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MATHEMATICAL MODELING OF HEAVY METALS CONTAMINATION FROM MUNICIPALITY LANDFILL SITE KHONKAEN

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A Thesis Submitted in Partial Fulfillment of the Requirements
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ญาณี นาคสกุล : แบบจำลองคณิตศาสตร์ของการปนเปื้อนโลหะหนักจากหลุมฝังกลบขยะชุมชน: กรณีศึกษาเทศบาลนครขอนแก่น (MATHEMATICAL MODELING OF HEAVY METALS CONTAMINATION FROM MULNICIPALITY LANDFILL SITE KHONKAEN อ. ที่ปรึกษาวิทยานิพนธ์หลัก: ผศ.ดร.เนตรนภิส ตันเต็มทรัพย์, 109 หน้า.

สถานที่กำจัดขยะมูลฝอยของเทศบาลนครขอนแก่นเริ่มดำเนินการตั้งแต่ปีพ.ศ.2521และได้มีการตรวจพบโลหะหนักซึ่งได้แก่ ตะกั่ว โครเมียม และแคดเมียมในน้ำชะขยะที่มาจากหลุมฝังกลบขยะดังนั้นวัตถุประสงค์หลักในงานวิจัยครั้งนี้คือการศึกษาการปนเปื้อนของโลหะหนักดินและน้ำโดยใช้แบบจำลองทางคณิตศาสตร์และได้มีการตรวจสอบการปนเปื้อนของโลหะหนักในปัจจุบันจากดิน ,น้ำผิวดินและน้ำใต้ดินพื้นที่ 2 กม จากหลุมฝังกลบขยะ จากการวิจัยพบว่ามีการปนเปื้อนของโลหะหนักทั้ง 3 ชนิด ตะกั่ว(0.50-5.00มก/กก) โครเมียม(2.00-5.00มก/กก), และแคดเมียม (0-0.25มก/กก) ในดิน,น้ำผิวดินและน้ำใต้ดินโดยจะปนเปื้อนอยู่ที่ความลึกไม่เกิน 2 ม จากชั้นผิวดินและมีการกระจายตัวไปไม่เกิน 500ม จากหลุมฝังกลบขยะ อย่างไรก็ตามปริมาณการปนเปื้อนของโลหะหนักในดิน,น้ำผิวดินและน้ำใต้ดินยังอยู่ในเกณฑ์มาตรฐานที่ควบคุมโดยกรมควบคุมมลพิษ ในการวิจัยได้มีการใช้โปรแกรม Visual MODFLOW 3.1 สำหรับการติดตามตรวจสอบเส้นทางการแพร่กระจายของโลหะหนักในน้ำใต้ดิน จากจำลองพบว่าปริมาณการปนเปื้อนของโลหะหนักจะมีค่าสูงในแนวทิศตะวันออกเฉียงเหนือและทิศตะวันออกเฉียงใต้เนื่องจากสภาพพื้นที่ศึกษาและการไหลของน้ำผิวดินซึ่งจะไหลจากทิศเหนือและทิศตะวันออกของหลุมฝังกลบลงสู่แหล่งน้ำผิวดิน นอกจากนี้ยังพบว่าในระยะเวลา 20 ปี โลหะหนักมีแนวโน้มที่จะแพร่จากดินระดับตื้นสู่ดินระดับลึกแต่รัศมีในการกระจายตัวของโลหะหนักจะยังอยู่ในรัศมีไม่เกิน 500 ม จากหลุมฝังกลบขยะ

เนื่องจากการปนเปื้อนของโลหะหนักในพื้นที่อาจจะก่อให้เกิดผลเสียต่อสิ่งแวดล้อมและสุขภาพของประชาชนในพื้นที่ ดังนั้นจึงควรมีการแยกขยะอันตรายออกจากขยะทั่วไปและมีการติดตามตรวจสอบการปนเปื้อนของโลหะหนักในน้ำใต้ดินและชั้นน้ำใต้ดินที่ลึกลงไปอย่างใกล้ชิด นอกจากนี้ควรงดการใช้น้ำใต้ดินในรัศมี 500 ม จากหลุมฝังกลบขยะเนื่องจากน้ำใต้ดินในบริเวณนี้มีการปนเปื้อนของโลหะหนักค่อนข้างสูงกว่าบริเวณอื่นๆและควรหาวัสดุมาปิดบริเวณผิวหน้าของขยะในฤดูฝนเพื่อเป็นการป้องกันการซึมผ่านของน้ำฝน และในอนาคตควรมีการซ่อมแซมหลุมฝังกลบ-ขยะเพื่อเป็นการป้องกันและยับยั้งการแพร่กระจายของโลหะหนักจากหลุมฝังกลบขยะสู่สิ่งแวดล้อม

สาขาวิชา การจัดการสิ่งแวดล้อม ลายมือชื่อนิสิต .....

ปีการศึกษา 2552 ลายมือชื่อ อ.ที่ปรึกษาวิทยานิพนธ์หลัก.....

5187526720 : MAJOR ENVIRONMENTAL MANAGEMENT

KEYWORDS : LANDFILL / CONTAMINATION / HEAVY METALS / MODFLOW

YARNEE NAKSAKUL : MATHEMATICAL MODELING OF HEAVY METALS CONTAMINATION FROM MULNICIPALITY LANDFILL SITE KHONKAEN. THESIS ADVISOR: ASST. PROF. NETNAPID TANTEMSAPYA, Ph.D., 109 pp.

Kham Bon landfill site is one of many unsanitary municipality waste disposal sites in Thailand. The site has been receiving municipality and industrial wastes since 1968. Heavy metals were reported found in landfill leachate including Pb, Cr, and Cd. The main objective of this research is to study the contamination of heavy metals in soil and water using mathematical modeling. The existing condition of heavy metals contamination was investigated by measuring Pb, Cd, Cr in surface water, groundwater and soil in 2 000 meter radius around the site. Contamination of such heavy metals in the environmental receptors was resulted as the pollutant migrated with runoff and subsurface aquifer at least 2 meters in depth and 500 meters radius surrounds the site. Contamination of Pb (0.50-5.00mg/kg), Cr (2.00-5.00mg/kg), and Cd (0-0.25 mg/kg) were found. However, heavy metals concentration in soil samples did not exceed the Pollution control Department (PCD) recommended standard for agriculture. In addition, Heavy metal concentration in surface water and groundwater did not exceed the Thai drinking water quality standard recommended by PCD.

Contamination transport modeling was performed using Visual MODFLOW 3.1. Model results showed that heavy metals especially Pb and Cr migrated to the northeastern and southeastern part more than other parts due to the geological and flow network drain from the site northward and eastward to the surface water sources. 20 years prediction showed that, heavy metals tends to move from the top soil to deeper aquifer. The migration will not exceeded 500 m after 20 years and considered a slow process.

It is recommended that hazardous waste sorting and ground water contamination in deeper aquifer should be closely monitored. In additional, the consumption of groundwater in 500 m radius should be avoided because it was contaminated with high level of heavy metals. During rainy season, the material to cover the waste from leaching with runoff should be applied. In the future, rehabilitation of the landfill site should be undertaken to prevent further mobilization of pollutants.

Field of Study: Environmental Management Student's Signature Yarnee Naksakul

Academic Year :2009 Advisor's Signature Netnapid Tantem

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CHAPTER I

INTRODUCTION

1.1 Statement of Problem

Khon Kaen Municipality has been disposing its waste into Kham Bon landfill since 1968. From the beginning up to 1997, the landfill was unlined. Later in 1998, the landfill was reconstructed with liner (PCD, 1998). However, the current disposal practice is dumping waste into the plastic liner pit, with an average depth of 5–18 m, then covering the waste with soil without compaction. Leachate collection ditch is blocked with waste and cannot collect runoff from the garbage pile. All types of waste accounting to 100 tons per day are being dumped in the landfill including 2 tons per day of hazardous waste. The co-disposal hazardous waste are used battery, insecticide containers, spray paint cans, cleaning and detergent containers, motor oil/filter containers and used fluorescence lamps (Kirathithorn, 2004). In addition, waste from small industries is collected together with municipality solid waste and disposed in the landfill. The landfill was not designed for hazardous waste disposal and is therefore not environmentally safe in a long perspective. Thus, it is a potential for heavy metals contamination in surface and subsurface environment around the landfill site (PCD, 1998). Kayandee (1999), Boonsener (1991), Buaphan (1999) and Promlao (2008) reported contamination of heavy metals which are: Lead(Pb), Zinc(Zn), Chromium(Cr) and Cadmium(Cd) in groundwater nearby the site. Similar to monitoring results from the Regional Environmental Office 10, which is reported that lead was found in monitoring well nearby the site.

As mentioned above, there are many studies revealed that heavy metals contamination occurred nearby the landfill site. However, the site characterization including model prediction of the site has not been done. Thus, this research aims to study heavy metals contamination from municipal solid waste (MSW) landfill site in

groundwater covering 2 km radius around the site. Groundwater and heavy metals transportation model for prediction of heavy metals concentration in groundwater was also applied. The results can be used to explain contamination pathway and to predict heavy metals concentration in groundwater in the future.

1.2 Objectives

1) To study heavy metals contamination from MSW landfill site in soil, surface water and groundwater in 2 km radius around the site.

2) To employ groundwater and heavy metals transportation model to predict heavy metals concentration in groundwater in the future.

1.3 Study Area

The study area is Khon Kaen MSW landfill site locates at Kham Bon Village, Muang District, Khon Kaen Province, Northeastern Thailand (Figure 1.1). It is about 17 km north of Khon Kaen City along the Friendship Highway heading toward Udontani Province. Figure 1.2 is the 1:50,000 scale topographic map (Military map sheet 5542 II series L 7017) showing study area. The landfill covers an area about 0.15 km^2. The study area covers roughly 0.32 km^2 in four villages namely; Kham Bon; Sam Chan; Bueng Kae and Non. The landfill serves Khon Kaen municipality and eight local Sub-Districts (15 communities)

1.4 Expected Outcome

The results can be used to explain contamination pathways and to predict heavy metals concentration in soil and groundwater in the future.

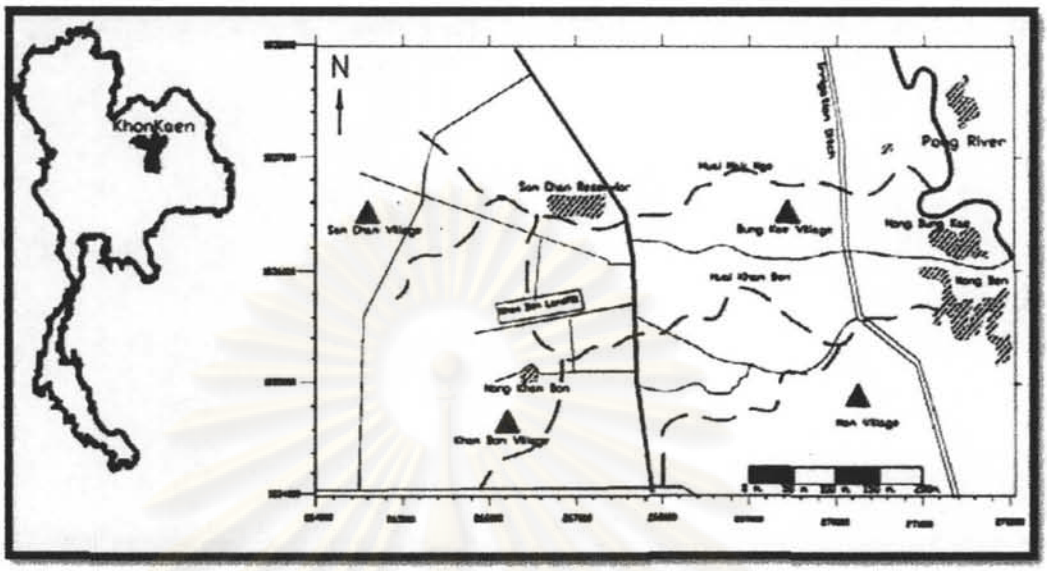


Figure.1.1 Location of study area

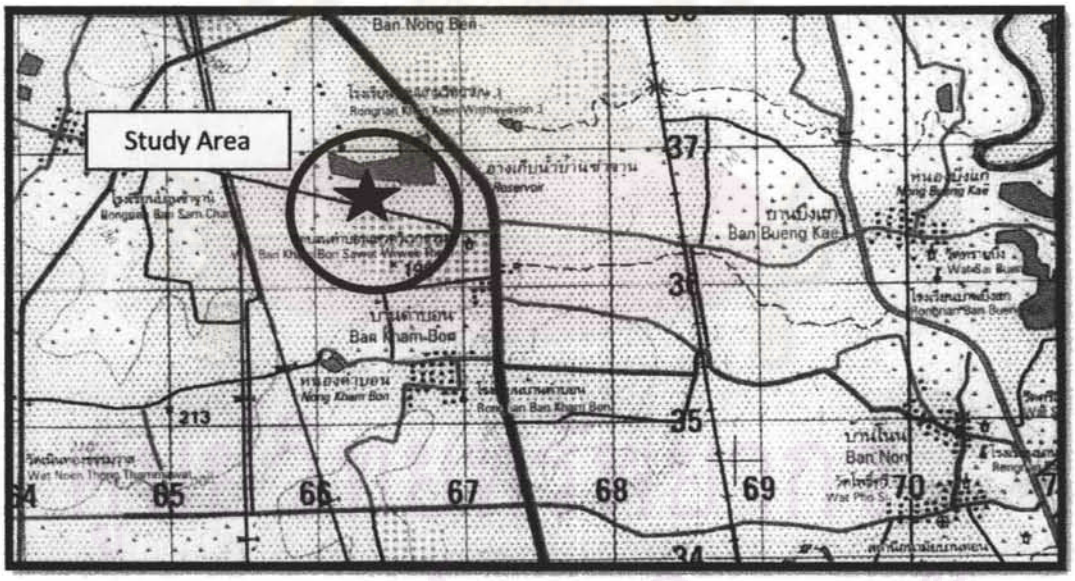


Figure 1.2 Military map showing study data

CHAPTER II

LITERATURE REVIEWS

In order to understand heavy metals transport and fate from landfill leachate to the environmental receptors including soil, surface water and groundwater, background knowledge in the area must be understood. In this study, background knowledge included mechanisms of contaminate transport and heavy metals mobility in environmental especially in contamination from Landfill leachate is required. In addition, mathematical model that used to explain transport mechanisms is needed to know. In this chapter, theoretical background and literature review on the relate research of the above topics are explained.

2.1 Mechanisms of Contaminate Transport

Contaminants in groundwater usually move primarily in horizontal direction that is determined by hydraulic gradient. The contaminants concentration decreases because of processes include dispersion (molecular and hydrodynamic), filtration, sorption, various chemical processes, microbial degradation, time, rate release of contaminants and distance of travel. Processes such as hydrodynamic dispersion affect all contaminants equally, while sorption, chemical processes, and degradation may affect various contaminants at different rates.

There are three processes controlling the transport of contaminants in subsurface conditions: physical, chemical and biological processes. The physical processes that control the flux in and out of the system are advection and hydrodynamic dispersion. Meanwhile the loss or gain of solute mass in the system is described by the chemical and biological reaction. For heavy metals, biological process has little effected to chemical change. Parameters which influence solute transport through soil and groundwater are soil water velocity, soil solute adsorption-desorption characteristic, chemical reactions and transformation by microorganism Mechanisms of each process are explained below.

2.1.1 Physical Processes

Physical processes control the contamination migration with groundwater in the subsurface system

Advection: Advection refers to the contaminant movement by flowing groundwater in response to hydraulic gradient at a macro scale level. As a result, the rate of solute particle transport is equal to the average linear groundwater velocity. The porous media parameters that control the advection transport are: hydraulic gradient; hydraulic conductivity, specific yield, storage, porosity and effective porosity.

Hydrodynamic dispersion: Hydrodynamic dispersion expresses the non-uniform velocity and causes dilution of the solute. It occurs because of molecular diffusion and mechanical dispersion phenomena. *Molecular diffusion* is defined as the movement of contaminants under a chemical concentration gradient. The *mechanical fluid mixing* or *mechanical dispersion* shows the difference in macro scale water velocities due to path length differences and friction in pores.

2.1.2 Chemical Processes

The pollutant may not move passively with the water. They are often retarded by adsorption on the soil or degraded by microorganisms resulting in the change of solute mass. Four chemical processes have been reported to control heavy metals concentration in landfill leachate: sorption; precipitation; complexation and oxidation-reductions (Christensen et al., 2001; Yong, 2001; Selim and Spark, 2001 and Ward et al., 2005). These processes may be reversible if the controlling conditions change overtime.

Sorption: Sorption is probably the most important chemical process affecting the transport of organic contaminants in the subsurface environment. Sorption refers to partitioning of contaminants between the fluid and solid phrases and includes processes of: adsorption; absorption; desorption; surface complexation and ion

exchange. This process generally decreases heavy metals dispersion from contaminant source such as landfill leachate. The adsorption of heavy metals in soils is a competitive process between metals in solution and those adsorbed to soil particles. In soil phrase, metal can be bound mainly to organic matter and onto iron and manganese oxide surfaces (Sharma and Reddy, 2004). Divalent metal cation tend to favor sorption with negatively charge sites such as colloidal particles, calcite, clay minerals, organic and oxides of Fe, Mn and Si (Fetter, 2001; Spark, 2005 and Yong, 2001). However, it is difficult to differentiate between sorption and ion exchange processes. Sorption can cause the lowering of total dissolve solids and attenuate leachate whereas ion exchange simply exchanges solutes with cations, due to electrostatic forces.

Sorption in soil is described by *Patition Coefficient,* K_d, which is defined as the ratio between concentration in soil and water phase at equilibrium (Yong, 2001). Low values of K_d indicate that most of the metals presented in the system remained in the solution and are available for transport and plant uptake. On the other hand, high values of K_d reflect a large affinity of solid soil components for the metals (Morera et al., 2001).

Precipitation: Precipitation occurs when a metal species dissolution as solid. Sulfides and carbonates are capable of forming precipitates with Cd, Ni, Zn, Cu and Pb. Occasionally, phosphates and hydrolysis will also precipitates metals. Hydroxide precipitates form at pH natural or above which is typically the case in methanogenic leachate. In general, sulfide precipitation is expected to dominate heavy metal attenuation compared to other complexation agents. Metals sulfide is formed from sulfate during waste decomposition causes low concentration of heavy metals (Christensen et al., 2001). Even small concentrations of sulfides will precipitate heavy metals except for Cr, which does not form an insoluble sulfide compound. However, Cr does tend to form insoluble precipitate with hydroxide while carbonates are abundant in landfill leachate. Cr mobility can be reduce by iron where Cr(VI) changes it from to Cr(III) by Fe(II)

Complexation: Complexation occurs when ions or molecules that dissolved in water combine with a variety of other ions or molecules to form several different species, known as *complexs*. Complexation reactions are important mechanisms resulting in increased solubility if metals present in groundwater, if adsorption is not enhance; major ion complexation will increase the quantity of a solid dissolved in solution (Yu et al., 2002). Therefore, complexation is usually considered carefully when designing remedial systems to either enhance contaminant is soils and groundwater.

Oxidation-Reduction (Redox) Reactions: Oxidation-Reduction reactions involve the transfer of electrons which are pH dependent. These processes are important for heavy metals that have more than one oxidation state. Heavy metals such as Cr, As, Mn, Fe and Hg are referred to as redox elements or redox couples since they have more than one possible oxidation state (Christensen et al., 2001) .While Ag, Cd, Cu and Zn with only one valence state , can also be influenced by redox processes. Under very low redox conditions, Pb and Cd, with one oxidation state, form insoluble sulphide minerals. Moreover, at pH of 7 or 8 where redox conditions not moderately low, they form insoluble carbonate minerals. The changes in redox potential affect the soil pH. Reducing conditions enhance pH value while oxidations bring pH down.

2.2 Heavy Metals in Landfill Leachate

Landfills have served as the ultimate disposal sites for solid waste generated from residential, commercial, and industrial activities. Generation and subsequent flow of leachate to groundwater is one of the main hazards from the disposal of waste by landfilling. Landfill leachate is generated by excess rainwater percolating through the waste transfer pollutants from the waste material to the percolating water (Christensen et al, 2001). There are two sources of water in landfill; initial water present in the waste and water added to the landfill from percolations through the top layer or groundwater flowing through the sides (Fetter, 2001). Factor that affect leachate generation are: climate, topography, land cover, vegetation and type of waste (Calace et al., 2001).

Leachate migration has been a implicated worldwide as a source of environmental pollution (Vogelin et al.,2003 and Sparks, 2005). It contains a large number of compounds, some of which can be expected to create a threat to health and nature if release into the natural environment.

2.2.1 Leachate Generation

The concentration of heavy metals in leachate is related to the properties of the leachate such as pH, organic content and organic matters. Several researchers studied about the biological, chemical and physical properties of landfill environments. They found that these environments change over time. There are 5 stages of MSW decompose in landfill as described below (Aucott, 2006).

Phase I: Initial Adjustment - Within a short time after the waste is deposited, a community of microorganisms builds up to a population sufficient to begin to significantly after the waste.

Phase II: Transition – Transformation from the initial aerobic condition to an anaerobic environment takes place. A trend toward reducing conditions, in which elements of molecules gain electrons, is established as electron acceptors shift from oxygen to nitrates and sulfates. By the end of this phase, measurable concentrations of chemical oxygen demand (COD) and volatile organic acids (VOAs) appear in the leachate.

Phase III: Acid Formation – During this phase, some of the waste is hydrolyzed. In this stage, anaerobic acid forming bacteria metabolizes biodegradable organic matter in the waste producing VOAs. The resulting levels of VOAs Pb to a lowering pH, and tend to increase the load of dissolved metals in the leachate.

Phase IV: Methane Production – This period is characterized by the rise to dominance of another group of microorganisms, methane producing bacteria. These convert the VOAs to methane and carbon dioxide. A highly reducing chemical

environment develops, resulting in the reducing of sulfate(SO_4^{-2}) to sulfide (S^{-2}). The pH rises as NH_3 ammonium (NH_4^+) ions. The pH is maintained in the neutral range, however, by bicarbonates (HCO_3^+), and this supports the continued flourishing of the methanogenic bacteria. The presence of sulfides and hydroxides (OH^-) favors the precipitation of metals.

Phase V: Maturation – In this phase, biological activity declines due to the depletion of readily-degradable organic matter and other nutrients. Gas production also declines, and concentrations of pollutants in leachate are lower than previous phases.

Other researchers have characterized the life cycle of landfill in slightly different ways. Kjeldsen et al. (2002) described eight phase. They lump phases I and III as described above into a single phase, the aerobic phase, and expand the methanogenic phase into 3 parts. They add 3 stages beyond the methanogenic phase. The air intrusion phase, the carbon dioxide phase, and the soil air phases. The reduction and production of chemicals composition in MSW landfill with time is shown in Figure 2.1.

