Waste Properties

According to USDA Classification, the soil type prevalent in the area has been classified as clay loam (CL) to silty clay loam (SCL), sandy loam (SL), loamy sand (LS) and sand (S). The barrier soil type is clay loam. Field capacity and wilting point of the cover layer and barrier soil was measured in the laboratory. Field capacity, wilting point, porosity and saturated hydraulic conductivity of the municipal waste were taken from the database of the HELP model. Percentage of sand and clay were obtained from grain size distribution curve of the soil layer and soil porosity was also determined. However, saturated hydraulic conductivity, field capacity, porosity and wilting point of the municipal waste taken from the database of the HELP model.

Table 3.9 Important Parameters input in the Visual HELP model

Parameters	Unit	Top soil	Waste	Loessial Soil	Clay
Layer No.		1	2,4,6,8	3,5,7,9	10
Material type		Vertical Drainage	Vertical Drainage	Barrier soil	Barrier soil
Total porosity	vol./vol.	0.39	0.67	0.40	0.36
Field capacity	vol./vol.	0.094	0.29	0.072	0.34
Wilting capacity	vol./vol.	0.042	0.077	0.029	0.21
Saturated hydraulic conductivity ($x10^{-5}$)	cm/s	100	100	52	6.4
Subsurface Inflow	cm/day	0	0	0	0
Top Slope	%	3	0	3	3
Bottom Slope	%	0	0	0	0
Top slope length	M	153	0	0	146
Bottom slope length	m	0	0	146	0
Thickness	m	0.60	1.50	0.30	0

3.3.1.4 Landfill Design Data

The landfill is a controlled open dump with some part of engineered liners within the area and leachate collection system. Collected waste from the Khon Kaen municipality and surrounding areas are initially spread into ground and then dumped into 7 to 10 meters deep pits, build for the purpose. Once the pits are filled with the waste, they are covered with the layer of soil. The landfill profile comprises of 5 layers (Figure 3.6); fine sandy loam as a top cover layer behaving as vertical percolation layer (0.6 m); compacted waste layer (2.5 m) as vertical percolation layer; sand layer (0.3 m) acting as lateral drainage; the HDPE geomembrane layer, and clay soil as geological barrier soil liner (0.3 m).