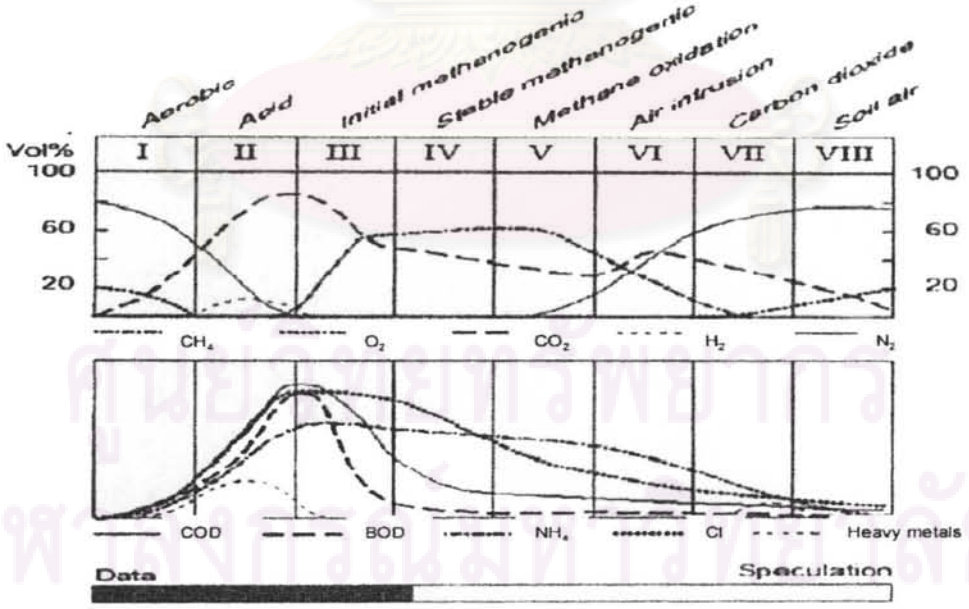


Figure 2.1 General trends in gas and leachate quality over the lifetime of a landfill (Kjeldsen et.al., 2002)

In MSW landfill, a significant part of the heavy metals in the waste is bonded on glass, plastics, slag, ceramics, steel, wood, etc. Products and materials stored in a landfill are slowly disintegrated over time. Heavy metals are slowly oxidized and later be dissolved. Heavy metals are released during the stage of anoxic condition and methane production which will be reached after a short time (Christensen et al., 2001) and expected to continue for a long period of time (Selim and Sparks, 2001and Yong, 2001).

2.2.2 Leachate Characteristics

Landfill leachate may be characterized as water based solution of 4 groups of pollutants (Chistensen, 2001); Dissolved organic matter: Inorganic macrocomponents, heavy metals, and xenobiotic organic compounds (XOCs) other trace compounds may be found in leachate from landfills, e.g., As, Se. Ba, Li, Hg and Co. Leachate composition varies significantly among landfills depending on waste composition, waste age and landfilling technology.

There are many studies on physical and chemical characteristics of landfill leachate as summarized in Table 2.1 (Çeçen et al., 2000; Chuagngcham, 2007 and Öman et al., 2008). From Table 2.1, pH ranges from 6.4 – 8.5, COD ranges from 250 to >10 000 mg/l and BOD ranges from 4 to > 10 000 mg/l. Pb, Cr and Cd were found at low concentration.

Table 2.1 Characteristic of Landfill Leachate

Authors	Characteristic of Landfill Leachate								
	pH	EC (mS/cm)	BOD (mg/l)	COD (mg/l)	Pb (mg/l)	Cr (mg/l)	Cd (mg/l)	Fe (mg/l)	Mn (mg/l)
Kayandee (1999)	7.5 -8.2	9 - 11	1100 - 2164	2587 - 3280	0.07-0.13	0.02-0.04	0.01-0.02	0.41-1.68	0.32-0.47
Ferhan Çeçen and Gül Gürsoy (2000)	7.3 – 8.0	12 - 15	500 - 15625	3784 - 37024	0.49 –1.91	0.00 – 2.24	0.08–0.25	2.66 – 25.2	0.20– 0.85
Anuluxtipun et.al. (2002)	-	-	-	-	0.004-.076	-	0.00– 0.01	-	-
Chuagngcham (2007)	6.5 – 7.9	10 - 17	1100 - 10055	351 - 11339	0.01 –0.03	1.5 – 3.42	N/D	5.0 -9.8	0.25– 0.63
.Öman (2008)	6.4 -8.5	230 - 2730	4 - 110	250 - 1300	0.0–0.015	0.001–0.045	0.00–0.003	0.2 –43	0.20– 5.20

2.3 Chemistry of Metals of Interest

Heavy metals are classified as toxic inorganic chemicals and are considered as hazardous pollutant at low concentrations. The presence of heavy metals among wastes can pose a long-term environmental hazard (Yong, 2001). The contamination of heavy metals depends on its physics and chemical properties as associated with the waste matrix and soil (Sharma and Reddy, 2004). Significantly downward transportation of metals from the soil surface occurs when the metal retention capacity of soil is overloaded or when metals are solubilized (Sparks, 2005). The properties and behavior of specific metals that are focused on in this study are discussed herein.

2.3.1 Pb (Pb)

Pb is a heavy metal that exists in three oxidation state: O, +2(II), and +4(IV). Pb is generally the most widespread and concentrated contaminant present at a Pb battery recycling site (i.e. battery breaker or secondary Pb smelter). The chemistry of Pb in soil is affected by 3 main factors: 1) specific adsorption to various solid phase, 2) precipitation of sparingly soluble of highly sTable compounds and 3) formation of relatively sTable complexes or chelates that result from intereaction with soil organic matter (Bradl, 2004). Figure 2.2 A show predicted aqueous special of Pb as a function of pH while Figure 2.2 B displays the predicted Eh-pH-stability field for Pb. Pb undergoes hydrolysis at low pH values and displays multiple hydrolysis reactions. Above pH 9, the formation of $Pb(OH)_2$ is important, while $Pb(OH)^+$ is predominant between pH 6 and 10 (Adriano, 2001).

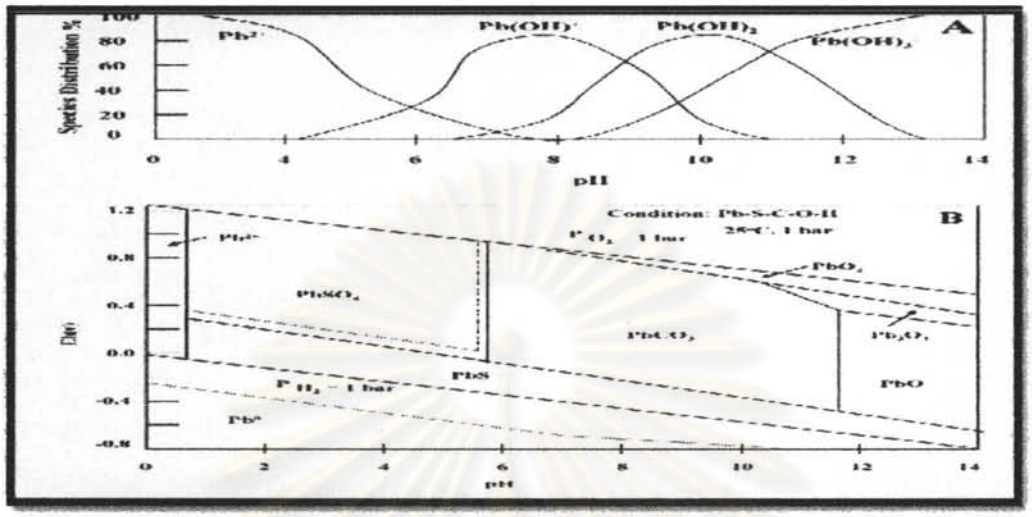


Figure 2.2 (A) Predicted aqueous special of Pb as a function of pH

(B) Predicted Eh-pH-stability field for Pb; the assumed activities of dissolved species are : Pb = 10^{-6}, S = 10^{-3}, C = 10^{-3} (Adriano, 2001)

Pb tends to accumulate in the soil surface. The capacity of soil to adsorb Pb increases with pH, cation exchange capacity, organic carbon content, soil/water, Eh (redox potential), and phosphate levels. Soil organic matter may immobilize of Pb via specific adsorption reactions (Yong, 2001 and Sharma and Reddy, 2004). On the other hand, the mobilization of Pb can also be facilitated by its complexation with dissolved organic matter or fulvic acids (Christensen et al., 2001). Pb exhibits a high degree of adsorption on clay-rich soil. Only a small percentage of the total Pb is leachable; the major partition is usually solid or adsorbed onto soil particles. USEPA (1999) reviewed partition coefficient of Pb which can be concluded as Table 2.2. Table 2.2 shows that higher pH would yield less soil retention (high K_d value).

Table 2.2 Estimated range of K_d values for Pb as a function of soil pH, and equilibrium Pb concentrations (USEPA, 1999)

Equilibrium Pb concentration (μg / l)	K_d (ml/g)	Soil pH		
		4.0 – 6.3	6.4 – 8.7	8.8 – 11.1
0.1 – 0.9	Minimum	940	4,360	11,520
	Maximum	8,650	23,270	44,580
1.0 – 9.9	Minimum	420	1,950	44,580
	Maximum	4,000	10,760	20,620
10 – 99.99	Minimum	190	900	2,380
	Maximum	1,850	4,970	9,530
100 - 200	Minimum	150	710	1,880
	Maximum	860	2,300	4,410

2.3.2 Cr (Cr)

Cr exists in soil in three forms: Cr^{3+}, $(Cr_2O_7)^{-2}$ and $(CrO_4)^{-2}$. The dichromate ions present a greater health hazard than chromate ions and both Cr(VI) ions are more toxic than Cr(III) ions. Because of its anionic nature, Cr(VI) associates only with soil surfaces at positively charged exchange sites. This association decreases with increasing soil pH. Although the Cr(III) is relatively immobile in soil it forms complexes with soluble organic ligands and its mobility may be enhanced. Cr is similar to Pb and typically found bound to particles. Some types of bacteria in soil can change Cr(VI) form to Cr(III)form by reduction process and decrease the solubility of Cr (McLean and Bledsoe, 1992 and Lia, 2007). Experimental data for Cr(VI) adsorption onto iron oxyhydroxide and aluminum hydroxide minerals indicated that adsorption increases with decreasing pH over the pH range 4 to 10 UESPA (1999). K_d value ranges from 1.7 to 135 -160 ml/gm depends on soil type.

Fe(II) containing minerals reduce Cr(VI); however, this reaction only occurs in the subsurface soil with a pH less than 5, decreasing to a pH of 2.5. The presence of

oxidized manganese serves as an electron acceptor for Cr(IV) reduction. Figure 2.3 A shows the distribution of Cr(III) species as a function of pH while Figure 2.3 B presents the predicted Eh-pH stability field for Cr species in aqueous systems (Adriano, 2001).

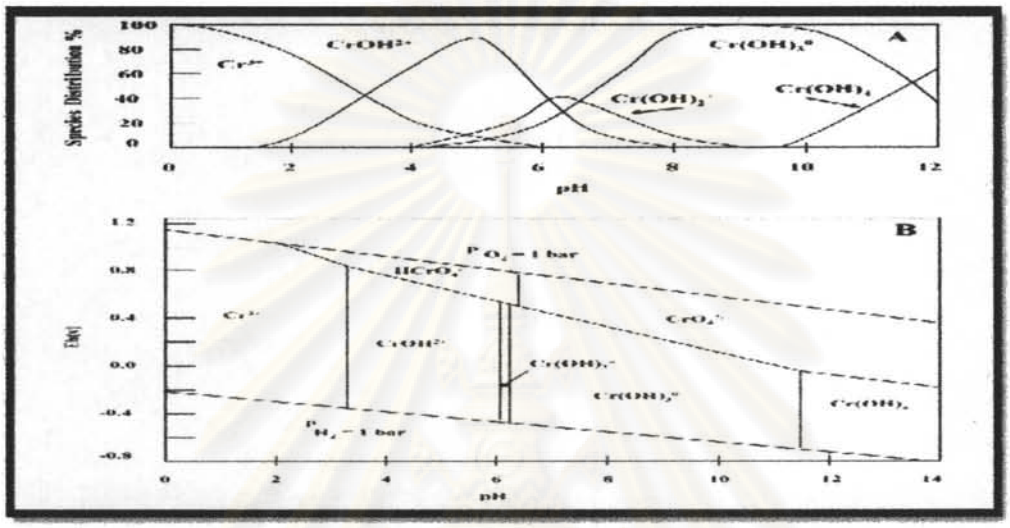


Figure 2.3 (A)Distribution of Cr(III) species as function of pH where the solution is in equilibrium with $Cr(OH)_3$ (B) Predicted Eh-pH-stability field for Cr species in aqueous species in aqueous ayatems (Adriano, 2001)

2.3.3 Cd (Cd)

Cd is highly toxic to plants, animals, and humans. The adsorption of Cd onto soil and silicon of aluminum oxides is strongly pH-dependent, as increasing the pH conditions become more alkaline. The solubility of Cd is higher in alkaline pH, as a result of the formation sTable soluble organomineral complexes. On the other hand, if pH ranged between 4 and 6, the solubility of these metals will be lower because of the formation of insoluble sulfides or insoluble organomineral complex (Ksiezopolska, 2005). In alkaline soils, the solubility of Cd is much greater and is controlled by adsorption on to clay minerals, oxides and soil organic matter. USEPA (1999) estimated range of K_d values for Cd based on pH as in Table 2.3. Tabulated values pertain to systems consisting of natural soils, low ionic strength (< 0.1 M), low humic material concentrations (<5 mg/l), no organic chelates, and oxidizing conditions.

Table 2.3 Estimated range of Kd values for Cd as a function of soil pH. (USEPA, 1999)

K_d (ml/g)	pH		
	3 - 5	5 - 8	8 - 10
Minimum	1	8	50
Maximum	130	4,000	12,600

2.4 Heavy Metals Mobility in Landfill Soil

2.4.1 Factor Controlling Heavy Metals in Soil

The factors controlling exchange between heavy metals in the solution and soil particles are soil pH, organic matter, multiple ions in the solution, solid and solution mass ratio, metal concentration, metal speciation, and contact time (Alumaa et al., 2001; Morera et al., 2001; Apple et al., 2002; Yin et al., 2002; Bradl, 2004; Arias et al., 2005; Das and Jana, 2006 and Sastre and Ma, 2006). Among them, soil pH has the greatest effect of any single factor on the solubility of metals retention (Elzahabi and Yong, 2001).

Soil pH: Lower pH values (acidic conditions) tend to increase the solubility of metals. The mechanism for this increased solubility is in part the displacement of cations on the soil adsorption sites by H^+ ions. Adsorption then increases at intermediate pH from near zero to near complete adsorption over a relatively small pH range; this pH range is referred to as the pH-adsorption edge. For examples, 50% of the copper is adsorbed at pH 2.1, and 50% of the Cd or Zn is adsorbed between pH 2.8 – 2.9 (Bradl, 2002).

Organic matter: Soil organic matter exhibits a large number and variety of functional group which results in enhanced heavy metals retention ability. Over the long term a landfill is hypothesized to have high organic content from waste degradation. Carbon-containing macromolecules in soil may form chelates with the metals in the

landfill which retain heavy metals inside the landfill (Östman et al., 2006). Ageing of soil may play an important role for heavy metals retention as sTable surface coatings are formed as a function of time and heavy metals retention onto aged soils acquires a more irreversible character (Apak, 2002).

Multiple ions in the solution: There are many factors impact metals selectivity. Competition from monovalent metal in background electrolytes has relatively little effect on adsorption on heavy metals. Preference of affinity is measured by selectivity of distribution coefficient K_d. The reduction of this selectivity with increased adsorption is observed for metal on both clays as soil components and pure mineral. (Bradl, 2004)

2.4.2 Heavy Metals Retention in Soil

For heavy metals contamination from landfill leachate, soil is the major recipient of metal contaminants. Metal ion transfer occurs at solid-solution interface consisting of inorganic colloids (e.g. clay), metal oxides and hydroxides, metal carbonates and phosphates, organic matters and living microorganisms (Sharma and Reddy, 2004). Another influencing parameter is the ligands in the solution responsible for the distribution of metal ions, inorganic and organic ligands such as humic and fulvic acids (Christensen et al., 2001and Yong, 2001).

One significant role in heavy metal retention, mobility and bioavailability is controlled by oxides of Fe, Al and Mn as well as soil organic matter (Silvera et al., 2003). Metals are subject to strong attenuation by sorption and precipitation in the plume (Christensen et al., 2001). Concentration of heavy metals found in landfill soil is different as shown in Table 2.4. Form Table, Pb and Cr concentration is much higher than Cr concentration in soil.

Table 2.4 Heavy metals in landfill soil

Authors	Locations	Pb, mg/kg	Cr, mg/kg	Cd, mg/kg
Anuluxtipun et.al. (2002)	Suphanburi, Thailand	0.004-0.076	-	0.0004 – 0.010
Östman et al. (2006)	12 landfills, Sweden	80.3 – 2837	39.9 – 115	0.1 – 5.1
Xiaoli et al (2007)	Shanghai Laogang, China	0.28 – 0.33	0.11 – 0-12	0.001 > 0.002
Kasassi et al.(2008)	North Greece	2.50 – 92.50	3.88 – 171.88	0.50 – 18.75
Vijukrattana (2009)	Kham Bon, Thailand	209	228	6

2.4.3 Heavy Metals Mobility

The concentration of soluble metals depends on chemical conditions, speciation of the metals and the degradation or disintegration of products in which the metals are embedded. Many of these processes are slow and strongly influenced by the presence of oxygen, water and acids. Transport of heavy metals within a mature landfill can be compared to transport in soil and should be taken as a very slow processes. The time requirement for a complete wash-out of a specific metal may be in the range of hundreds to thousands of years or more (Yong, 2001).

Ramos et al. (1994) studied sequential fractionation of Cu, Pb, Cd and Zn in soils from or Donana National Park, South Western Spain. They reported the mobility of soil metals is as follows; Cd > Zn > Pb > Cu. Meanwhile, Pichtel et al. (2000) studied the distribution of Pb, Cd and Ba in soils of two contaminated sites. They found that soil Pb occurred mostly in the organic and carbonate fractions, whereas Lu et al. (2003) pointed

out that Cu, Zn, Pb and Cr were dominated by the residual fraction and were least present in the exchangeable fraction in Nanjing urban soil.

2.4.4 Heavy Metals Attenuation

In the unsaturated zone, both air and water fill the pores between soil particles. The slow movement of leachate in that zone causes attenuation of certain leachate chemicals. Leachate pollutants, such as VOCs and acids, are not easily attenuated, and they move contaminant through the soil. However, positively charged Pb, zinc, Cd and mercury metals, are easily attenuated. As leachate containing these metals flows through soil, the metals stick or adsorbs to the soil and is removed from the leachate (Fetter, 2001 and LaGrega et al., 2001).

The composition of a soil and the characteristics of its binding sites affect its attenuation capability. Different soils have different abilities to attenuate and exchange chemicals. Once the binding sites of the soil particles become full, they can hold on more chemicals and henceforth, pollutants will move through the soil towards the groundwater (Freeze and Cherry, 1979; Domenico and Schwartz, 1998; Fetter, 2001and LaGrega et al., 2001).

2.5 Heavy Metals Contamination in Landfill

2.5.1 Heavy Metals Contamination in MSW Landfill

The major environmental problem experienced at landfills is loss of leachate from the site and the subsequent contamination of soil, surface water and groundwater resources. There are several reports on site characterization which identified the influence of human activity as a major cause for metals contamination of the ecosystem (Banat et al., 2005 and Öman, C.B. and Junestedt, C., 2008).

Anuluxtipun et al. (2002) reported the dispersion of Pb and Cd with leachate found in top of soil (0-15 cm) around a sanitary landfill of Muang District, Suphanburi

Province. Aliko et.al. (2003) studied the characterization of leachate from municipal solid waste landfill site in Nigeria and pointed out that the quantity and composition of leachate gives and insight into appropriate, effective and sustainable treatment approaches. Corresponding to Sharma and Reddy (2004), they stated that waste containment and remediation problem require an understanding of the physical and chemical characteristic of the subsurface and the ability to engineer pollution control and remove the contaminants. In 2008, Öman, C.B. and Junestedt, C. screened landfill leachate from 12 Swedish municipal landfill sites for 400 parameters and compound. They found that more than 90 organic & metal organic compounds and 50 inorganic elements (Cr, Cd, and Pb etc.) were detected in landfill leachate. In the same year, Kasassi et al. (2008) study the characteristic of soil samples of a closed unlined landfill of North Greece in relation to heavy metal values and samples were obtained by drilling difference depth. They found that most soil samples were contaminated by Pb, Cr, and Cd. Moreover, many researchers have been attempted to define the extent of leachate impact on surface and subsurface environment by integrating the various hydrogeochemical data with consideration for the site hydrogeology (Sterckeman et.al., 2000; Abu-Rukal and Al-Kofahi, 2001; Critto et.al., 2003; Mitra et. al., 2003; Yaqout, 2003; and Frascari et. al., 2004)

2.5.2 Heavy Metals Contamination in Kham Bon MSW Landfill

The study of impact form Kham Bon MSW landfill to the nearby environmental receptors has been done since 1994. Table 2.5 is the list of studies focused on contamination from the site.

Table 2.5 Researcher on Kham Bon site contamination

Author	Summary
Boonsaner et al., (1991)	**Objective**: To study the hydrogeology of Kham Bon site and monitor quality of groundwater around the site. **Finding**: Kham Bon site is underlain by the unconfined aquifer with loosely cemented-fine, grained sandstone, laterite and gravel beds. The overall

Author	Summary
	groundwater flow is southeastward direction. Groundwater was contaminated with Cl^-(5.0-1749.45 mg/l), NO_3^-(0 -27.5), Na (1.0-815 mg/l), K (0.3-16 mg/l), Ca (5.0-4100 mg/l), and Mn (0.008-2.3 mg/l) the concentration of these matter is high in the southern part and rather low in the northern part of the site. Surface water was contaminated with Cl^- (2109.35 mg/l), NO_3^-(2.32 mg/l), Na (1350 mg/l), K (1470 mg/l), Ca (10.8 mg/l), and Mn (0.006 mg/l).
Buaphan et al., (1999)	**Objective**: To study heavy metals contamination of groundwater. **Finding**: Groundwater flowed from southwestern part to northeastern part of the site and down to Pong River. Storage coefficients obtained from pumping test ranges from $1.592x10^{-4}$ to 2.6869 $x10^{-4}$, Transmissivity ranges from 0.47-2.11 m^2/day, hydraulic conductivity ranges from 2.9407 $x10^{-2}$ -9.375 $x10^{-2}$ m/day and pumping rates between 12.58 to 68.13 m^3/day with drawdown range from 13.05-22.28 m
Kayandee (1999)	**Objective**: To study characteristic of Kham Bon landfill leachate and monitoring heavy metals contamination in groundwater within 1.5 km radius around the site. **Finding**: Quantity of pollutants had the direction of flow from west to north and east to south follow groundwater flow direction. Pollutants in leachate were Fe (1.568mg/l), Mn(0.588mg/l), Pb(0.01mg/l), Cu(0.0445mg/l) and Cd(0.0005 mg/l). Pollutants in shallow well were Fe(0.0322-0.4107mg/l), Mn(0.0033-0.0324mg/l), Pb(0.0322-0.410mg/l), Cu(0.0027-0.00726mg/l) and Cd(0.00093-0.0001mg/l).
Chuangcham (2008)	**Objective**: To study the adsorption behavior of Cd, Pb and Zn onto soil landfill leachate by column test method. **Finding**: The physicochemical properties of soil effect to the behavior of heavy metals adsorption which Zn > Pb > Cd > Cr.
Promlao (2008)	**Objective**: To study Pb, Cr, and Cd in soil, surface water, groundwater and plants within 500 m radius around the site. **Finding**: Pb, Cr and Cd contamination in soil, groundwater,, surface water and plants. Pb was found in groundwater and surface water higher than Cd and Cr.

2.6 Groundwater Modeling

2.6.1 Theory

Groundwater models are physically based mathematical models derived from Darcy's law and law of conservation of mass. Various established solution techniques based either finite difference or finite element approximations, or a combination of both, are available for solving the governing equation of the model. Equations involve direction of flow, geometry of the aquifer, the heterogeneity or anisotropy of sediments or bedrock within the aquifer, the contaminant transport mechanisms and chemical reactions. The accuracy of the solution (model predictions) is dependent upon the reliability of the estimated model parameters and the accuracy of the prescribed boundary conditions. The models are a useful investigation tool that groundwater hydrologists may use for a number of applications (Singh, 2008).

Groundwater model can be classified in several ways: steady state or transient; confined, unconfined, or a combination of confined and unconfined; one, two, quasi-three, or three. 3D groundwater flow through heterogeneous, porous media used to calculate the rate and direction of movement of groundwater through aquifers and confining units in the subsurface is described by the partial-differential equation (Karlheinz,1996).

$$\frac{\partial}{\partial x}\left[K_{xx}\frac{\partial h}{\partial x}\right]+\frac{\partial}{\partial y}\left[K_{yy}\frac{\partial h}{\partial y}\right]+\frac{\partial}{\partial z}\left[K_{zz}\frac{\partial h}{\partial z}\right]-W=S_s\frac{\partial h}{\partial t} \qquad (4)$$

Where:

K_{xx}, K_{yy} , and K_{zz} = the hydraulic conductivity xx yy zz along the x, y, and z axes that are assumed to be parallel to the major axes of hydraulic conductivity (L/T)

h = the potentiometric head (L),

W = volumetric flux per unit value (L/T)

S_s = specific storage of porous material (L^{-1})

T = time (T)

Fate and transport models estimate the concentration of a chemical in groundwater beginning to the environment to locations down gradient of the source and can be described as second-order partial differential equation.

$$\frac{\partial c}{\partial t} + \frac{(1-n)}{n}\rho_s \frac{\partial c_a}{\partial t} = -\frac{\partial}{\partial x_i}(v_i c) + \frac{\partial}{\partial x_i}\left(D_{ij}\frac{\partial c}{\partial x_i}\right) - \lambda c - \varepsilon Q c_{in} \quad (5)$$

Where

I,j = 1,2,3 (principal coordinate directions)

c = concentration at time t (M / L^3)

c_a = adsorbed contaminants (I)

λ = rate constant that characteristic decay (T^{-1}),

n = total porosity (I)

ρ_s = density of dry matrix material (M / L^3)

Q = local sources and sinks per unit volume (T^{-1})

v = transport velocity (L/T)

D = dispersion coefficient (L^2/T)

x = space coordinate (L)

t = time (T)

Equations can be solved using *finite difference method* or *finite element methods* or a combination of these. The finite element method consists of a triangular discretization as illustrated in Figure 2.4. In nature system, finite element is more flexible in design. It is easy to define the boundaries of irregularly shaped aquifers to ensure that node points coincide with monitoring wells or various types of geographic features (Kriz, 2004).

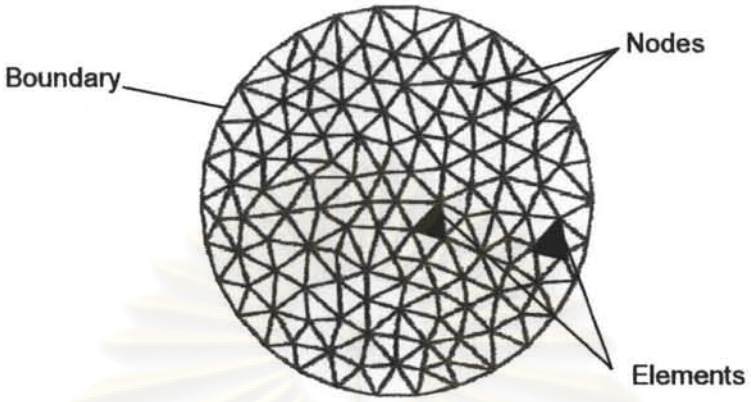


Figure 2.4 Finite element mesh

Available from: http://commons.wikimedia.org/wiki/File:Finite_element_triangulation.svg

2.6.2 Groundwater Modeling Application

The use of groundwater flow models is common in the field of environmental engineer. Models have been applied to investigate hydrogeologic conditions and applied to predict the fate and transport of contaminants for risk evaluation. There are many groundwater computer models available both as commercial and freeware. Commonly used groundwater model is listed in Table 2.6

Table 2.6 Commonly used groundwater flow and transport models

Name	Distributor	Description
EPA-WHPA	USEPA	A semi-analytical ground water flow simulation program is used for delineating capture zones in a wellhead protection area. The program consists of four computational modules. Available from: http://www.epa.gov/ada/csmos/models/whpa.html
USGS Software	USGS	USGS has been developed many groundwater model form many application including contamination transport which are. BIOMOC - A multispecies solute-transport model with biodegradation HST3D - 3D flow, heat, and solute transport model MF2K-GWT -3D groundwater flow and solute-transport model integrated with MODFLOW-2000 MODFLOW-3D finite-difference model PHAST -Simulating ground-water flow, solute transport, and multicomponent geochemical reactions Available from: http://water.usgs.gov/software/lists/groundwater
AT123D	International Groundwater Modeling Center,	An analytical groundwater transport model. It computes the spatial-temporal concentration distribution of wastes in the aquifer system and predicts the transient spread of a contaminant plume.
PLUME3D	IGWMC	A solute transport from point source, uniform flow field
MODFLOW	IGWMC	A 3D, finite difference model. Layers can be simulated as confined, unconfined or a combination of the two. Flow associated with external stresses. Such as wells areal recharge, evaporation, drains, and stream, can also be simulated.
PRINCE	Waterloo Hydrologic	An analysis models including advective-dispersive transport with decay and retardation Available from: http://www.waterloohydrogeologic.com/

Name	Distributor	Description
FEFLOW	DHI	A finite element simulation for groundwater flow, mass transfer and heat transfer in porous media. The program solves for both saturated/unsaturated conditions as well as mass and heat transport, including fluid density effects and chemical kinetics for multi-component reaction systems. Available from: http://www.feflow.info/aboutfeflow.html
MicroFEM	University of Colorado	A finite element ground-water modeling. Feature includes preprocessing, calculation, postprocessing, graphical interpretation and plotting. Confined, semi-confined, phreatic, stratified and leaky multi-aquifer systems can be simulated with a maximum of 20 aquifers. Available from: http://www.microfemnl/

2.6.3 Visual MODFLOW

Visual MODFLOW provides professional 3D groundwater flow and contaminant transport modeling using MODFLOW-2000, MODPATH, MT3DMS and RT3D. The model feature includes:

- Graphically design the model grid, properties and boundary conditions,
- Visualize the model input parameters in two or three dimensions,
- Run the groundwater flow, path line and contaminant transport simulations,
- Automatically calibrate the model using WinPEST or manual methods, and
- Display and interpret the modeling results in 3D space using the Visual MODFLOW 3D-Explorer

MODFLOW: The MODFLOW Model is a 3D groundwater flow model that is used in estimating groundwater flows in multi-layers either of unconfined of confined subsurface conditions depending on their corresponding hydrologic characteristic. Results from the model will show the hydraulic heads and groundwater flow as well as the velocity and flow distance at specified time intervals (Kumar, 2001).

Input data for the MODFLOW is from the soil borings and geotechnical testing for landfill site. Data input are hydraulic conductivity, groundwater level at various monitoring wells and the observed water levels of surrounding surface water. The obtained ground elevation data of the site will be used to determine the groundwater flow direction and to assess the possible impact of leachate contamination to the nearby drinking water well. The observed groundwater Table will be input to the MODFLOW Model to compare with the data obtained from the model for calibration. Results from the model are the display of contamination plum and prediction of contamination migration in the future.

MT3DMS: MT3DMS is a mass transport model incorporated into the Visual MODFLOW environment that simulates advection, dispersion, and reaction of solutes in groundwater. After a flow model is developed and calibrated, the information needed by the transport model can be saved in disk files which are then retrieved by the transport model. Since most potential users of a transport model are likely to have been familiar with one or more flow models, MT3DMS provides an opportunity to simulate contaminant transport without having to learn a new flow model or modify an existing flow model to fit the transport model.

2.6.4 Mathematical Modeling for Groundwater Contamination

Models have been applied to investigate a wide variety of hydrogeologic conditions and contaminant transport. MODFLOW model was applied and report as listed in Table 2.9. From the Table, it can be seen that MODFLOW is well established model for groundwater and fate and transport to predict the migration pathway and concentrations of contaminants in groundwater.

Table 2.7 List of research using MODFLOW model in environmental application

Author	Location	Model	Model Type		Summary
			Ground water	Transport	
GURUNADHA et al. (2000)	Patancheru, India	MODFLOW, MT3D	√	√	**Objective:** To study the migration of contaminants in Nakkavagu stream **Finding:** The migration of contaminants is rapidly in stream aquifer of eastern part of Nakkavagu stream
Chaisayun et al. (2004)	Sukhothai, Thailand	MODFLOW	√		**Objective:** To simulation and compare MODFLOW, MIKE SHE and SGDP models. **Finding:** The pumping rate and amount of rainfall were factors affecting water level fluctuations. MODFLOW model is the most accurate.
Tiwary et al. (2005)	Sukinda chromite valley, India	MODFLOW, MODPATH	√	√	**Objective:** To study Cr(VI) in groundwater, surface water, mine effluents and seepage water and predict migrationin 20 years. **Finding:** All sample were contaminated with Cr (VI). The migration of Cr(VI) is very low in groundwater and thus surface water is mostly affected due to surface runoff.
Lautz et al.(2006)	Red Cayon Creek, USA	MODFLOW, MT3D	√	√	**Objective:** To simulated hyporheic zones around debris dams along a semi-arid stream **Finding:** Debris dams are a key driver of surface water into the subsurface along Red Cayon Creek. The model approach simulated surface and groundwater mixing in the hyporheic zone, and provides numerical approximations that are more comparable to field-based observations.

Author	Location	Model	Model Type		Summary
			Ground water	Transport	
Mondal et al. (2008)	Industrial belt, India	MODFLOW, MODPATH	√	√	**Objective**: To study contamination in groundwater and contaminant migration. **Finding**: The migration phenomenon is mainly through advection rather than dispersivity. This modeling study indicated that if the pollutant sources were reduced to 50% of the present level, TDS in groundwater, would not be reduced below 50%.
Naimolee (2002)	Tambon Khlong Kwang, Amphong Sainoi, Thailand	MODFLOW, MT3D	√	√	**Objective**: To study the contamination in groundwater and surface water. **Finding**: Groundwater in shallow subsurface level and surface water were contaminated with heavy metal. The pattern of observed contamination in the shallow wells, together with the groundwater flow from northeast to southeast.

CHAPTER III

METHOD OF STUDY

This research focuses on investigate heavy metals contamination from MSW landfill site in soil, surface water and groundwater where the study area covered 2 km radius of the site center. The study is divided into two parts. First, contamination in the study area was investigated by soil, surface water and groundwater sampling. Then, groundwater modeling using Visual MODFLOW was employed to determine heavy metals transport in groundwater. Study process is shown in Figure 3.1.

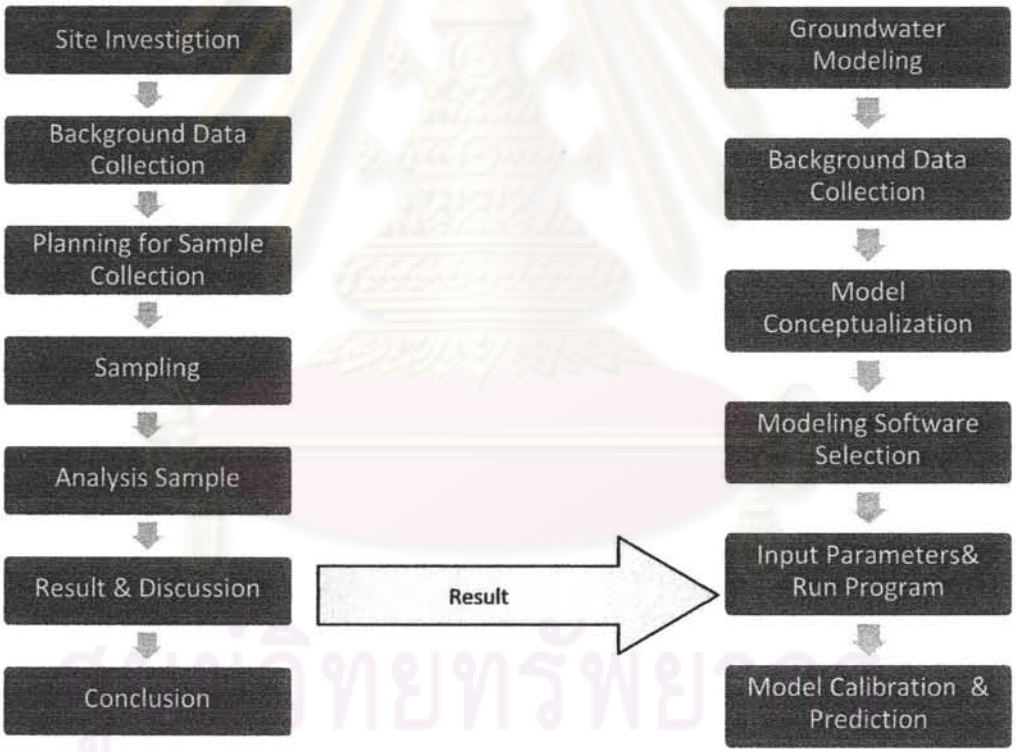


Figure 3.1 Study process

From Figure 3.1, site investigation was started from study and review data on soil, geology and hydrogeology in the study area. The previous works were reviewed as well as site visit was performed. Then, the surveying and planning for design suitable sampling collection in the site were done. After samples were collected from fields and analyzed, the results were used as input data for Visual MODFLOW model. Modeling results were used to explain heavy metal contamination distribution pathway and predict future contamination.

Details of study methodology is as follows

3.1 Site Investigation

Site investigation involved gathering information on the site geology together with chemical and physical nature of the site. In this research, site investigation was performed as described below.

3.1.1 Background Data Collection

Background data included historic data of the site, current status, site location and site environment. The site information was gathered from geological reports, archived material, aerial photographs, maps, field survey and interview.

3.1.2 Planning of Sample Collection

Sampling was undertaken two times in order to cover dry and wet season. Wet or rainy season samples were taken in October 2009. Dry season samples were taken in February 2010.

Sample collection for soil, surface water and groundwater was planned on the basic of site history and reconnaissance information as follow.

Soil: From the aerial photograph (Figure 3.2), topographic map and site survey, it was found that the site situates on top of elevated land about 180 to 220 m above mean sea level. During rainy season, runoff from the landfill flows over the area around the landfill to nearby creeks in the north and south of the landfill. Area around the site was covered by economic plants which are cassava, sugar cane, orchard and rice field. In order to investigate heavy metals contamination in soil due to leachate, soil sampling was design to collect cover the area in all direction.

In this research, 20 locations were selected for soil samplings. The samples were collected within 2 km radius from the landfill corners, at the distance of 100, 500, 1 000, 1 500 and 2 000 m in 4 directions oblique from the corners as shown in Figure 3.3.

Figure 3.2 Arial photo of Kham Bon landfill site

Avialable from: http;//www.google.com

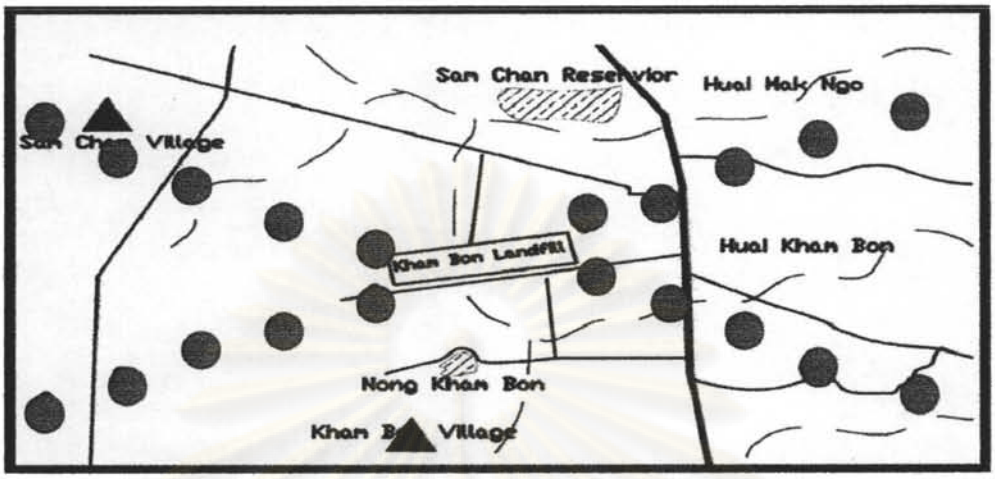


Figure 3.3 Location of soil sample collection

Surface water: Surface water sample was selected from the manmade and natural pond in 2 km radius from the landfill center. Location of surface water sampling is shown in Figure 3.4. Details of each sampling point are in Table 3.1.

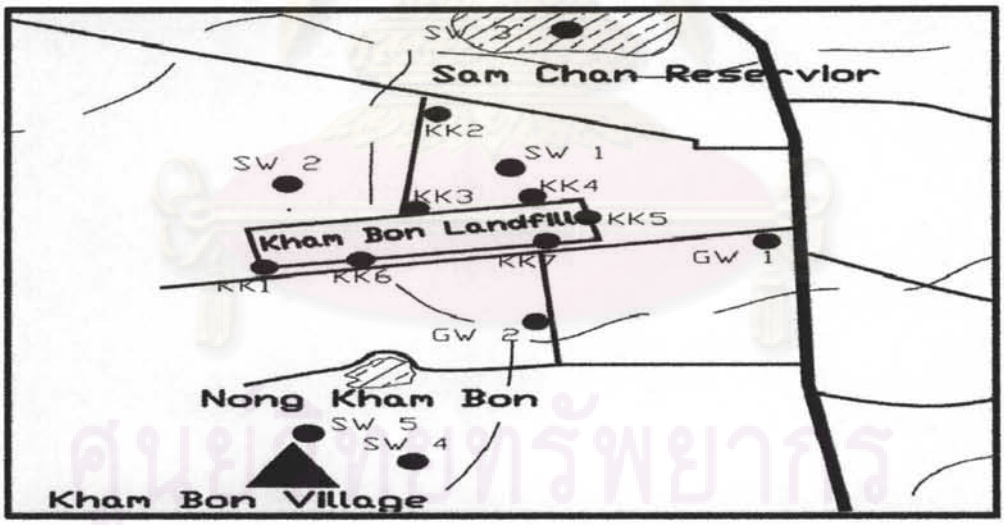


Figure 3.4 Location of surface water and groundwater sampling points

Table 3.1 Details of surface water sampling points

Sample No.	Name	Usage	Direction	Distance from the site, m
SW1	-	Personal use for rice field	North	100
SW2	-	Personal use for agriculture	Northwest	100
SW3	Sam Chan reservoir	Public Water Supply	Northeast	300
SW4	-	Personal use for agriculture	Southwest	500
SW5	-	Personal use for agriculture	Southwest	500

Groundwater: When the landfill was renovated in 1998, 7 monitoring wells were constructed around the site and maintenance in 2010 by Groundwater Resources Department. In this study, samples were taken from the monitoring wells and farmers' private wells in the radius of 2 km around the site. Sampling locations are shown in Figure 3.4. Details of each sampling point are stated in Table 3.2

Table3.2 Details of groundwater sampling points

Sample No.	UTM		Elevation, m	Observation Head, m	Usage
	East	North			
KK1	265705	1835893	189.027	5.6	Monitoring – well
KK2	266119	1836284	181.05	1.35	Monitoring – well
KK3	266113	1836087	182.86	2.24	Monitoring – well
KK4	266192	1836060	148.89	7.55	Monitoring – well
KK5	266317	1836110	187.807	4.7	Monitoring – well
KK6	265911	1835899	185.576	7.3	Monitoring – well
KK7	266185	1835931	184.452	3.25	Monitoring – well

Sample No.	UTM		Elevation, m	Observation Head, m	Usage
	East	North			
GW1	-	-	-	-	Private well
GW2	-	-	-	-	Private well

3.1.3 Sample Collection and Analysis

After sample collection was planed, samples were collected and analyzed in the Chemical Laboratory, Department of Environmental Engineering, Khon Kaen University. Details of sample collection and analysis are as follows

Soil: Samples were collected, prepared and analyzed followed the procedure below.

1) Samples were collected from 20 – 200 cm. depth (20, 50, 100, 150 and 200 cm.) with hand auger (Figure 3.5). One sample was taken at one sampling location. At each depth, about 500 gm. of soil sample was collected and stored in a plastic bag, then taken to the laboratory.

2) Samples were air dried (Figure3.6), ground and sieved through a 2-mm. stainless steel sieve to remove gravel and rock. Then, there are stored in the sealed plastic for analysis (Figure 3.7).

3) Samples were analyzed according to the standard method (Standard Method for the Examination of Water and Wastewater, 1998) which are;

pH: pH was analyzed by diluting soil with water ratio 1:1, then measured with pH meter, TOA Model HM-5ES, using buffer of pH 7.0 and 9.2 as standard.

EC (Electrical conductivity): EC was analyzed by diluting soil with water ratio 1:1, and measured with a conductivity meter (TOA, Model CM-78)

OM (Organic matter): OM was determined by the wet oxidation method of Walkeley and Black (Black, 1965). The procedure of OM analysis is shown in Figure 3.3.

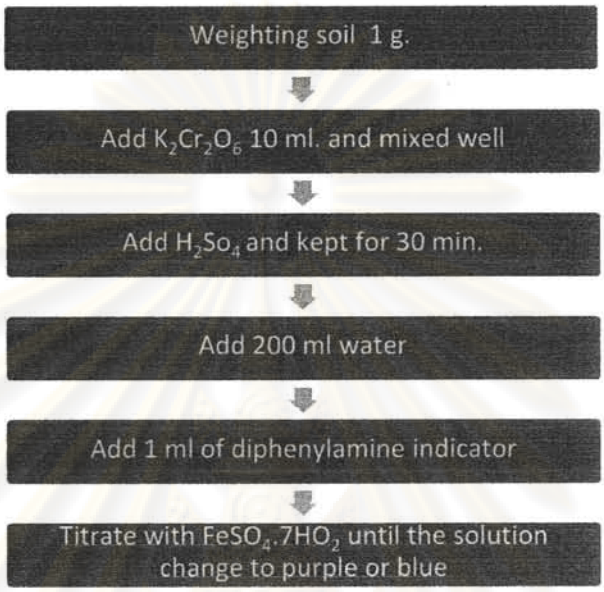


Figure 3.5 Procedure of Organic Matter analysis

Heavy metals: Heavy metals were determined by digesting with acid following method 3050 B (USEPA, 1995), then analyzed for heavy metals in aqueous phase using Atomic Absorption Spectroscopy. Chemical used for acid digestion are Nitriç acid, (65%, Merck, Germany) and Hydrogen peroxide aqueous solution (30 %, Merck, Germany). Step of soil digestion is shown in Figure 3.4.

After digesting to aqueous phase, samples were analyzed using a Shinmadzu AA 6501F Series Flame Atomic Absorption Spectrophotometer (Figure 3.8). Standard Solution used are Pb, Cr and Cd concentration 1000 mg/l, Merck, Germany.

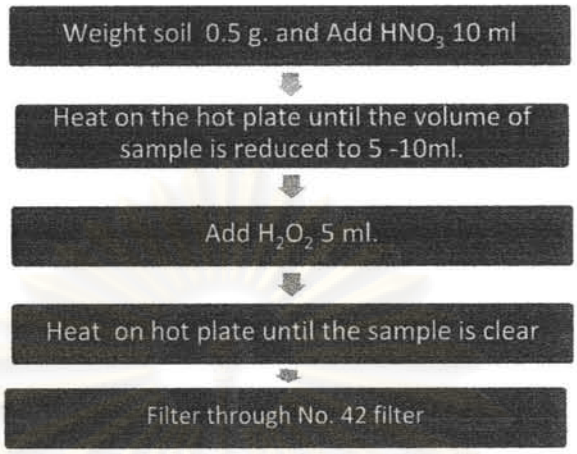


Figure 3.6 Procedure of soil preparation for heavy metals analysis

Figure 3.7 Soil auger

Figure 3.8 Soil sample was air dried

Figure 3.9 Soil sample in sealed

Figure 3.10 Flame Atomic Absorption Spectrophotometer

Surface Water: Surface water samples were collected by water bucket. Samples were prepared by acidified with HNO_3 to pH 2, filtered through Whatman No. 42 filter paper prepared and stored at a temperature of 4 °C prior to analysis. Surface water sample analysis for pH, EC and heavy metals is the same as soil sample analysis as described previously.

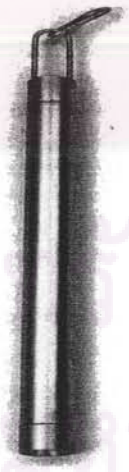


Figure 3.11 Stainless Bailer

Groundwater: Groundwater samples were collected from monitoring wells by Stainless Bailer (Figure3.11). For private well, water was pumped for 15 minute before collecting to ensure that sample collected is from the aquifer. Groundwater samples were prepared and analyzed the same as surface water samples.