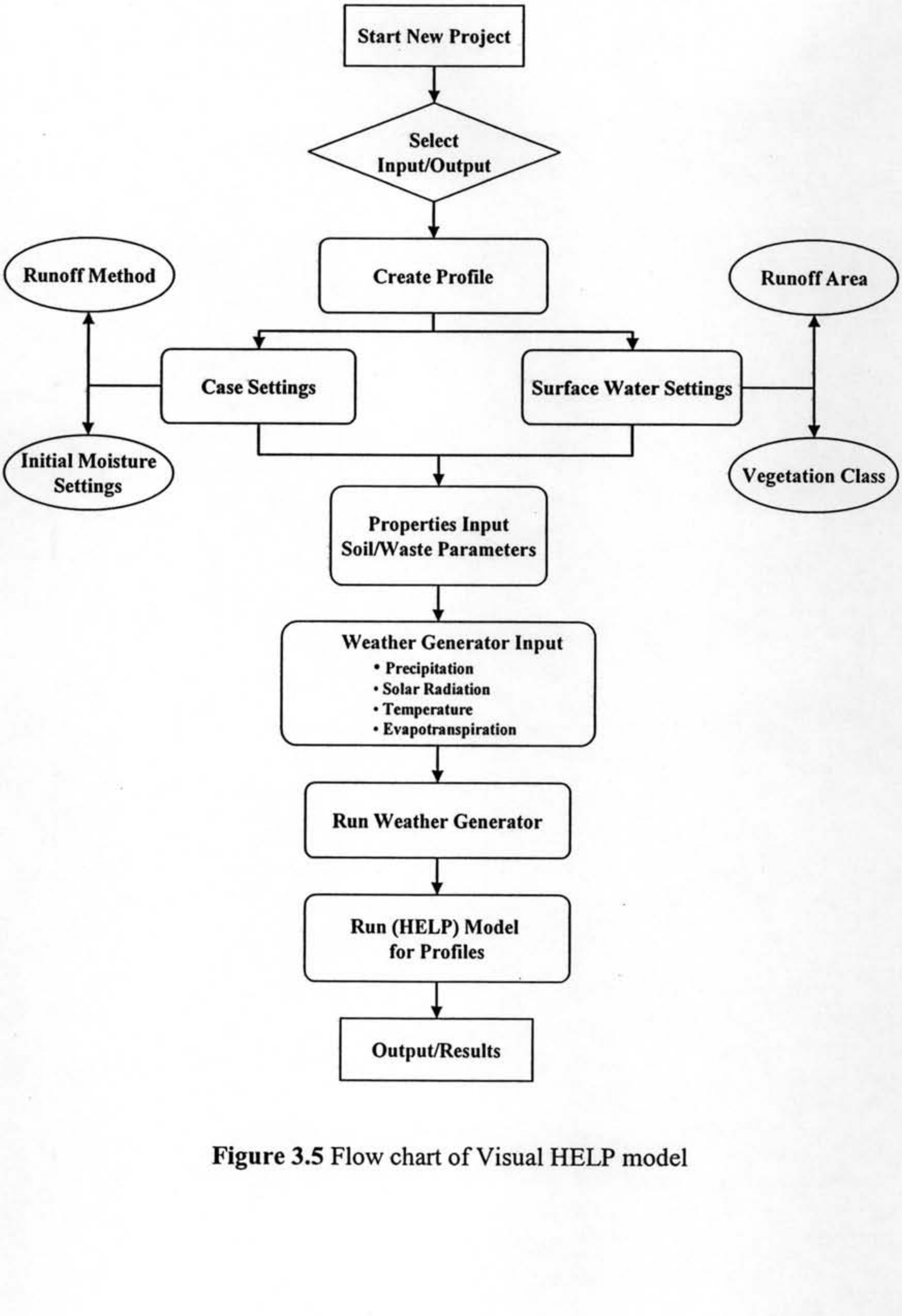

Figure 3.5 Flow chart of Visual HELP model

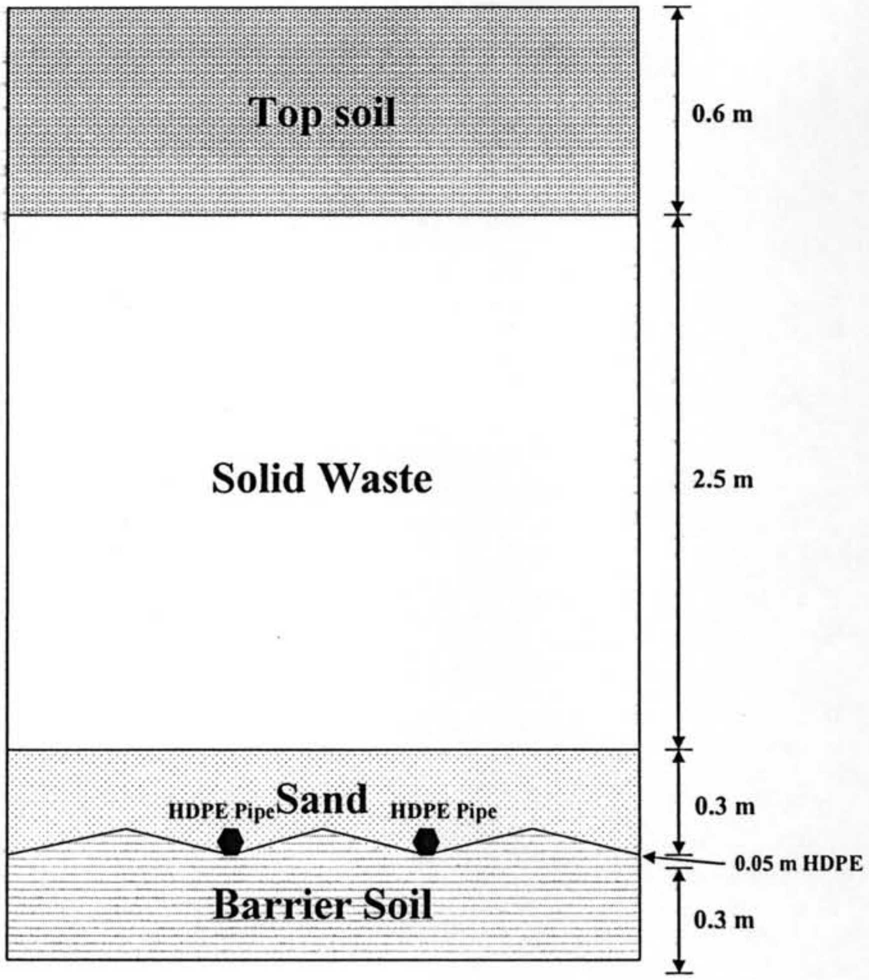

Figure 3.6 Kham Bon landfill profile for the application of Visual HELP model

3.3.1.5 Approach for the Visual HELP Simulation

The simulation was done for water balance after completion of filling of each lift in the Kham Bon landfill. Three simulations were concentrated. These simulations are water balance calculation of single lift with/without HDPE liner and landfill design for three lifts.

Waste cell in the landfill pit with the active area of 3.73 hectares (153 m x 244 m) was estimated as the landfill area to be simulated. A profile of 5 layers of materials and each thickness of the layers were provided by the FS & DD project (1998).

3.3.2 HYDRUS 2D : This model was used to express as the transport models for simulating advection-dispersion and chemical reaction of contaminant in two dimension. The data requirements are weather data, soil properties, distribution coefficient (K_d) as well as data obtained from column experiment (Retardation factor, effective porosity, diffusion coefficient).