Background Blank Samples: Background blank samples were collected and analyzed to determine heavy metals in the background soil, surface water and groundwater.

Soil: The samples were collected around Kaennakorn Lake and Sethan Lake approximately 15 km form Khambon landfill site. Soil samples were collected by hand auger at the depth of 20, 50, 100, 150 and 200 cm from the ground surface. Then, samples were analyzed same as the samples from Kham Bon Landfill Site.

Surface Water: The surface water samples were collected from Kaennakorn Lake and Sethan Lake approximately 15 km form Kham Bon landfill site. Then, samples were analyzed the same as the samples from Kham Bon Landfill Site.

Groundwater: Heavy metals concentration in the public groundwater wells has been routinely monitored by the Groundwater Resource Department. In this research, monitoring data from 3 wells in Khon Kaen was used. Two wells located in Muang District (17 km from the site) and 1 well located in Ubonratana Dam District (30 km from the site). The sampling period was during September 2009-February 2010.

3.1.4 Statistical analysis

The statistic analysis was performed by using *Independent Samples t-test* for significant association between variables. The correlation between distribution of heavy metals (distance, depth, direction, seasonal) and three heavy metals (Pb, Cr, and Cd) were calculated. In additional, all samples in this research were analyzed 3 duplicates.

3.2 Groundwater Modeling

Site investigation provides the information of contamination in the area. However, in order to elucidate contamination migration and future contamination in the area, mathematical model can be used. In this study, data from site investigation were used to set up mathematical model of groundwater contamination at the site.

3.2.1 Background data collection

Background data including soil and hydrology data were collected from survey and reports

3.2.2 Model Conceptualization

Groundwater modeling, information was sourced out from geological reports, archived materials, aerial photographs and map interpretation. Then, these information were used to make the conceptual model of the study area. From the conceptual model, MODFLOW was selected to use in this study because it is a well-documented and extensively tested.

3.2.3 Modeling Software Selection

After site investigation was completed and the conceptual model was developed, the computer model software was selected. Since the contaminant is transported through groundwater with leachate and contamination in subsurface occurred in saturate zone, groundwater model is suitable for this site. In this case, 3D groundwater flow and transport models was selected based upon the hydrogeological characterization and model conceptualization.

Computer program Visual MODFLOW 3.1 developed by Waterloo Hydrogeologic Software (WHS) is a computer program that is wildly used in groundwater and contamination modeling. It has features to support the 3-dimetional calculation, display

result in graphic, suitable for subsurface contamination and easy to use. Thus, it was selected to use in this study. Visual MODFLOW 3.1 was used to determine the contaminant distribution pathway. and to assess the possible impact of leachate contamination to the nearby drinking water well within the 2 km. radius around the site. The groundwater flow model was calibrated to steady-state condition.

3.2.4 Input Parameter Collecting

Input parameter includes all parameters that are used to develop a calibrated model. The input parameters used are model grid size and spacing, layer elevations, boundary conditions, hydraulic conductivity/transmissivity, recharge, any additional model input, steady state modeling, dispersion coefficients. Parameters input were collected from many source and method. Details of parameter input, and collection method is shown in Table 3.3.

Table 3.3 Method of collecting parameter input

Model Input Parameters	Potential Source of Data	From
1. Hydraulic conductivity	Slug, pump and packer tests, and published data	Groundwater Resource Department
2. Specific storage	Slug and pump test	Karlheinz, S and Moreno, J,1996
3. Specific yield	Pump test and porosity data	Karlheinz, S and Moreno, J,1996
4. Porosity	Soil analysis	Karlheinz, S and Moreno, J,1996

Model Input Parameters	Potential Source of Data	From
5.Recharge/discharge	Precipitation, soil properties, stream flow, pumpage records, elevation, vegetation maps, land use	The Thai Methrologic Department Land Develop Dept.
6. Initial water levels, gradients	Fields water level	Field survey
7. Background concentrations	Fields concentrations	Field survey
8. Adsorption distribution coefficient	Batch and column tests, empirical equation for organic, and published data	Udomporn Chuangcham, 2007
9. Dispersivity	tracer tests, other field-test models, or published data	Karlheinz, S and Moreno, J,1996
10. Soil bulk density	Soil analysis	Karlheinz, S and Moreno, J,1996
11. Density and viscosity	Published data	Karlheinz, S and Moreno, J,1996
12. Contaminant sources	Material inventory, storage, and use, leachate tests, aerial photographs. Etc.	Field Survey

3.2.5 Model Calibration

Model calibration consists of changing values of model input parameters in an attempt to match field conditions within some acceptable criteria. In this study, hydrology model calibration was done by computed hydraulic head and measured head values were compared and model parameter adjusted to improve the degree of fit

between the simulated and observed water levels and contaminant model was calibrated by computed concentration and measured concentration values were compared and model parameters adjusted to improve the degree of fit between the simulated and observed concentration. The model were calibrate until the different between filed data and model result is less than 10 %. Analysis of the difference between measured and location of parameter adjustment in order to minimize the difference.

3.2.6 Model Prediction

After calibration, the model was used to predict contaminant transport condition in the future. Migration pathway and concentrations of contaminants in groundwater was elucidated using the model. In addition, concentration of heavy metals in soil around the site in the future was predicted.

CHAPTER IV

RESULT & DISCUSSION

Results of this study can be divided into two parts, 1) the investigation of Pb, Cr, and Cd accumulation in soils, groundwater, and surface water from Kham Bon Landfill site and 2) mathematical modeling of groundwater contamination from the landfill. This chapter is organized into 3 main sections:

Description of study area: Descript the Kham Bon Landfill site in terms of its location, history, topography, geology and drainage.

Heavy metals contamination: Results of surface groundwater and soil samples collection and analysis for heavy metals during rainy and dry season in year 2008.

Mathematical model: Results of Mathematical model simulation of the pollution transport in groundwater using MODFLOW.

4.1 Description of study area

4.1.1 Site Characteristic

The study area lies within the boundaries of the Kham Bon sub district, Khon Kaen province, Thailand. It is about 17 km. north of Khon Kaen city along national highway A2 (Friendship Highway) as shown in Figure 4.1. The site covers area of 156 800 m^2. The landfill has been used since 1968 and operated by Khon Kaen Municipality.

The community closet to the landfill is Kham Bon Noi community with approximately 70 households with population of 200. It locates about 20 m

south of the site. The community does their living by sorting garbage in landfill to collect and sell recyclable items to recycle shops nearby (Figure 4.2).

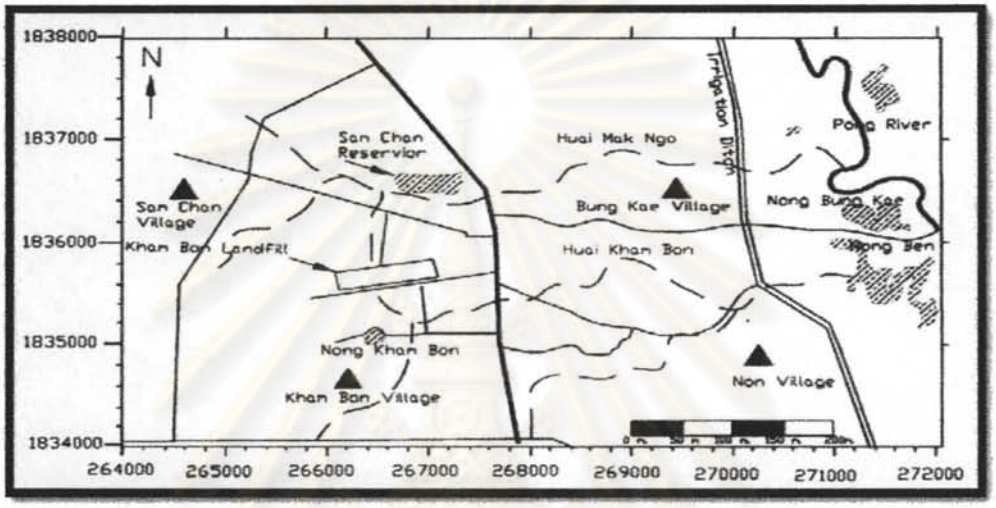


Figure 4.1 Location of Kham Bon landfill site

Figure 4.2 Villagers from Kham Bon Noi sorting garbage

4.1.2 Surface and Groundwater Direction

The site is situated on top of elevated land, surrounding with crops cultivation, typically cassava, sugar cane, eucalyptus and rice. It is located on a ridge about 180 to 220 m above mean sea level between Huai (stream) Mak Ngo at the North and Huai Kham Bon at the South. The ridge is part of the rolling terrain of the Middle terrace, a geomorphological feature of Khon Kaen region and slope gradually down eastwards to the floodplain of Phong River at the east (Boonsener, 1991).

Site survey, aerial photograph interpretation and topography map examination reveals that surface water drains in 2 pathways. First, surface runoff drains northwards from the site into Sam Chan reservoir and then flows eastwards to Huai Mak Ngo before discharge to Pong River. Second, runoff drains southwards into Huai Kham Bon and then flow to Nong Bung Kae and Pong River (Figure 4.3). Groundwater aquifer depth in the area is less than 1.0 m. in some area during wet season and moves to the southeast direction toward the River as shown in Figure 4.4.

4.1.3 Site Geology

Figure 4.5 and 4.6 shows geological characterization and geology cross section along east-waste direction. The site is on Khorat plateau. The geological features are Khorat group of sedimentary rocks, Phu Phan and Khok Kruat formation. Phu Phan formation consists of sandstone, conglomeratic sandstone and conglomerate. Alluvial sediments of Quaternary age are also found on top of Phu Phan formation in some area.

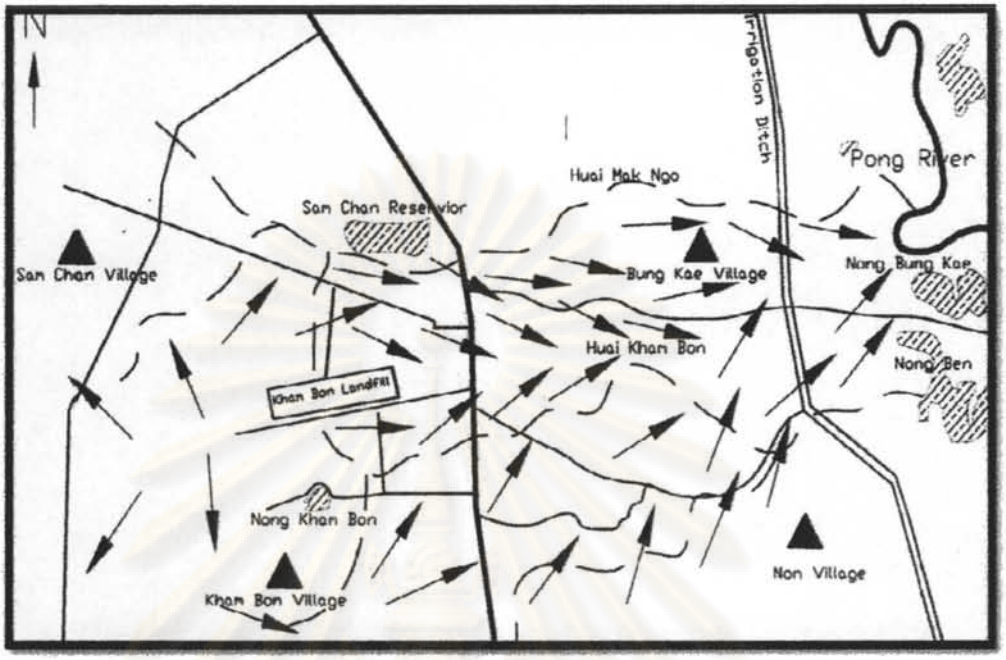


Figure 4.3 Surface run-off flow directions

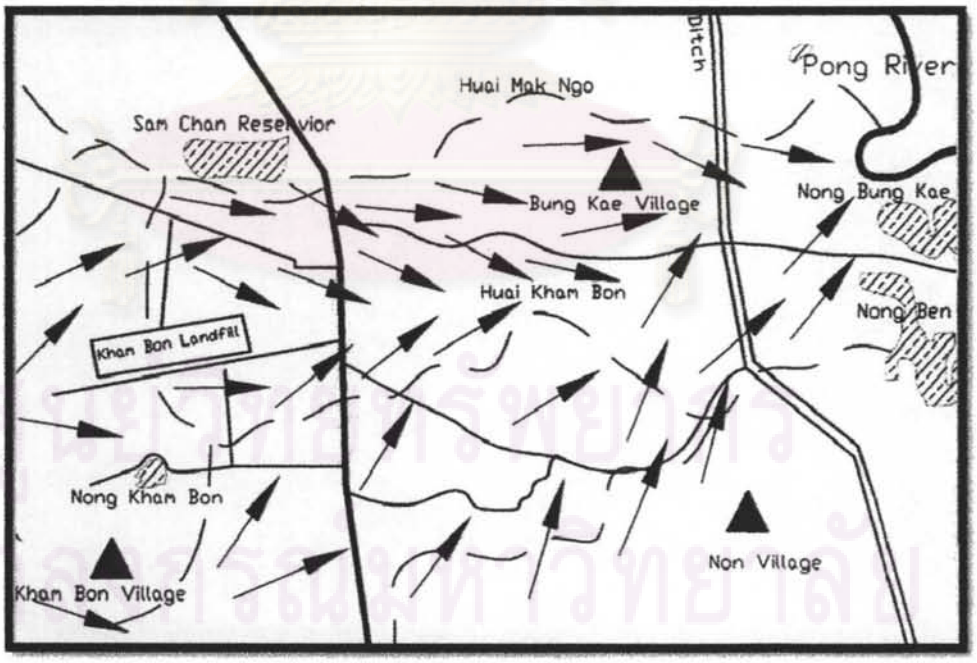


Figure 4.4 Groundwater flow directions

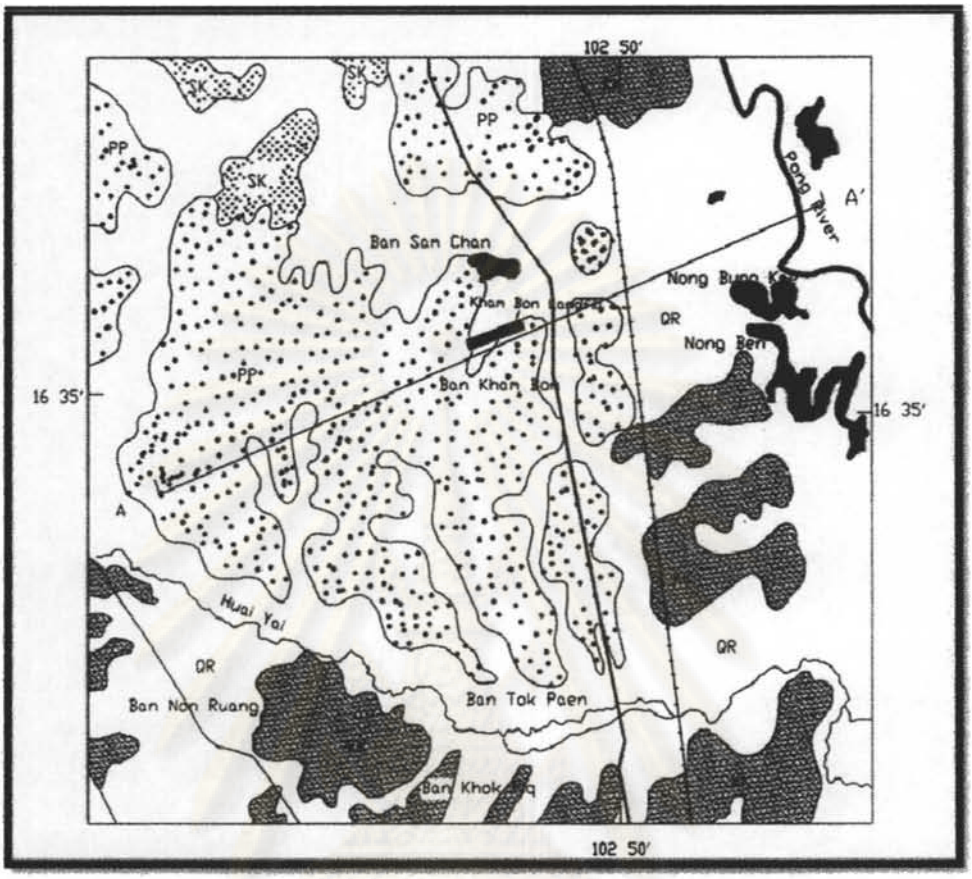


Figure 4.5 Geological characterization (Buaphan C. et al. 1999)

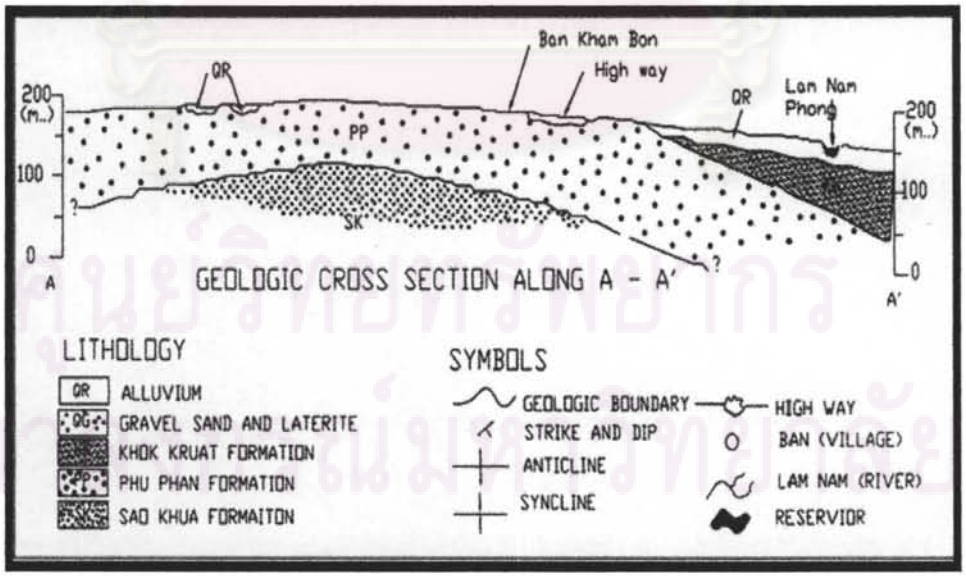


Figure 4.6 Cross section along east -west direction (Buaphan C. et al. 1999)

4.1.4 Site Management and Problem

Kham Bon Landfill site received MSW from Khon Kaen municipality along with 15 nearby communities which is approximately 200 tons/day of waste. Waste disposed at this site consists of food, plastic, paper and cardboard, wood, glass, metals and related municipal garbage. A study determined the composition of waste and the results are shown in Figure 4.7 (Priyaprasit 1996). In addition to the MSW, hazardous waste such as batteries, used fluorescent lamp, used aerosol spray cans, insecticide containers and paint containers are also found in the site. Estimated composition and percentage of hazardous waste disposed in the landfill are shown in Table 4.1 (Kirathithorn, 2004).

The landfill was not designed for hazardous waste disposal. Therefore, hazardous chemicals from this site have potential of leaching into soil, surface water and groundwater around the site. Chuangcham (2008) reported that mixed wastes had been burnt repeatedly in the open air within the site, which might cause heavy metals to be released to environment. The contamination has been clearly identified (PCD,1998; Kayandee 1999; Boupan 1999; Chuangchum , 2008 and Promlao et. al. 2008) , especially heavy metals content, cadmium (Cd), chromium (Cr) and lead (Pb), in monitoring wells surrounding the landfill site, private wells and wells used for community water supply. Thus, it is posting negatively impact to groundwater and providing a health risk to nearby villagers.

4.1.5 Climate

The average annual rainfall in this area (The local of meteorological) is approximately 1,750 mm, with about 80% falling between June and September. The average relative humidity is 76% and the potential evaporation rate is about 1,575 mm. per year, with the highest evaporation occurring between February and June.

The average annual temperature is 26.5 °C, with an average maximum of 33 °C in April and an average minimum of 20 °C in January.

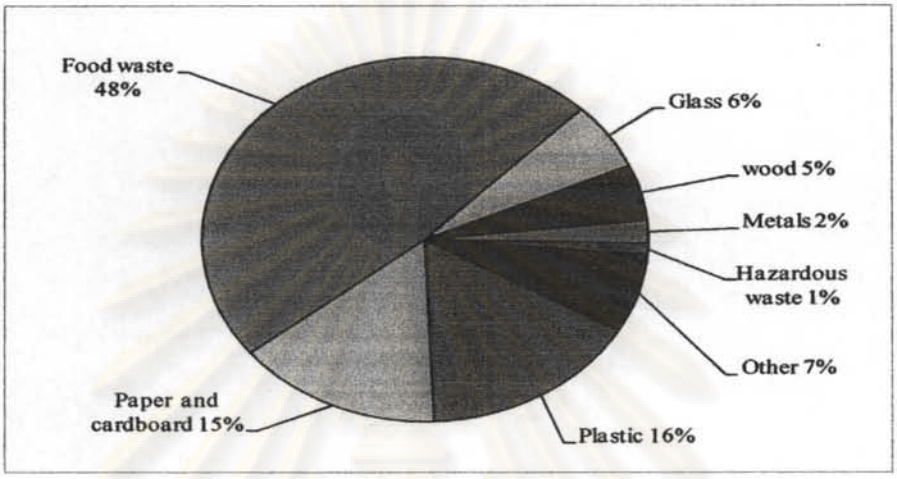


Figure 4.7 Percentage of waste deposed in the landfill (Priyaprasit, 1996)

Table 4.1 Composition of hazardous waste in Kham Bon landfill site (Kirathithorn, 2004)

Item	Percentage of Hazardous Waste Deposited
1. Used battery	0.41
2. Insecticide Containers	0.36
3. Spray paint cans	0.50
4. Cleaning and Detergent Containers	0.20
5. Motor oil/filter Cans	0.18
6. Used Fluorescence Lamps	0.24
Total	1.48

4.2 Kham Bon Landfill Site Investigation

Sample collection was designed on the basic of site history and reconnaissance information. Soil, surface water, and groundwater up and down gradient of the landfill site were collected. Sampling was undertaken two times per year to monitor the impact of season to the concentration of contaminants from landfill. Analytical results are in Appendix A. Discussion of heavy metals contamination is as follow.

4.2.1 Heavy Metals Contamination in Soil

Analytical results of heavy metals analysis, organic content and pH of soil samples from Kham Bon site concludes in Table 4.2, 4.3 and 4.4, respectively. Details of heavy metals analysis result are in Table A1, Appendix A. From the analysis, heavy metals were found in most soil samples. Thus, it demonstrates the contamination of Pb, Cr and Cd with runoff and subsurface aquifer at least 2 m in depth and 2 km radius surrounds the site. Amount of Pb (0.50-5.00mg/kg), Cr (2.00-5.00mg/kg), and Cd (0-0.25mg/kg) were found while heavy metals in background samples were non-detectable. Concentration of all metals in soil samples was lower than standard for agriculture recommended by PCD. The highest concentration of heavy metals was found within a radius of 500 m of the landfill site, decreasing with distance from the site.

Organic matters in soil samples in dry season (0.133 – 0.236%) is higher than in rainy season (0.115 – 0.188 %). However, organic matter in Kham Bon soil is lower than general soil in northeast part of Thailand. Because, standard of organic matter from Land Development Department (Table 4.5) is general soil in northeast part of Thailand usually have the organic matter about 1.5%. However, amount organic matter in northwest direction is lower than in northeast, southeast and southwest direction.

Table 4.2 Analytical results of Pb, Cr and Cd in soil samples

Direction	Concentration (mg / kg)					
	Pb		Cr		Cd	
	Rainy	Dry	Rainy	Dry	Rainy	Dry
Northeast	2.25 ± 1.1	0.483 ± 0.0	2.90 ± 1.0	2.162 ± 0.9	0.099 ± 0.1	0.10 ± 0.16
Southeast	5.067 ± 4.5	2.974 ± 3.7	5.032 ± 2.4	2.336 ± 1.1	0.199 ± 0.1	0.24 ± 0.18
Southwest	3.388 ± 1.4	1.300 ± 1.0	2.59 ± 1.01	4.015 ± 3.2	0.021 ± 0.02	0.04 ± 0.05
Northwest	2.16 ± 1.01	0.885 ± 0.7	2.51 ± 1.05	2.167 ± 1.3	0 ± 0.00	0 ± 0.00
Background Blank	N/D		N/D		N/D	
Standard*	400		300		37	

Note: *Water quality Cass III recommended for agriculture usage as published in the Royal Government Gazette, Vol. 111, Part 16, dated February 24, B.E.2537 (1994).

Table 4.3 Organic matter of soil samples

Direction	% Organic Matter	
	Rainy	Dry
Northeast	0.180±0.177	0.217±0.211
Southeast	0.188±0.151	0.236±0.149
Southwest	0.183±0.109	0.219±0.131
Northwest	0.115±0.11	0.133±0.118

Table 4.4 pH of soil samples

Phase	pH
Surface water	5.79 – 6.88
Groundwater	5.60 – 6.91
Soil	5.50 – 6.50

Table 4.5 Organic matter in Thailand

Part of Thailand	Organic Matter, %
Northeast	> 1.5
North	1.5 – 3.5
Central	3.5 – 5.0
South & East	< 5

Note: Distribution of organic matter in Thailand surveyed by Land Development Department

Lead(Pb) Contamination in Soil

Pb was found highest in Kham Bon soil comparing to Cr and Cd while Pb in background samples were non-detectable. Pb was found in all soil depth and increase in rainy season. Result from independent samples t-test found that Pb concentration was found increasing with depth (92%) and decreasing with distance (95%). In northeast direction and southeast direction have chance to contaminate more than other direction. Pb concentration was found higher in rainy season than dry season and distributed both horizontally and vertically throughout the area.

From previous study, Pb was found in leachate 0.01 – 0.03 mg/l (Chuagngcham, 2008) and in landfill soil 209 mg/kg (Vijukrattana 2009). From Table 4.2, Pb is 0.50-5.00 mg/kg. It can be seen that Pb trends to adsorb in landfill soil rather than migrate to environment. This may due to the binding to organic content in landfill (Östman et al., 2006). Kham Bon landfill has been operated than 30 years, thus heavy metals retention as stable surface coatings could be formed as a function of time and became irreversible character (Apak, 2002). Kham Bon Soil has pH range from 5.50 – 6.50 (Table 4.4), thus, soil in the site is under acidic condition which provide good solubility of Pb (McLean and Bledsoe 1992). Organic matters in Kham Bon soil is 0.115 – 0.236 % which might affect to Pb adsorption by immobilizing Pb via specific adsorption reaction (Yong, 2001and Sharma and Reddy, 2004).

Chromium (Cr) Contamination in Soil

Amount of Cr in soil sample is 2.00-5.00 mg/kg which is higher than general concentration of Cr in soil, 0.07– 1.0 mg/kg (Bradl, 2004). From previous study, Cr was found in leachate 1.5 – 3.42 mg/l (Chuagngcham, 2008) and in landfill soil 228 mg/kg (Vijukrattana 2009). Thus, it is indicates contamination from the landfill site. Cr concentration was found higher in rainy season than dry season. Cr is accumulated in soil than groundwater and surface water resources.

The independent samples t-test of analytical results confirmed that Cr concentration decreased with depth and distance from the site with 95% confidential interval. Southeast direction has the highest Cr concentration. This might due to the migration with surface water toward the south since Cr is highly mobile in soil especially, in acidic soil (McLean and Bledsoe, 1992). The pH of soil in the landfill site as shown in Table 4.4 is slightly acidic (5.50 – 6.50) which is provides condition for Cr mobility. Results reveal that, Cr was found in southeast (2.336 – 5.032 mg/kg) and southwest (2.542 – 4.015 mg/kg) direction more than the other. This might be because of organic matter in Kham Bon soil in southeast (0.188 – 0.236%) and southwest (0.183 – 0.219%) of the site is higher than other direction. So that, more Cr might accumulate in those directions.

Cadmium (Cd) Contamination in Soil

Results from the analysis reveal that Cd in Kham Bon soil is quite low (0.021-0.238 mg/kg) comparing to Pb and Cr. Chuangcham (2008) reported study non-detectable Cd in leachate from Kham Bon site except some ditches and rivulets.

Genrally, Cd is usually not found in soil (Bradl, 2004). The adsorption of Cd onto soil and silicon of aluminum oxides is depended on pH of soil. Because the solubility of

Cd is higher in alkaline pH (mention in Chapter II). However, the pH of soil in the landfill site as shown in Table 4.4 is slightly acidic (5.50 – 6.50). Therefore, the solubility of Cd will be Vijukrattana (2009) reported Cd in landfill soil 6 mg/kg which is much higher than Cd around the site. It indicated the Cd is more likely to retain in the landfill then migrate to environment.

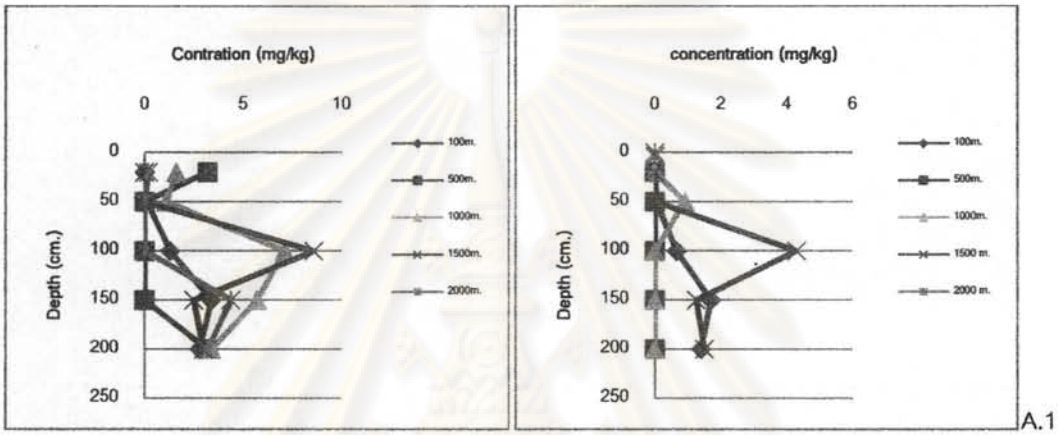
In additional, organic matter in soil is one important factor to control the mobility of Cd in soil because Cd will be fixed in organic matter (USEPA, 1999). In Kham Bon soil organic matter is 0.115 – 0.236 % and in southeast part of the site has the values of organic matter more than other direction. So that the highest Cd (0.199 – 0.238 mg/kg) was found in southeast part of Kham Bon site. All of Cd in soil was suspected that from the landfill.

Heavy Metals Distribution in Different Depth

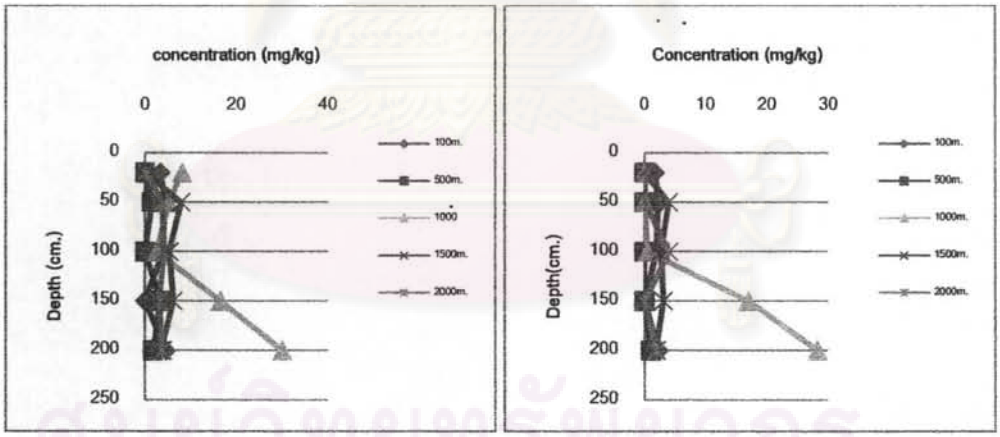
Concentration of metals in soil showed subsurface contamination in all directions. Figure 4.8 shows plots of Pb, Cr and Cd in soil at different depth and different direction. The concentration of heavy metals is greatest in the southeast direction which is the groundwater flow direction toward the river.

The concentration of Pb and Cr were higher in the top 50 cm, decreasing with distance from the site ($p>0.5$). The high concentration of Pb and Cr related to the high organic matter and pH. Because of high pH Pb and Cr will be enhanced to precipitate in the system and organic matter may immobilize of Pb and Cr via specific adsorption reactions (Fetter, 2001 and Chofqi et al. 2004). On the other hand, the mobilization of Pb and Cr can also be facilitated by its complexion with dissolved organic of fulvic acids (Spark, 2005). The concentration of Cd was lower retained in the site since precipitation of Cd occurs in low organic matter and high pH. Considering contamination at different

depth up to 200 cm, heavy metals were found in all depth. Groundwater level in the some areas is less than 1 m. during rainy season. Thus, the contamination is suspected to occur from both surface runoff and groundwater.

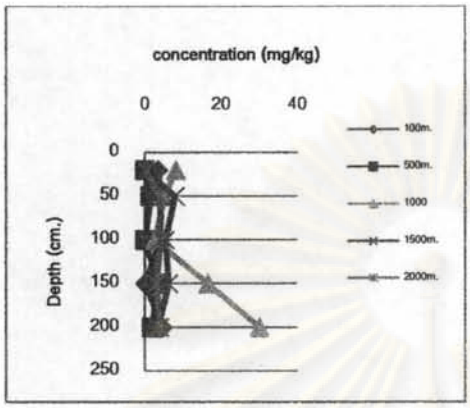


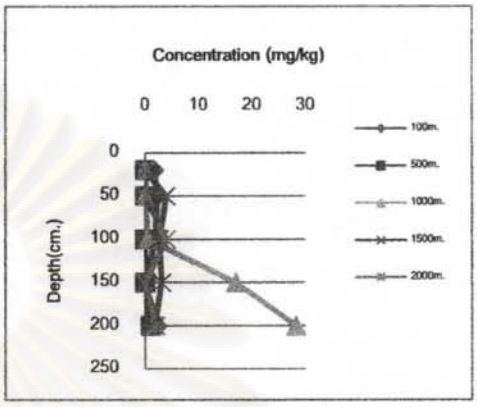
A.1 Pb in Northeast direction (Rainy season) A.2 Pb in Northeast direction (Dry season)



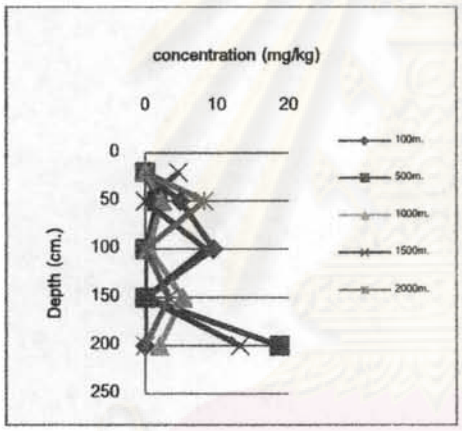
A.3 Pb in Southeast direction (Rainy season) A.4 Pb in Southeast direction (Dry season)

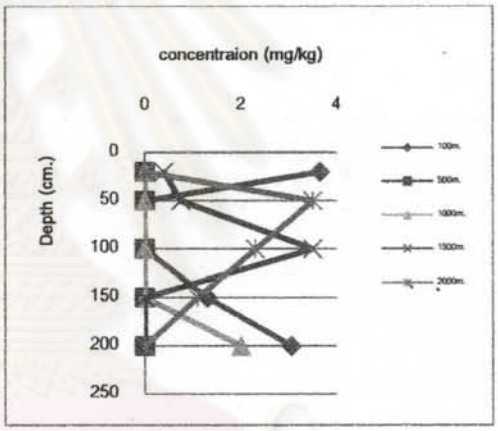
Figure 4.8 Heavy metals distribution at difference depth



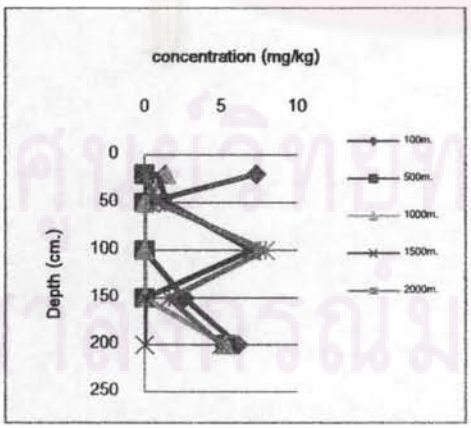


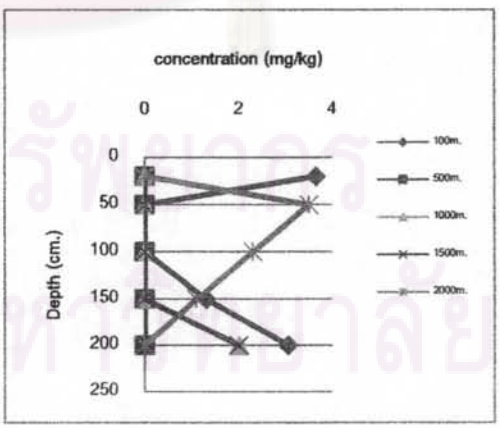
A.3 Pb in Southeast direction (Rainy season) A.4 Pb in Southeast direction (Dry season)





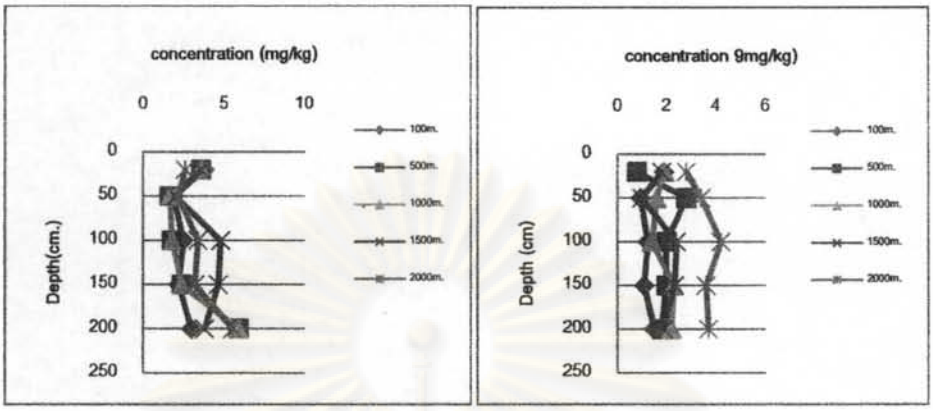
A.5 Pb in Southwest direction (Rainy season) A.6 Pb in Southwest direction (Dry season)



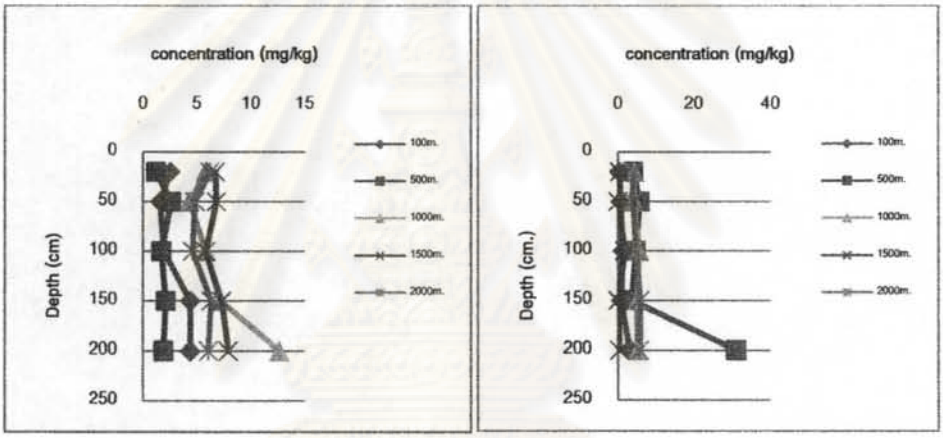


A.7 Pb in Northwest direction (Rainy season) A.8 Pb in Northwest direction (Dry season)

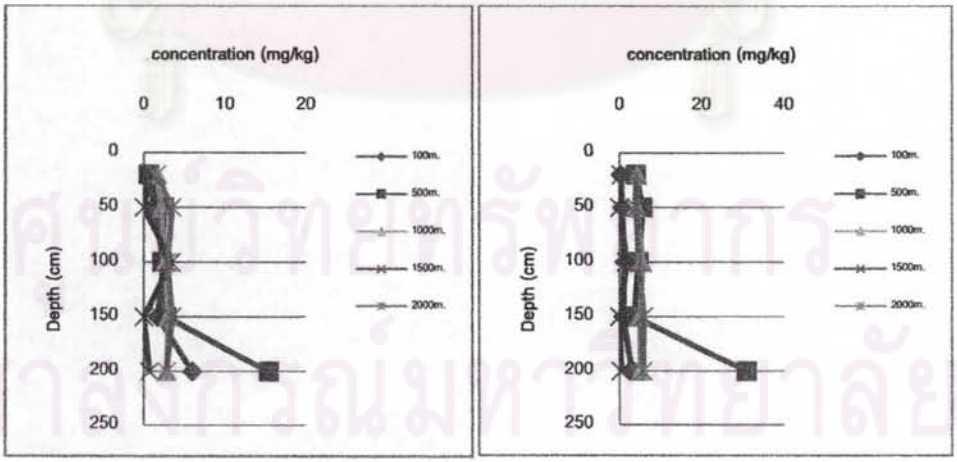
Figure 4.8 Heavy metals distribution at difference depth (cont.)



B.1Cr in Northeast direction (Rainy season) B.2 Cr in Northeast direction (Dry season)

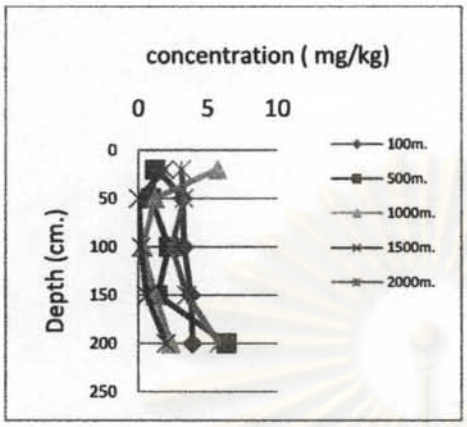


B.3 Cr in Southeast direction (Rainy season) B.4 Cr in Southeast direction (Dry season)

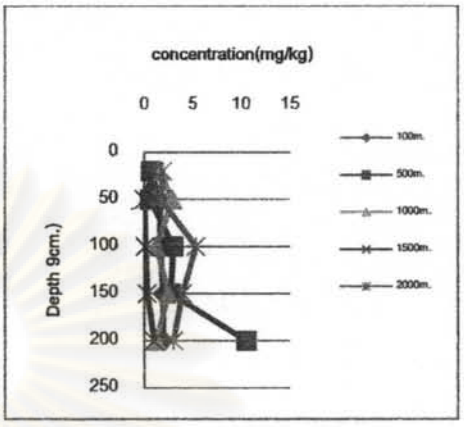


B.5 Cr in Southwest direction (Rainy season) B.6 Cr in Southwest direction (Dry season)

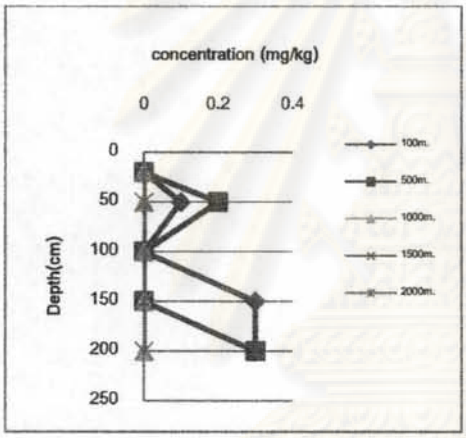
Figure 4.8 Heavy metals distribution at difference depth (cont.)



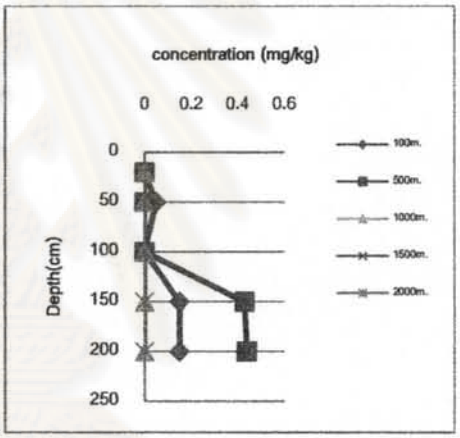
B.7 Cr in Northwest direction (Rainy season)



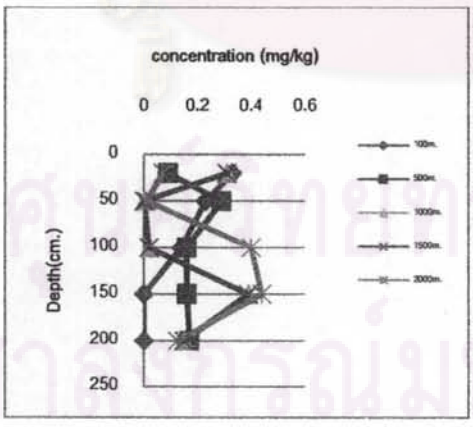
B.8 Cr in Northwest direction (Dry season)



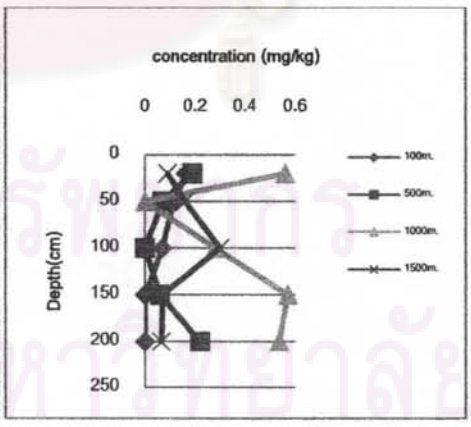
C.1 Cd in Northeast direction (Rainy season)



C.2 Cd in Northeast direction (Dry season)

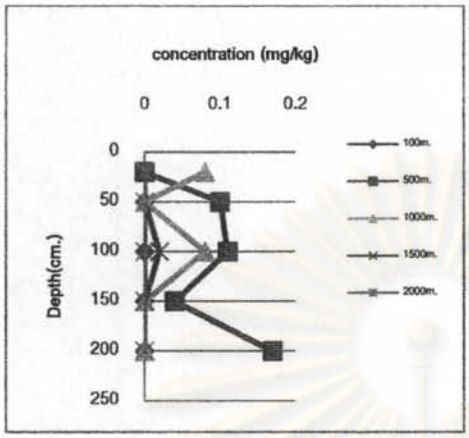


C.3 Cd in Southeast direction (Rainy season)

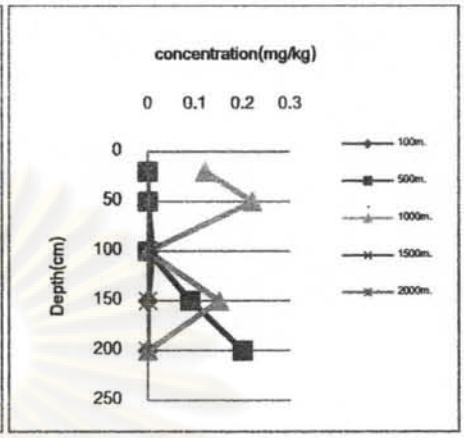


C.4 Cd in Southeast direction (Dry season)

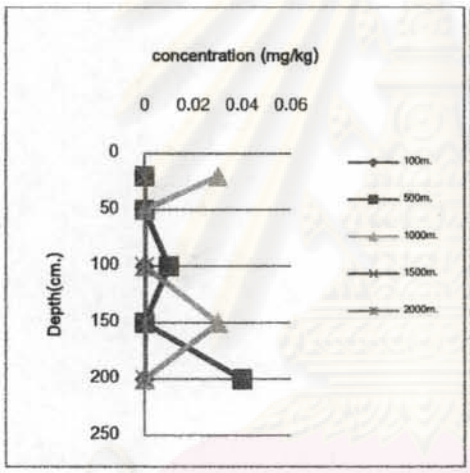
Figure 4.8 Heavy metals distribution at difference depth (cont.).



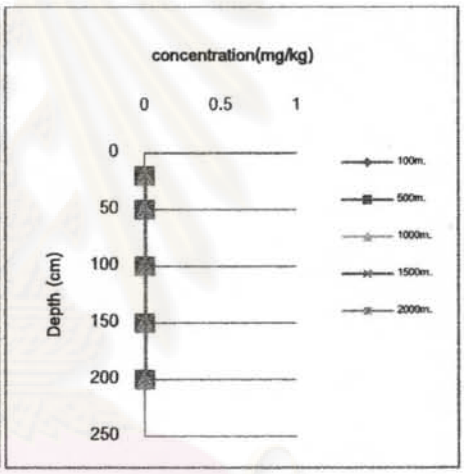
C.5 Cd in Southwest direction (Rainy season)



C.6 Cd in Southwest direction (Dry season)



C.7 Cr in Northwest direction (Rainy season)



C.8 Cr in Northwest direction (Dry season)

Figure 4.8 Heavy metals distribution at difference depth (cont.).

4.2.2 Heavy Metals Contamination in Groundwater

Analytical result for groundwater is shown in Table 4.6. Detail results are in Table A2, Appendix A. Heavy metals found in groundwater samples indicate the contamination from landfill leachate. However, the concentration of all samples is still lower than PCD's standard except Pb in monitoring well in southeast direction.

In this site, groundwater flows from northeastern and southeastern of the landfill site to the eastern boundary of the study area. Therefore, the major pathway for landfill-derived contaminants is thought to be downward to the northeast and southeast through to the Pong River (Figure 4.3 and 4.4).

Lead (Pb) Contamination in Groundwater

Concentration of Pb in both rainy and dry season is lower than PCD's standard except Pb in monitoring well in southeast direction. Result from independent samples t-test shows that Pb concentration is higher in rainy season with 87% confidential interval. The depth of aquifer in this area is 4 – 10 m (PCD, 1998). Thus, contamination of Pb might due to the migration of metals in leachate then to groundwater. Note that, solubility of Pb is higher at low pH where Pb hydroxide dissolves in Pb^{2+} form in pH 4.0 – 7.5 (Bradl, 2004). In this site, groundwater pH ranges from 5.60 – 6.91 (Table 4.4) which Pb can be easily dissolve and contaminate in groundwater.

Chromium (Cr) Contamination in Groundwater

Concentration of Cr in groundwater is very low, ranged from 0.00 to 0.02mg/l. Cr concentration was found higher in rainy season than dry season. This might due to Cr from landfill leacahte in rainy season distributed in form of Cr(VI) with groundwater and runoff. Chaungcham et al. (2008) reported that the Cr distribution coefficient (K_d) of soil around Kham Bon landfill site is 4.4 – 16.5 l / kg as shown in Table 4.7. The low distribution coefficient shows that most of Cr accumulated in soil more than water.

Table 4.6 Heavy metals concentration in groundwater

Sample number	Direction	Concentration (mg / l)					
		Pb		Cr		Cd	
		Rainy	Dry	Rainy	Dry	Rainy	Dry
KK 5	East	0.046±1.3E-03	0.024±6.6E-4	0.006±1.5E-04	0.01 ±1.3E-04	0.007±1.9E-04	0.004±1.2E-04
KK 2	North	0.049±1.3E-03	0.046±1.3E-03	0.003±8.4E-05	N/D	0.00±8.4E-06	0.003±8.9E-05
KK3	North	0.045±1.3E-03	0.046±1.3E-03	0.001±8.4E-05	N/D	0.01±8.4E-06	0.002±8.9E-05
KK 4	Northeast	0.014±3.9E-04	0.007±2.0E-04	N/D	N/D	0.007±2.0E-04	0.003±8.3E-05
KK 6	South	0.062±1.7E-03	0.042±1.2E-03	0.002±5.6E-05	0.001±3.9E-05	0.002±4.9E-05	0.002±4.2E-05
GW 2	South	0.052±1.9E-03	0.052±1.2E-03	0.001±5.6E-05	0.001±3.9E-05	0.002±4.9E-05	0.002±4.2E-05
KK 7	Southeast	0.723±2.0E-02	0.541±1.5E-02	N/D	N/D	0.005±1.3E-04	N/D
GW 2	Southeast	0.676±1.0E-02	0.433±1.8E-02	N/D	N/D	0.003±1.3E-04	N/D
KK 1	Southwest	0.047±1.3E-03	0.032±8.7E-04	0.011±3.0E-04	0.001±2.8E-05	0.009±2.3E-04	N/D
Background blank*		N/D		N/D		N/D	
Thailand's drinking water standard*		0.05		0.05		0.01	

N/D = Non Detectable

*Data from Groundwater Resource Department

** Water quality recommended for drinking water industrial as published in the Royal Government Gazette. Vol.95 part 68, dated July 4, B.E.Industrail (1978)

Table 4.7 Distribution Coefficient (K_d) of Kham Bon Soil (Chaungcham et al., 2008)

Heavy Metals	K_d (l / kg)		
	Silty Clay Loam	Sand	Silty Loam Sand
Pb	83.4	8.8	30.8
Cr	16.5	4.4	9.7
Cd	32.3	10.7	17.2

Cadmium (Cd) Contamination in Groundwater

The concentration of Cd in rainy and dry season is lower than PCD's standard. The concentration of Cd in two season has no difference ($p>0.5$). Cd was found lowest comparing to Pb (0.02 – 0.8 mg/l) and Cr (0 – 0.02 mg/l). For Cd, factors controlling migration are high pH ionic strength, and exchangeable ions. In low pH (4.5-5.5) Cd can dissolve and released to groundwater. For this site, pH in soil is 5 .0-6.5. Thus mobility of Cd in this site is low causing small contamination in groundwater.

4.2.3 Heavy Metals Contamination in Surface Water

Surface water samples were collected from natural and manmade ponds around the site. Concluded analysis results are in Table 4.8. Detail results are in Table A3, Appendix A. From the study, Pb, Cr and Cd ranges from 0.005 -0.03, 0.00 – 0.04 and 0.00 – 0.01 mg/l, respectively. Heavy metals concentration in all samples is lower than drinking water standard recommended by PCD. Heavy metals in background samples were absented indicate that heavy metals contamination occurred from the landfill. From site survey, lechate runoff flowed to the reservoirs in southwest direction during rainy season (Figure 4.3). Hence, heavy metal contamination in surface water is suspected from surface runoff from the site.

Lead(Pb) Contamination in Surface Water

Pb found in all sampling analysis ranges from 0.005 to 0.03 mg/l. The concentration of Pb in rainy season was higher than in dry season with 95% confidential interval. Pb accumulated in northern more than other direction because runoff and leachate flowed to the reservoirs in north direction (Figure 4.3) during rainy season.

Chromium (Cr) Contamination in Surface Water

Cr was not found in dry season but was found in rainy season in northern and northeastern direction. This might due to surface runoff during the rainy season.

Cadmium (Cd) Contamination in Surface Water

Cd was not found in dry season except in northeastern. Cd was found in all direction in rainy season where the concentration in northeastern is the highest. However, Cr concentrations in all samples are lower than drinking water standard recommended by PCD.

Table 4.8 Heavy metals concentration in surface water

Sample number	Direction	Concentration (mg / l)					
		Pb		Cr		Cd	
		Rainy	Dry	Rainy	Dry	Rainy	Dry
SW1	North	0.007 ± 1.8E-04	0.009 ± 2.3E-04	0.006 ± 1.5E-04	N/D	0.003 ± 7.3E-05	N/D
SW3	Northeast	0.026 ± 1.0E-03	0.017 ± 4.7E-04	0.008 ± 2.2 E-04	N/D	0.004 ± 1.0E-04	0.001 ± 2.8E-05
SW2	Northwest	0.026 ± 1.0E-03	0.013 ± 3.6E-04	N/D	N/D	0.0002 ± 5.6E-06	N/D
SW4	Southwest	0.007 ± 1.9E-04	0.005 ± 1.4E-04	N/D	N/D	0.004 ± 1.2E-04	N/D
SW5	Southwest	0.004 ± 1.0E-04	0.005 ± 1.7E-04	N/D	N/D	0.001 ± 1.0E-04	N/D
Background blank		N/D		N/D			N/D
Thailand's drinking water standard		0.05		0.05			0.01

Note: N/D = Non Detectable

* Water quality recommended for drinking water industrial as published in the Royal Government Gazette. Vol.95 part 68, dated July 4, B.E.Industrail (1978)

4.3 Groundwater Modeling

Simulation is based on Visual MODFLOW using MODFLOW for groundwater model and MT3DMS contaminant transport model. Details about parameter input, model calibration and contamination prediction is as follow.

4.3.1 Groundwater Flow Model Input Data

Input data in MODFLOW is list in Table 3.3. Details of obtaining input parameter are as follow.

1) Topographic Data

In this study use Military map scale 1:50,000 overlay on Autocad program and the n change file from .dxf file to text file. After that, the data was imported to Visual MODFLOW. After imported, the interface of topographic used displayed as shown in Figure 4.9.

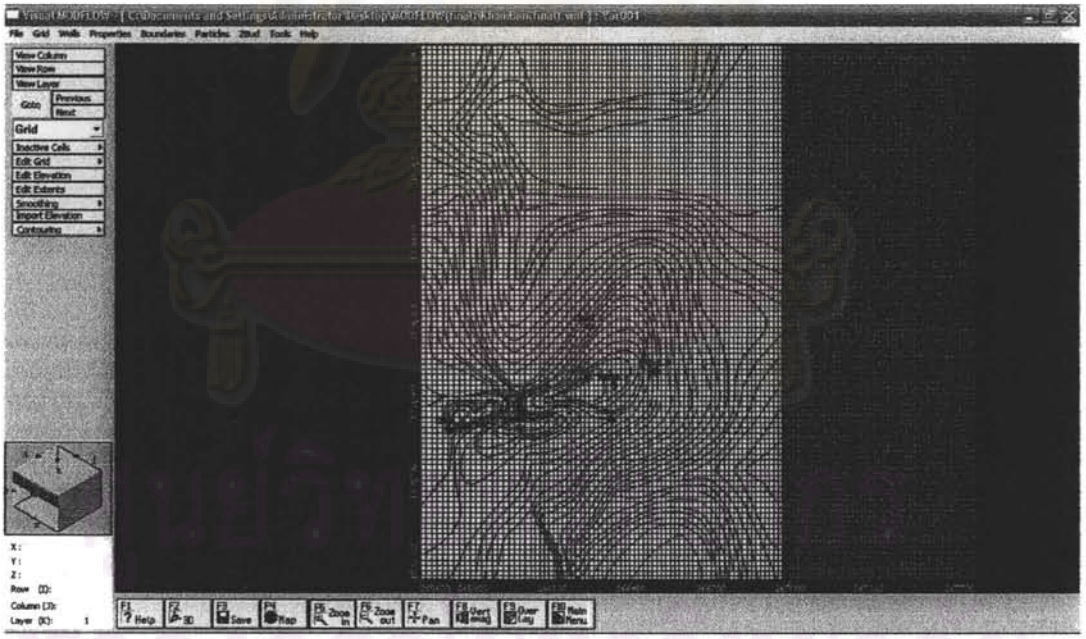


Figure 4.9 The study area map in Visual MODLFOW

2) Geologic Data

Geologic data is information about soil. In this study, information was obtained from many sources as previously shown in Table 3.3. Here, data from previous work (Choungchum, 2008) and surveyed from Groundwater Resource Department is used. Kham Bon landfill site mainly composed with 3 soil type; sand, clayed sand, sandstone. Therefore in the model divided in 3 layer and detail follow in Table 4.9. After input data into MODFLOW, the interface appeared as shown in Figure 4.10.

Table 4.9 Layer of Soil in Groundwater Flow Model

Layer	Types of Soil	Characteristic of Soil	Thickness (m)
1	Sand	Medium grained, well sorted, well roundness, loose, non-plastic	10
2.	Clayed Sand	Medium to coarse rained, well sorted, well roundness, moderately to highly plastic, soft.	15
3.	Sandstone	Very fine to fine grained, well sorted, well roundness, calcareous cemented, moderately hard, composed of micas	25

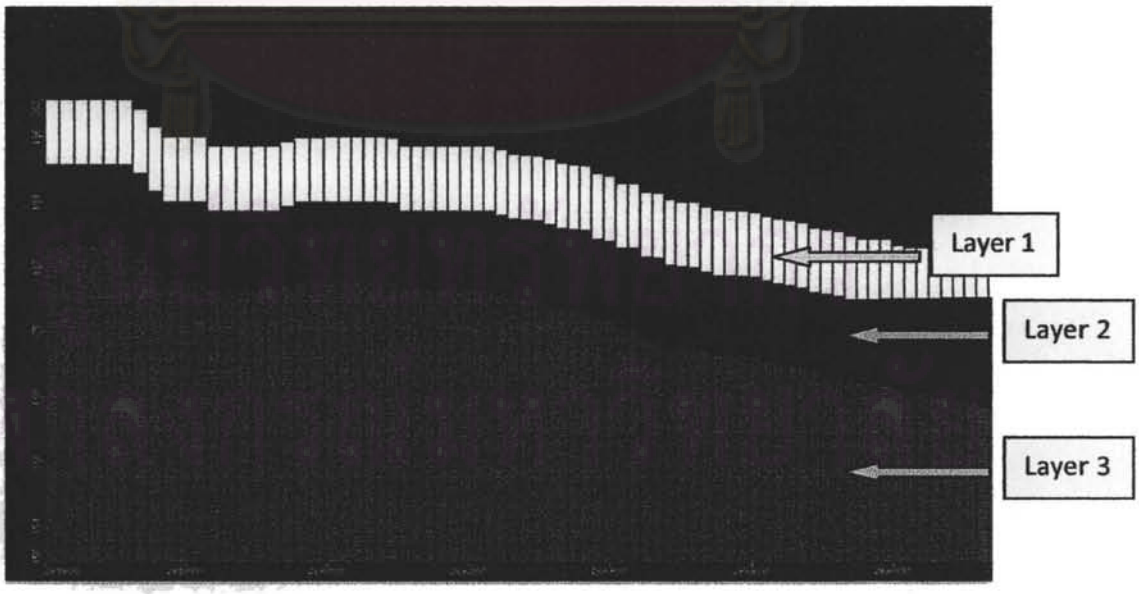


Figure 4.10 Soil Layer in Visual MODFLOW

Table 4.10 is list of input parameter used in the model. Hydraulic Conductivity of soil Specific storage (S_s), Specific yield (S_y), Total porosity (n) and Effective porosity (n_e) obtained from the value recommended by Karlheinz (1996). Input parameter, hydraulic conductivity of waste is from PCD (1999) in the Kham Bon landfill site.

Table 4.10 Input Parameters of the study area for Ground Water Flow Model

Parameter	Unit	Value		
		Layer 1	Layer 2	Layer 3
1. Hydraulic Conductivity of soil				
1.1 K_x	m / d	1	0.01	1
1.2 K_y	m / d	1	0.01	1
1.3 K_z	m / d	0.1	0.001	0.1
2. Hydraulic Conductivity of waste layer $K_x=K_y=K_z$	m / d	0.864		
3. Specific storage (S_s)		0.01	0.001	0.001
4. Specific yield (S_y)		0.2	0.2	0.15
5. Total porosity (n)		0.33	0.29	0.2
6. Effective porosity (n_e)		0.22	0.2	0.15
7. Recharge				
7.1 General Area	mm / yr	0, 35.73		
7.2 Landfill Area	mm / yr	100, 426		
8. Evapotranspiration				
8.1 General Area	mm / yr	100, 120		
8.2 Landfill Area	mm / yr	50, 70		
9. Extinction Depth	m.	3		
10. Contaminated Area	m^2	2.36 x 3.11		
11. Simulation time	Years	20		

3) Hydrologic Data

In this research the values precipitation data from Thai Metrologic Department for 30 years from 1978 – 2008. The model simulated under rainy season and dry season condition not cover in worst case (100 periods). Base on topography and land use, recharge in this model divided in 2 zones (Figure 4.11) which are general area (15% of precipitation values) and landfill area (85-90 % of precipitation values).

4) Discretization

The study cover area 2.36 x 3.11 km^2 and the study area is divided into 118 rows, 155 columns that divided follow to characteristic of soil. The location and width of the constant head boundary were designated based on an aerial photograph of the site, coupled with elevation data from direct surveys that imported into Visual MODFLOW as shown in Figure 4.12.

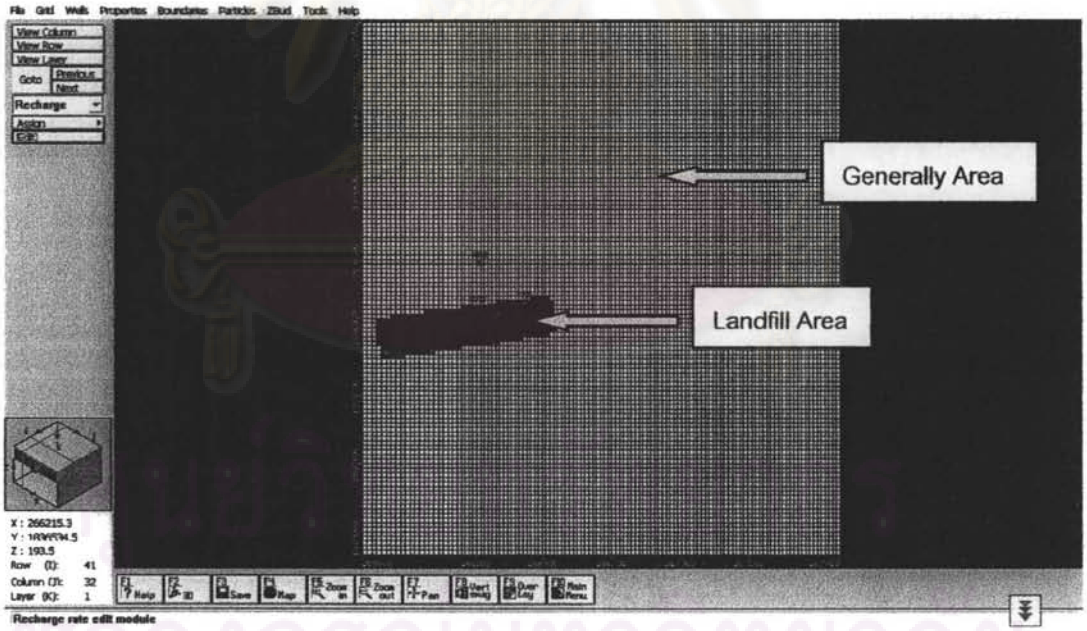


Figure 4.11 Recharge Area of study area

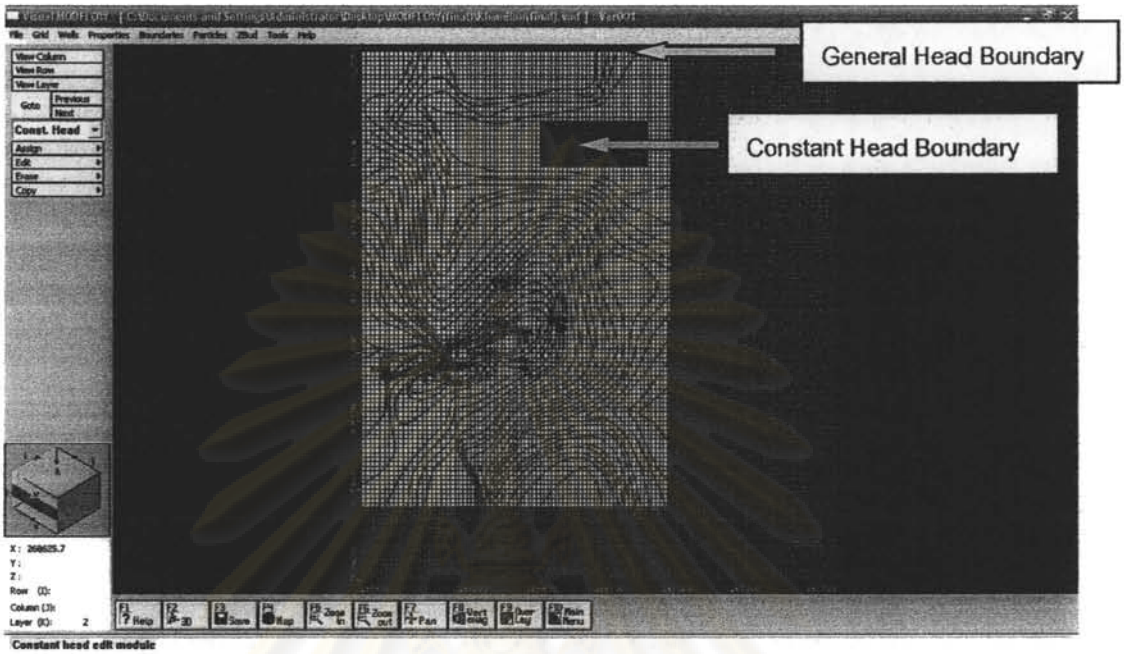


Figure 4.12 Grid and boundary of study area

4.3.2 Contaminant Transport Model

1) Dispersivity: This parameter control the distribution pathway of contaminant in the model and in this research use the dispersivity value from Karlheinz, 1996. Different type of soil has different value as listed in Table 4.11.

Table 4.11 Dispersivity of layer used in model

Layer No.	Longitidinal Dispersivity	Horizontal Dispersivity Ratio	Vertical Transverse Dispersivity Ratio
1	3	0.1	0.1
2	1	0.1	0.1
3	1	0.1	0.1

2) **Distribution Coefficient**: This parameter is affect to the mobility of contaminant in soil and this parameter depended on type of soil. In this research, distribution coefficient values reported by Chuangcham (2008) is used as shown in Table 4.7.

3) **Initial Concentrtion**: Initial concentration as in Table 4.12 were assigned in the model cell and other boundaries are convective flux boundaries and adjusted until concentration of contaminants in model equal to real concentration from field data. The transport model was run at 180-day time interval for a total of 20 years.

Table 4.12 Metals Concentration for Contaminant Transport Model

Location of samples	Recharge concentration for (mg/l)		
	Pb	Cr	Cd
KK1	0.04	0.018	0.01
KK2	0.24	0.027	Name.
KK3	0.08	0.027	N/D
KK4	0.21	0.026	N/D
KK5	0.32	0.038	N/D
KK6	0.17	0.027	0.01
KK7	0.17	0.028	0.01
Recharge Concentration	0.001		

4.3.3 Model Calibration

1) **Flow model**: Computed hydraulic head and measured head values were compare and model parameters adjusted to improve the degree of fit between the simulated and observed water level.

Average differences between simulated and measured head is commonly expressed by standard error, root mean square, the root mean squared (RMS) and correlation coefficient. Errors are considered to be acceptable if the ratio of theses value error to the total head loss in the system is minimized.

In this study, 7 monitoring well is used for calibration under steady-state condition as shown in Table 4.13. Figure 4.13 showed the curve fitting of calibration. The maximum residual is 1.65 m and the absolute residual mean is 0.908 m. The normalized residual mean square error of the model is 13.11 %. The normalized residual mean is 0.675 m. The observation versus predicted head values has a correlation coefficient of 0.995 m. In general, the model-simulated heads are slightly higher than the observed heads. Results of ground water flow model after as show in Figure 4.14. Form the Figure, black area is surface water body where no water flows in and out. Arrow indicates direction of flow. Model results reveal that groundwater flow direction from landfill is from west to east.

Table 4.13 Hydraulic Head of 7 monitoring wells

Name.	UTM-m.		Borehole Elevation (m)	Groundwater Level (m.)	Observation Head (m.)
	East	North			
KK1	265705	1835893	194.627	5.6	189.027
KK2	266119	1836284	182.399	1.35	181.05
KK3	266113	1836087	185.103	2.24	182.86
KK4	266192	1836060	190.393	7.55	148.89
KK5	266317	1836110	192.507	4.7	187.807
KK6	265911	1835899	192.876	7.3	185.576
KK7	266185	1835931	187.702	3.25	184.452

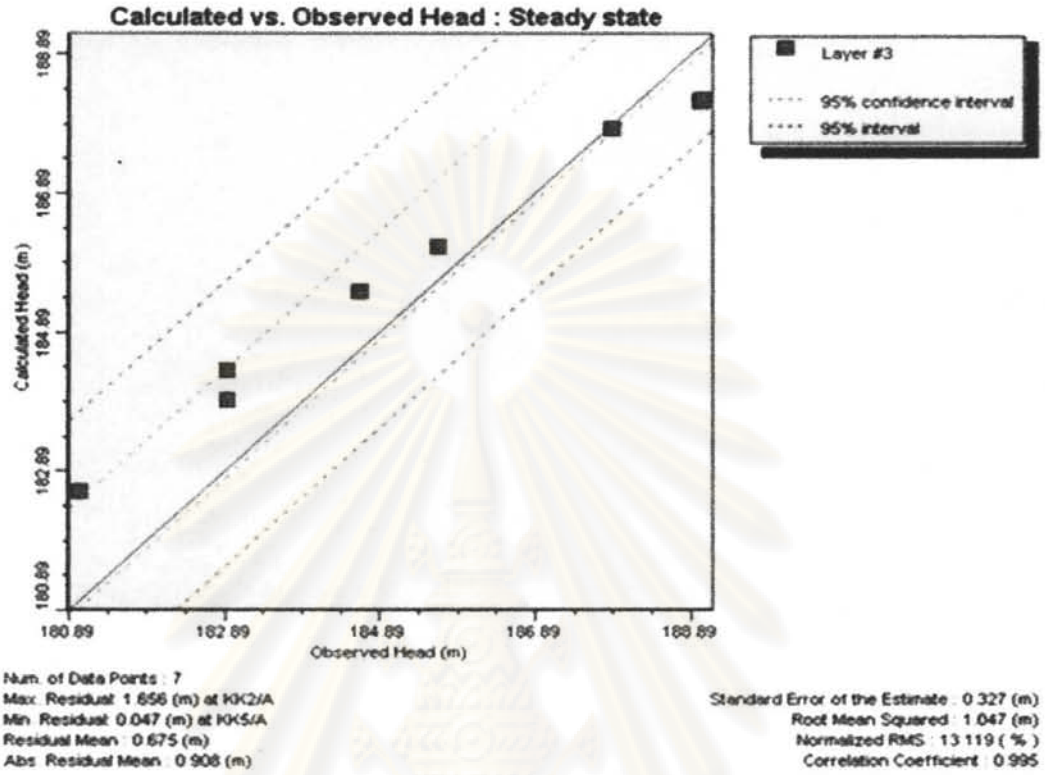


Figure 4.13 Relationship between simulated and observed head under steady-state flow condition

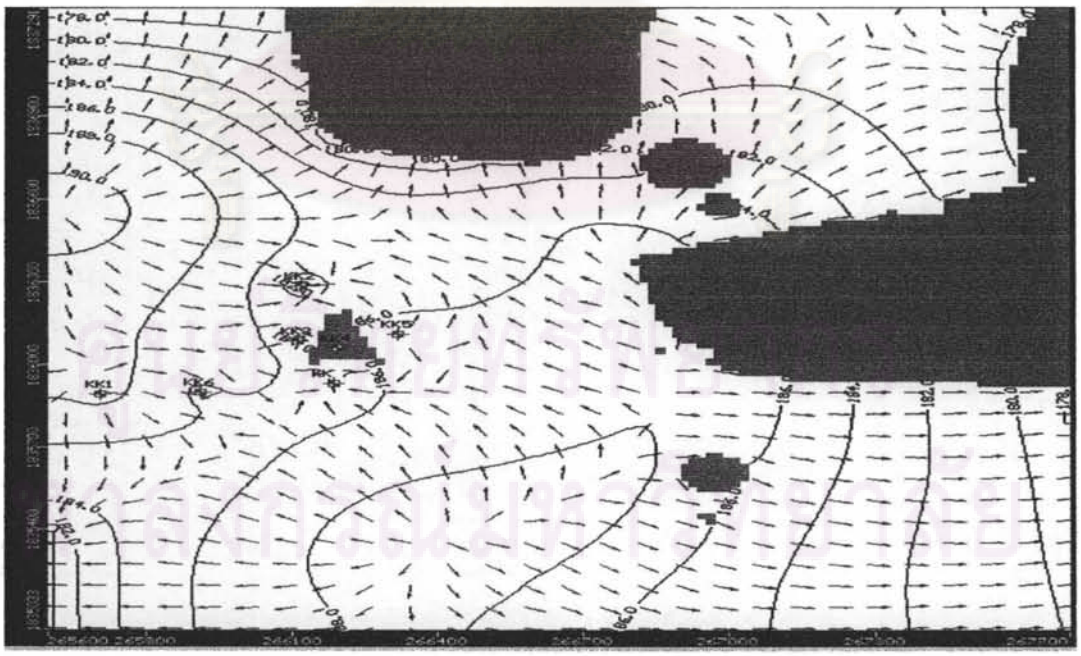


Figure 4.14 Groundwater Flow Direction under Steady-state flow model condition

4.3.4 Model Result and Prediction

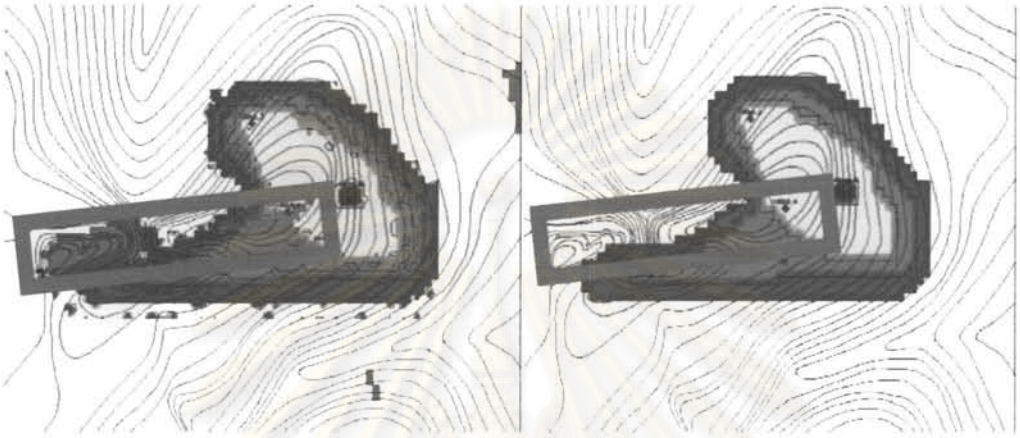
After calibrated with field data, the plume of contamination migration from the Kham Bon landfill site is obtained from MODFLOW model.

Figure 4.15 A and B showed contamination of Pb in the present. From the Figure, contamination of Pb is higher in north east direction. This is due to the site geology where water drains northwards from site into Sam Chan reservoir and flow eastwards to Huai Mak Ngo. Concentration in Layer 1 (0-10 m from surface) is higher in Layer 2(10-25 m from surface).

Contamination plums of Cr and Cd are displayed in Figure 4.16 A, B and 4.17 A, B, respectively. The directions of Cr and Cd migration are the same as Pb. Cd migration covers smallest area due to the low solubility.

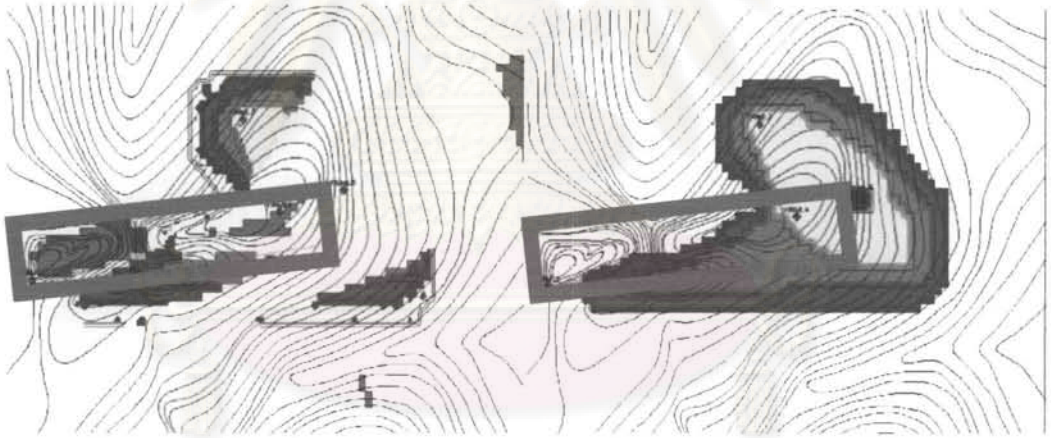
From the monitoring result, it was found that contamination was occurred mainly from surface runoff. If the runoff collection system is well operated, the contamination might not go further. Thus, the remediation action might not be required. The 20 year simulation was run under the assumption that leachate collection system is constructed and well operated.

Figure 4.15 C and D is a prediction of Pb contamination in the future, 20 years. From the results, heavy metals tend to move from the top soil to deeper aquifer. The horizontal distance does not expand while vertical distance goes further down. The migration is not exceeded 500 meter after 20 years and consider a slow process which the same as previously reported Tiwary et al. (2005) Similarly to Pb, Cd and Cr demonstrated similar results as shown in Figure 4.16 C,D and 4.17 C, D respectively. From the assumption of the simulation, it can be concluded that even the leachate collection system is applied, contamination still migrate to aquifer. Thus, the mitigation measured is required.



A. Plume of Pb in layer 1 in the present

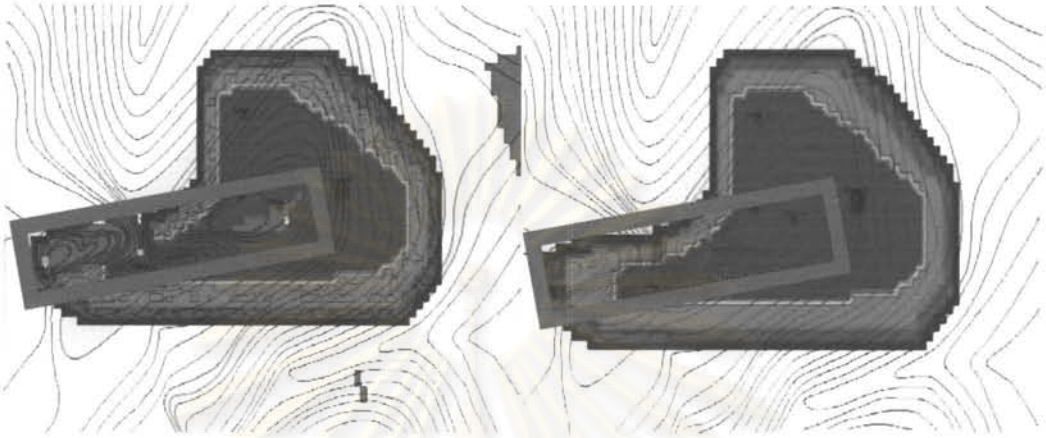
B. Plume of Pb in layer 2 in the present



C. Plume of Pb in layer 1 (20 years)

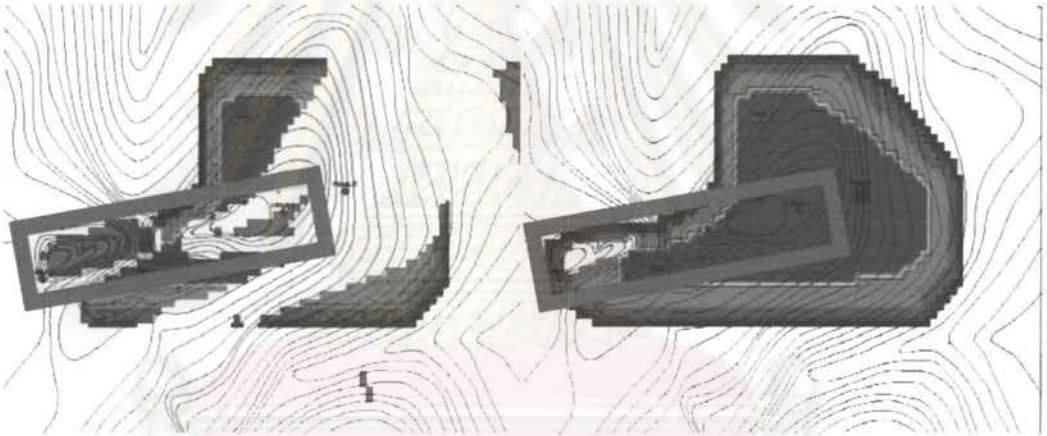
D. Plume of Pb in layer 2 (20 years)

Figure 4.15 Plume of Pb from MODFLOW simulation



A. Plume of Cr in layer 1 in the present

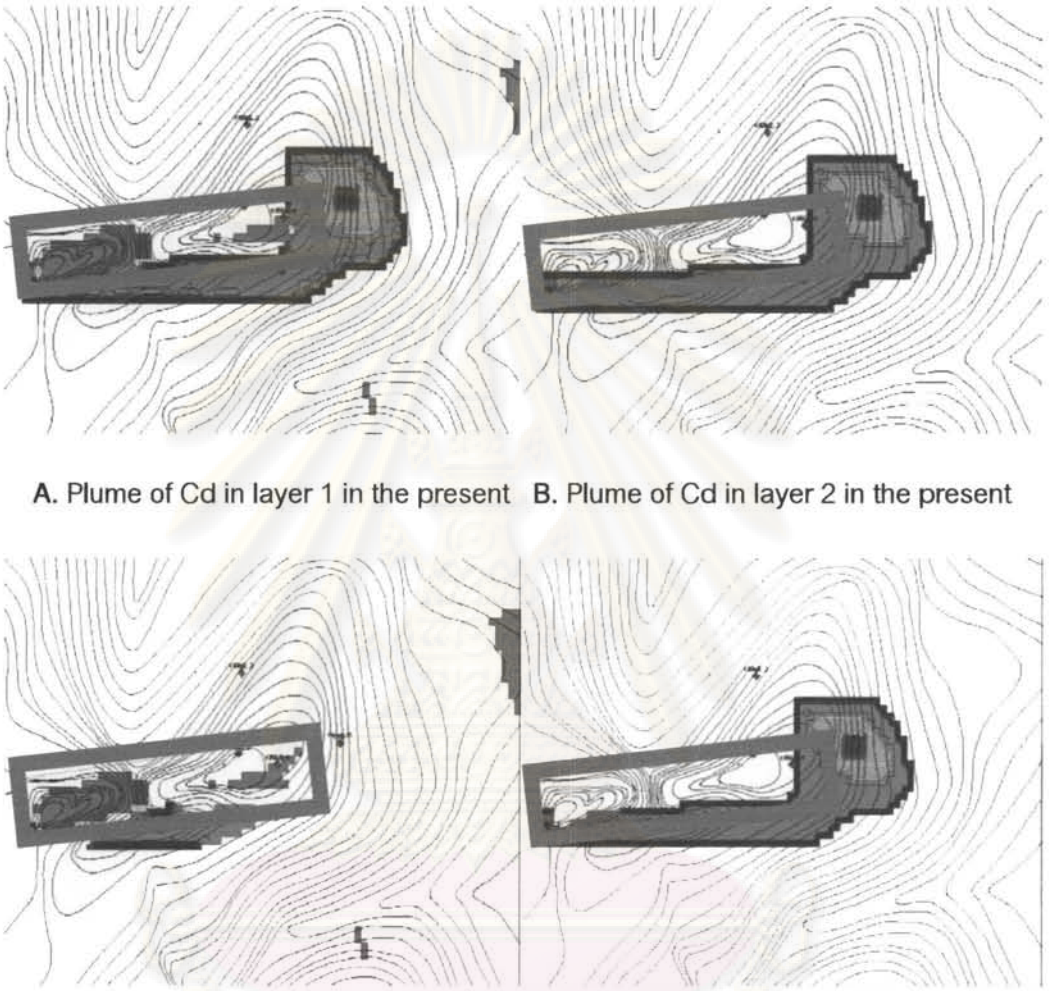
B. Plume of Cr in layer 2 in the present



C. Plume of Cr in layer 1 (20 years)

D. Plume of Cr in layer 2 (20 years)

Figure 4.16 Plume of Cr from MODFLOW simulation



A. Plume of Cd in layer 1 in the present B. Plume of Cd in layer 2 in the present

C. Plume of Cd in layer 1 (20 years) D. Plume of Cd in layer 2 (20 years)

Figure 4.17 Plume of Cd from MODFLOW simulation

CHAPTER V

CONCLUSION

5.1 Conclusion

5.1.1 Site Investigation

Site investigation revealed that Pb, Cr, and Cd in surface water, groundwater and soil were contaminated the area of 2 km radius surround the site and migrated at least 2 m depth in subsurface. Concentration of metals was found higher in the 500 m radius. Although heavy metals seem to spread everywhere in the area, but there were patterns of distribution where heavy metals migrate toward northeast and southeast directions. The order of concentration degree is Pb>Cr>Cd which affect from chemical characteristic of metals, soil pH and organic matter in soil.

Comparing in two phases, heavy metals were more adsorbed by Kham Bon soil rather than filtrate into groundwater. Cr were likely accumulated in soil while Pb and Cd are potentially released to groundwater and surface water. The contamination of heavy metals in surface water and groundwater was not exceeded Thai drinking water standard recommended by PCD. The concentration of heavy metals in soil did not exceed standard I for Agriculture standard recommended by PCD.

Since heavy metals were found in to soil and surface water more than in groundwater and higher in rainy season, thus major contamination pathway was suspected to migrate with runoff.

5.1.2 Mathematical modeling

In this study Visual MODFLOW model was used to predict the distribution pathway of heavy metals contamination from Kham Bon site in 20 years. The model simulated under rainy season and dry season condition not cover in worst case (100 periods) and the root mean squared (RMS) error from model calibration in the system is 1.047 m. The model result was generated to show Pb, Cr and Cd migration pathway which showed that heavy metals especially Pb and Cr migrate to northeastern and southeastern part more than other parts. Because of site geology and water drains northwards from site into Sam Chan reservoir and flow eastwards to Huai Mak Ngo. The degree of migration was Pb>Cr>Cd. In the next 20 years, heavy metals tends to move from the top soil to deeper aquifer. The horizontal distance does not expand while vertical distance goes further down. The migration would not exceed 500 m after 20 years and the migration is considered a slow process. Even the leachate collection system is applied, contamination still migrate to aquifer. Thus, mitigation measure is needed.

5.2 Recommendation

From site investigation and mathematical model simulation, Pb, Cr and Cd were found contaminated from the landfill to area nearby. Even though, heavy metals concentration in samples was lower than the recommended standard by PCD, it still posed hazard to the environment and human health. Thus, mitigation measure to monitor and reduce the risk is recommended as follow.

1. Regular monitoring program for environmental receptors including soil groundwater, and surface water is recommended in order to create the database of the contaminants at the landfill site and its vicinity.

2. A source separation of hazardous waste and rehabilitation at the landfill site should be done to prevent the transfers of pollutants.

3. Groundwater within 500 m radius from the site was contaminated with high level of heavy metals which is a risk for health impact. Villagers who use ground water from well in the area should be informed about the risk. The consumption of groundwater in 500 m radius should be avoided.

4. The concentration of heavy metals in soil, surface water, and groundwater was higher in rainy season due to surface runoff. Therefore, the surface runoff to the area nearby should be prevented. During rainy season, the material to cover the waste from rainy should be applied. The leachate collection system should be renovated to be able to use effectively. In addition, natural buffer such as Vetiver grass should be planted around the site to help bind metals from migrating with runoff.

5. From the model result, heavy metals tend to move from the top soil to deeper aquifer even the leachate collection system is applied. Thus, ground water contamination in deeper aquifer should be closely monitored. If the contaminant go further, remediation action should be performed to prevent further migration.

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APPENDICES

APPENDIX A: Data obtained from experiment

Table A1 : Heavy metals in soil samples

Direction	Distance (m.)	Depth (cm.)	Duplicates	Heavy Metals Concentration in Rainy Season (mg/kg)			Heavy Metals Concentration in Dry Season (mg/kg)		
				Pb	Cr	Cd	Pb	Cr	Cd
Northeast	100	20	1	0	3.8	0	0	1.9	0
		50		0.1	1.9	0.1	0.05	0.95	0.05
		100		1.3	2.5	0	0.65	1.25	0
		150		3.4	2.2	0.3	1.7	1.1	0.15
		200		2.8	3	0.3	1.4	1.5	0.15
Northeast	100	20	2	0.0	3.9	0.0	0.0	1.9	0.0
		50		0.1	1.9	0.0	0.1	1.0	0.0
		100		1.3	2.6	0.1	0.7	1.3	0.1
		150		3.5	2.3	0.0	1.7	1.1	0.0
		200		2.9	3.1	0.3	1.4	1.5	0.2
Northeast	100	20	3	0.0	4.0	0.0	0.0	2.0	0.0
		50		0.1	2.0	0.0	0.1	1.0	0.0
		100		1.4	2.6	0.1	0.7	1.3	0.1
		150		3.6	2.3	0.0	1.8	1.2	0.0
		200		3.0	3.2	0.3	1.5	1.6	0.2
Northeast	500	20	1	3.2	3.6	0	0	0.8	0
		50		0	1.65	0.2	0	2.8	0
		100		0	1.8	0	0	2	0
		150		0	2.4	0	0	2	0.43
		200		3.2	5.9	0.3	0	1.8	0.44
Northeast	500	20	2	3.3	3.7	0.1	0.0	0.8	0.1
		50		0.0	1.7	0.0	0.0	2.9	0.0
		100		0.0	1.8	0.2	0.0	2.1	0.0
		150		0.0	2.5	0.0	0.0	2.1	0.0
		200		3.3	6.0	0.0	0.0	1.8	0.4
Northeast	500	20	3	3.4	3.8	0.1	0.0	0.8	0.1
		50		0.0	1.7	0.0	0.0	3.0	0.0
		100		0.0	1.9	0.2	0.0	2.1	0.0
		150		0.0	2.5	0.0	0.0	2.1	0.0
		200		3.4	6.2	0.0	0.0	1.9	0.5
Northeast	1000	20	1	1.6	0.7	0	0	1.9	0
		50		1.1	0.7	0	0.9	1.6	0
		100		7.1	1.4	0	0	1.4	0
		150		5.7	1.7	0	0	2.3	0
		200		3.4	1.6	0	0	2.2	0
Northeast	1000	20	2	1.6	0.7	0	0.0	1.9	0
		50		1.1	0.7	0	0.9	1.6	0
		100		7.3	1.4	0	0.0	1.4	0
		150		5.8	1.7	0	0.0	2.4	0
		200		3.5	1.6	0	0.0	2.3	0
Northeast	1000	20	3	1.7	0.7	0	0.0	2.0	0
		50		1.2	0.7	0	1.0	1.7	0
		100		7.5	1.5	0	0.0	1.5	0
		150		6.0	1.8	0	0.0	2.4	0

Table A1 : Heavy metals in soil samples (cont)

Direction	Distance (m)	Depth (cm)	Duplicates	Heavy Metals Concentration in Rainy Season (mg/kg)			Heavy Metals Concentration in Dry Season (mg/kg)		
				Pb	Cr	Cd	Pb	Cr	Cd
Northeast	1000	200	3	3.6	1.7	0	0.0	2.3	0
Northeast	1500	20	1	0	3.6	0	0	1.8	0
		50		0	2	0	0	1	0
		100		8.6	4.8	0	4.3	2.4	0
		150		2.5	4.65	0	1.25	2.325	0
		200		3	3.8	0	1.5	1.9	0
Northeast	1500	20	2	0.0	3.7	0	0.0	1.8	0
		50		0.0	2.1	0	0.0	1.0	0
		100		8.8	4.9	0	4.4	2.5	0
		150		2.6	4.8	0	1.3	2.4	0
		200		3.1	3.9	0	1.5	1.9	0
Northeast	1500	20	3	0.0	3.8	0	0.0	1.9	0
		50		0.0	2.1	0	0.0	1.1	0
		100		9.1	5.1	0	4.5	2.5	0
		150		2.6	4.9	0	1.3	2.5	0
		200		3.2	4.0	0	1.6	2.0	0
Northeast	2000	20	1	0.2	2.6	0	0	2.8	0
		50		0	2.15	0	0	3.4	0
		100		0	3.4	0	0	4.2	0
		150		4.4	3.2	0	0	3.6	0
		200		3.2	5.55	0	0	3.7	0
Northeast	2000	20	2	0.2	2.7	0	0.0	2.9	0
		50		0.0	2.2	0	0.0	3.5	0
		100		0.0	3.5	0	0.0	4.3	0
		150		4.5	3.3	0	0.0	3.7	0
		200		3.3	5.7	0	0.0	3.8	0
Northeast	2000	20	3	0.2	2.7	0	0.0	3.0	0
		50		0.0	2.3	0	0.0	3.6	0
		100		0.0	3.6	0	0.0	4.4	0
		150		4.6	3.4	0	0.0	3.8	0
		200		3.4	5.9	0	0.0	3.9	0
Southeast	100	20	1	3.4	2.55	0.33	1.7	1.275	0.165
		50		4.4	1.6	0.23	2.2	0.8	0.115
		100		3.9	1.9	0.14	1.95	0.95	0.07
		150		0	4.4	0	0	2.2	0
		200		4.6	4.4	0	2.3	2.2	0
Southeast	100	20	2	3.5	2.6	0.3	1.7	1.3	0.2
		50		4.5	1.6	0.2	2.3	0.8	0.1
		100		4.0	1.9	0.1	2.0	1.0	0.1
		150		0.0	4.5	0.0	0.0	2.3	0.0
		200		4.7	4.5	0.0	2.4	2.3	0.0
Southeast	100	20	3	3.6	2.7	0.3	1.8	1.3	0.2
		50		4.6	1.7	0.2	2.3	0.8	0.1
		100		4.1	2.0	0.1	2.1	1.0	0.1

Table A1 : Heavy metals in soil samples (cont)

Direction	Distance (m.)	Depth (cm.)	Duplicates	Heavy Metals Concentration in Rainy Season (mg/kg)			Heavy Metals Concentration in Dry Season (mg/kg)		
				Pb	Cr	Cd	Pb	Cr	Cd
Southeast	100	150	3	0.0	4.6	0.0	0.0	2.3	0.0
		200		4.9	4.6	0.0	2.4	2.3	0.0
Southeast	500	20	1	0	1.2	0.09	0	1.4	0.19
		50		1.5	2.6	0.29	0	1.7	0.07
		100		0	1.7	0.16	0	1.4	0
		150		3.4	2.1	0.16	0	1.5	0.06
		200		1.8	1.9	0.17	1	0.9	0.22
Southeast	500	20	2	0.0	1.2	0.1	0.0	1.4	0.2
		50		1.5	2.7	0.3	0.0	1.7	0.1
		100		0.0	1.7	0.2	0.0	1.4	0.0
		150		3.5	2.2	0.2	0.0	1.5	0.1
		200		1.8	1.9	0.2	1.0	0.9	0.2
Southeast	500	20	3	0.0	1.3	0.1	0.0	1.5	0.2
		50		1.6	2.7	0.3	0.0	1.8	0.1
		100		0.0	1.8	0.2	0.0	1.5	0.0
		150		3.6	2.2	0.2	0.0	1.6	0.1
		200		1.9	2.0	0.2	1.1	1.0	0.2
Southeast	1000	20	1	8.1	5.8	0.31	0	2.1	0.56
		50		5.1	4.3	.0	0	1.6	0
		100		2.6	5.8	0.02	0.5	3.7	0.28
		150		16.5	7.2	0.39	16.9	4.5	0.57
		200		30	12.6	0.15	28.2	4.65	0.535
Southeast	1000	20	2	8.3	5.9	0.3	0.0	2.2	0.6
		50		5.2	4.4	0.0	0.0	1.6	0.0
		100		2.7	5.9	0.0	0.5	3.8	0.3
		150		16.9	7.4	0.4	17.3	4.6	0.6
		200		30.8	12.9	0.2	28.9	4.8	0.5
Southeast	1000	20	3	8.6	6.1	0.3	0.0	2.2	0.6
		50		5.4	4.5	0.0	0.0	1.7	0.0
		100		2.7	6.1	0.0	0.5	3.9	0.3
		150		17.4	7.6	0.4	17.8	4.8	0.6
		200		31.7	13.3	0.2	29.8	4.9	0.6
Southeast	1000	20	2	8.3	5.9	0.3	0.0	2.2	0.6
		50		5.2	4.4	0.0	0.0	1.6	0.0
		100		2.7	5.9	0.0	0.5	3.8	0.3
		150		16.9	7.4	0.4	17.3	4.6	0.6
		200		30.8	12.9	0.2	28.9	4.8	0.5
Southeast	1500	20	1	0	6.7	0.18	0	3.35	0.09
		50		7.9	6.8	0.32	3.95	3.4	0.16
		100		5.3	5.8	0.6	2.65	2.9	0.3
		150		6.2	7.3	0.14	3.1	3.65	0.07
		200		3.5	7.9	0.13	1.75	3.95	0.065

Table A1 : Heavy metals in soil samples (cont)

Direction	Distance (m.)	Depth (cm.)	Duplicates	Heavy Metals Concentration in Rainy Season (mg/kg)			Heavy Metals Concentration in Dry Season (mg/kg)		
				Pb	Cr	Cd	Pb	Cr	Cd
Southeast	500	20	3	0.0	1.3	0.1	0.0	1.5	0.2
		50		1.6	2.7	0.3	0.0	1.8	0.1
		100		0.0	1.8	0.2	0.0	1.5	0.0
		150		3.6	2.2	0.2	0.0	1.6	0.1
		200		1.9	2.0	0.2	1.1	1.0	0.2
Southeast	1000	20	1	8.1	5.8	0.31	0	2.1	0.56
		50		5.1	4.3	0	0	1.6	0
		100		2.6	5.8	0.02	0.5	3.7	0.28
		150		16.5	7.2	0.39	16.9	4.5	0.57
		200		30	12.6	0.15	28.2	4.65	0.535
Southeast	1000	20	2	8.3	5.9	0.3	0.0	2.2	0.6
		50		5.2	4.4	0.0	0.0	1.6	0.0
		100		2.7	5.9	0.0	0.5	3.8	0.3
		150		16.9	7.4	0.4	17.3	4.6	0.6
		200		30.8	12.9	0.2	28.9	4.8	0.5
Southeast	1000	20	3	8.6	6.1	0.3	0.0	2.2	0.6
		50		5.4	4.5	0.0	0.0	1.7	0.0
		100		2.7	6.1	0.0	0.5	3.9	0.3
		150		17.4	7.6	0.4	17.8	4.8	0.6
		200		31.7	13.3	0.2	29.8	4.9	0.6
Southeast	1500	20	1	0	6.7	0.18	0	3.35	0.09
		50		7.9	6.8	0.32	3.95	3.4	0.16
		100		5.3	5.8	0.6	2.65	2.9	0.3
		150		6.2	7.3	0.14	3.1	3.65	0.07
		200		3.5	7.9	0.13	1.75	3.95	0.065
Southeast	1500	20	2	0.0	6.9	0.2	0.0	3.4	0.1
		50		8.1	7.0	0.3	4.0	3.5	0.2
		100		5.4	5.9	0.6	2.7	3.0	0.3
		150		6.4	7.5	0.1	3.2	3.7	0.1
		200		3.6	8.1	0.1	1.8	4.0	0.1
Southeast	1500	20	3	0.0	7.1	0.2	0.0	3.5	0.1
		50		8.3	7.2	0.3	4.2	3.6	0.2
		100		5.6	6.1	0.6	2.8	3.1	0.3
		150		6.5	7.7	0.1	3.3	3.9	0.1
		200		3.7	8.3	0.1	1.8	4.2	0.1
Southeast	2000	20	1	0.2	6.2	0.07	0.2	3.6	0.45
		50		3.8	4.8	0.01	0	2.1	0.53
		100		4.2	4.6	0.4	4	0.6	0.36
		150		3.1	6.3	0.44	0	0.6	0.66
		200		3.85	6.05	0.125	2	1.85	0.295
Southeast	2000	20	2	0.2	6.4	0.1	0.2	3.7	0.5
		50		3.9	4.9	0.0	0.0	2.2	0.5
		100		4.3	4.7	0.4	4.1	0.6	0.4

Table A1 : Heavy metals in soil samples (cont)

Direction	Distance (m.)	Depth (cm.)	Duplicates	Heavy Metals Concentration in Rainy Season (mg/kg)			Heavy Metals Concentration in Dry Season (mg/kg)		
				Pb	Cr	Cd	Pb	Cr	Cd
		150		3.2	6.5	0.5	0.0	0.6	0.7
		200		3.9	6.2	0.1	2.1	1.9	0.3
Southeast	2000	20	3	0.2	6.5	0.1	0.2	3.8	0.5
		50		4.0	5.1	0.0	0.0	2.2	0.6
		100		4.4	4.9	0.4	4.2	0.6	0.4
		150		3.3	6.7	0.5	0.0	0.6	0.7
		200		4.1	6.4	0.1	2.1	2.0	0.3
Northwest	100	20	1	7.3	1.4	0	3.65	0.7	0
		50		0	3.2	0	0	1.6	0
		100		0	3.3	0	0	1.65	0
		150		2.6	3.8	0	1.3	1.9	0
		200		6.1	3.9	0	3.05	1.95	0
Northwest	100	20	2	7.5	1.4	0	3.7	0.7	0
		50		0.0	3.3	0	0.0	1.6	0
		100		0.0	3.4	0	0.0	1.7	0
		150		2.7	3.9	0	1.3	1.9	0
		200		6.3	4.0	0	3.1	2.0	0
Northwest	100	20	3	7.7	1.5	0	3.9	0.7	0
		50		0.0	3.4	0	0.0	1.7	0
		100		0.0	3.5	0	0.0	1.7	0
		150		2.7	4.0	0	1.4	2.0	0
		200		6.4	4.1	0	3.2	2.1	0
Northwest	500	20	1	0	1.2	0	0	0.7	0
		50		0	0.9	0	0	0.6	0
		100		0	2.2	0.01	0	3	0
		150		0	1.4	0	0	2.7	0
		200		5.3	6.35	0.04	0	10.5	0
Northwest	500	20	2	0.0	1.2	0	0.0	0.7	0
		50		0.0	0.9	0	0.0	0.6	0
		100		0.0	2.3	0	0.0	3.1	0
		150		0.0	1.4	0	0.0	2.8	0
		200		5.4	6.5	0	0.0	10.8	0
Northwest	500	20	3	0.0	1.3	0	0.0	0.7	0
		50		0.0	1.0	0	0.0	0.6	0
		100		0.0	2.3	0	0.0	3.2	0
		150		0.0	1.5	0	0.0	2.9	0
		200		5.6	6.7	0	0.0	11.1	0
Northwest	1000	20	1	1.4	5.7	0.03	0	1.5	0
		50		0	1.2	0	0	2.9	0
		100		0	0.3	0	0	1.2	0
		150		0	1.2	0.03	0	2.5	0
		200		5.3	2.35	0	2	1.2	0

Table A1 : Heavy metals in soil samples (cont)

Direction	Distance (m.)	Depth (cm.)	Duplicates	Heavy Metals Concentration in Rainy Season (mg/kg)			Heavy Metals Concentration in Dry Season (mg/kg)		
				Pb	Cr	Cd	Pb	Cr	Cd
Northwest	1000	20	2	1.4	5.8	0	0.0	1.5	0
		50		0.0	1.2	0	0.0	3.0	0
		100		0.0	0.3	0	0.0	1.2	0
		150		0.0	1.2	0	0.0	2.6	0
		200		5.4	2.4	0	2.1	1.2	0
Northwest	1000	20	3	1.5	6.0	0	0.0	1.6	0
		50		0.0	1.3	0	0.0	3.1	0
		100		0.0	0.3	0	0.0	1.3	0
		150		0.0	1.3	0	0.0	2.6	0
		200		5.6	2.5	0	2.1	1.3	0
Northwest	1500	20	1	0.8	1.9	0	0.4	0.95	0
		50		1.5	0	0	0.75	0	0
		100		7	0.2	0	3.5	0.1	0
		150		0	0.6	0	0	0.3	0
		200		0	2	0	0	1	0
Northwest	1500	20	2	0.8	1.9	0	0.4	1.0	0
		50		1.5	0.0	0	0.8	0.0	0
		100		7.2	0.2	0	3.6	0.1	0
		150		0.0	0.6	0	0.0	0.3	0
		200		0.0	2.1	0	0.0	1.0	0
Northwest	1500	20	3	0.8	2.0	0	0.4	1.0	0
		50		1.6	0.0	0	0.8	0.0	0
		100		7.4	0.2	0	3.7	0.1	0
		150		0.0	0.6	0	0.0	0.3	0
		200		0.0	2.1	0	0.0	1.1	0
Northwest	2000	20	1	0	3.1	0	0	1.9	0
		50		0.8	3.3	0	3.5	1.7	0
		100		7.9	2.4	0	2.3	5.3	0
		150		1.6	3.5	0	1.1	3.9	0
		200		5	5.8	0	0	3	0
Northwest	2000	20	2	0.0	3.2	0	0.0	1.9	0
		50		0.8	3.4	0	3.6	1.7	0
		100		8.1	2.5	0	2.4	5.4	0
		150		1.6	3.6	0	1.1	4.0	0
		200		5.1	5.9	0	0.0	3.1	0
Northwest	2000	20	3	0.0	3.3	0	0.0	2.0	0
		50		0.8	3.5	0	3.7	1.8	0
		100		8.3	2.5	0	2.4	5.6	0
		150		1.7	3.7	0	1.2	4.1	0
		200		5.3	6.1	0	0.0	3.2	0

Table A1 : Heavy metals in soil samples (cont)

Direction	Distance (m.)	Depth (cm.)	Duplicates	Heavy Metals Concentration in Rainy Season (mg/kg)			Heavy Metals Concentration in Dry Season (mg/kg)		
				Pb	Cr	Cd	Pb	Cr	Cd
Southwest	100	20	1	0	0.6	0	0	0.3	0
		50		4.9	1.3	0	2.45	0.65	0
		100		9.5	2.4	0	4.75	1.2	0
		150		0	1.7	0	0	0.85	0
		200		0	6	0	0	3	0
Southwest	100	20	2	0.0	0.6	0	0.0	0.3	0
		50		5.0	1.3	0	2.5	0.7	0
		100		9.7	2.5	0	4.9	1.2	0
		150		0.0	1.7	0	0.0	0.9	0
		200		0.0	6.2	0	0.0	3.1	0
Southwest	100	20	3	0.0	0.6	0	0.0	0.3	0
		50		5.2	1.4	0	2.6	0.7	0
		100		10.0	2.5	0	5.0	1.3	0
		150		0.0	1.8	0	0.0	0.9	0
		200		0.0	6.3	0	0.0	3.2	0
Southwest	500	20	1	0	0.6	0	5.4	4	0
		50		1.7	2.5	0.1	0	5.7	0
		100		0	2.3	0.11	1.8	4.7	0
		150		0	2.8	0.04	0	3.6	0.09
		200		18.7	15.4	0.17	0.9	31	0.2
Southwest	500	20	2	0.0	0.6	0.0	5.5	4.1	0.0
		50		1.7	2.6	0.1	0.0	5.8	0.0
		100		0.0	2.4	0.1	1.8	4.8	0.0
		150		0.0	2.9	0.0	0.0	3.7	0.1
		200		19.2	15.8	0.2	0.9	31.8	0.2
Southwest	500	20	3	0.0	1.7	0.0	5.7	4.5	0.0
		50		1.8	2.3	0.1	0.0	4.5	0.0
		100		0.0	2.7	0.1	1.9	5.9	0.0
		150		0.0	3.2	0.0	0.0	5.3	0.1
		200		19.7	3.0	0.2	1.0	5.4	0.2
Southwest	1000	20	1	0	1.6	0.08	0	4.3	0.12
		50		2.3	2.2	0	0	4.3	0.22
		100		0.5	2.6	0.08	0	5.6	0
		150		5.2	3	0	0.7	5	0.15
		200		2	2.8	0	0	5.15	0
Southwest	1000	20	2	0.0	1.6	0.1	0.0	4.4	0.1
		50		2.4	2.3	0.0	0.0	4.4	0.2
		100		0.5	2.7	0.1	0.0	5.7	0.0
		150		5.3	3.1	0.0	0.7	5.1	0.2
		200		2.1	2.9	0.0	0.0	5.3	0.0

Table A1 : Heavy metals in soil samples (cont)

Direction	Distance (m.)	Depth (cm.)	Duplicates	Heavy Metals Concentration in Rainy Season (mg/kg)			Heavy Metals Concentration in Dry Season (mg/kg)		
				Pb	Cr	Cd	Pb	Cr	Cd
Southwest	1000	20	3	0.0	1.7	0.1	0.0	4.5	0.1
		50		2.4	2.3	0.0	0.0	4.5	0.2
		100		0.5	2.7	0.1	0.0	5.9	0.0
		150		5.5	3.2	0.0	0.7	5.3	0.2
		200		2.1	3.0	0.0	0.0	5.4	0.0
Southwest	1500	20	1	4.6	0.8	0	2.3	0.4	0
		50		0	0	0	0	0	0
		100		8.4	3.4	0.02	4.2	1.7	0.01
		150		0	0	0	0	0	0
		200		13.2	0.7	0	6.6	0.35	0
Southwest	1500	20	2	4.7	0.8	0.0	2.4	0.4	0.0
		50		0.0	0.0	0.0	0.0	0.0	0.0
		100		8.6	3.5	0.0	4.3	1.7	0.0
		150		0.0	0.0	0.0	0.0	0.0	0.0
		200		13.5	0.7	0.0	6.8	0.4	0.0
Southwest	1500	20	3	4.9	0.8	0.0	2.4	0.4	0.0
		50		0.0	0.0	0.0	0.0	0.0	0.0
		100		8.9	3.6	0.0	4.4	1.8	0.0
		150		0.0	0.0	0.0	0.0	0.0	0.0
		200		13.9	0.7	0.0	7.0	0.4	0.0
Southwest	2000	20	1	0	1.6	0.0	0	4	0.0
		50		8.2	3.5	0.0	0	4	0.0
		100		0	2.9	0.0	0	4.7	0.0
		150		3.3	3.5	0.0	0.9	5.9	0.0
		200		0	2.8	0.0	1.65	5.8	0.0
Southwest	2000	20	2	0.0	1.6	0.0	0.0	4.1	0.0
		50		8.4	3.6	0.0	0.0	4.1	0.0
		100		0.0	3.0	0.0	0.0	4.8	0.0
		150		3.4	3.6	0.0	0.9	6.0	0.0
		200		0.0	2.9	0.0	1.7	5.9	0.0
Southwest	2000	20	3	0.0	1.7	0.0	0.0	4.2	0.0
		50		8.7	3.7	0.0	0.0	4.2	0.0
		100		0.0	3.1	0.0	0.0	5.0	0.0
		150		3.5	3.7	0.0	1.0	6.2	0.0
		200		0.0	3.0	0.0	1.7	6.1	0.0

Table A2 : Heavy metals in groundwater samples

Sample number	Direction	Duplicates	Heavy Metals Concentration in Rainy Season (mg/l)			Heavy Metals Concentration in Dry Season (mg/l)		
			Pb	Cr	Cd	Pb	Cr	Cd
KK 5	East	1	0.045	0.005	0.007	0.024	0.005	0.004
		2	0.046	0.006	0.007	0.024	0.005	0.004
		3	0.048	0.006	0.007	0.025	0.005	0.004
KK2	North	1	0.048	0.003	0.000	0.045	N/D	0.000
		2	0.049	0.003	0.000	0.046	N/D	0.003
		3	0.050	0.003	0.000	0.047	N/D	0.003
KK3	North	1	0.045	0.004	0.000	00.05	N/D	0.001
		2	0.048	0.003	0.000	0.045	N/D	0.000
		3	0.047	0.002	0.000	0.049	N/D	0.001
KK4	Northeast	1	0.014	N/D	0.007	0.007	N/D	0.003
		2	0.014	N/D	0.007	0.007	N/D	0.003
		3	0.015	N/D	0.008	0.007	N/D	0.003
KK6	South	1	0.061	0.002	0.002	0.041	0.001	0.002
		2	0.063	0.002	0.002	0.042	0.001	0.002
		3	0.064	0.002	0.002	0.043	0.001	0.002
GW2	South	1	0.026	N/D	0.000	0.013	N/D	N/D
		2	0.029	N/D	0.000	0.011	N/D	N/D
		3	0.026	N/D	0.000	0.010	N/D	N/D
KK7	Southeast	1	0.026	0.005	0.003	0.02	N/D	0.001
		2	0.029	0.008	0.004	0.018	N/D	0.001
		3	0.028	0.005	0.005	0.016	N/D	0.002
GW2	Southeast	1	0.705	N/D	0.005	0.527	N/D	N/D
		2	0.723	N/D	0.005	0.540	N/D	N/D
		3	0.744	N/D	0.005	0.556	N/D	N/D
KK1	Southwest	1	0.046	0.011	0.008	0.031	0.001	N/D
		2	0.047	0.011	0.009	0.032	0.001	N/D
		3	0.049	0.012	0.009	0.033	0.001	N/D

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Table A3: Heavy metals in surface water samples

Sample number	Direction	Duplicates	Heavy Metals Concentration in Rainy Season (mg/l)			Heavy Metals Concentration in Dry Season (mg/l)		
			Pb	Cr	Cd	Pb	Cr	Cd
SW1	North	1	0.007	0.006	0.003	0.008	N/D	N/D
		2	0.007	0.006	0.003	0.009	N/D	N/D
		3	0.007	0.006	0.003	0.009	N/D	N/D
SW2	Northwest	1	0.015	0.007	0.003	0.007	N/D	N/D
		2	0.015	0.007	0.003	0.007	N/D	N/D
		3	0.015	0.007	0.003	0.007	N/D	N/D
SW3	Northeast	1	0.025	0.008	0.004	0.017	N/D	0.001
		2	0.026	0.008	0.004	0.017	N/D	0.001
		3	0.026	0.008	0.004	0.018	N/D	0.001
SW4	South	1	0.025	N/D	0.000	0.013	N/D	N/D
		2	0.026	N/D	0.000	0.013	N/D	N/D
		3	0.026	N/D	0.000	0.014	N/D	N/D
SW5	Southwest	1	0.007	N/D	0.004	0.005	N/D	N/D
		2	0.007	N/D	0.004	0.005	N/D	N/D
		3	0.007	N/D	0.004	0.005	N/D	N/D

APPENDIX B: Boring log data

Table B1: Boring Log Data

Borehole identification: KK_1	Type of drilling: Down the hole hammer
Location: 17 km. North of KhonKaen Town along the Friendship Road	Diameter: 102.6 mm.
Site description: Kham Bon Landfill Site	Borehole Elevations: 194.627 m.
	Groundwater level: 5.6 m.
UTME: 0265705	
UTMN: 1835893	Map sheet: 5542II
	Perforation interval: 9.4-13.4 m.
Total depth: 14.90 m.	Perforation range: 4 m

Depth (m.)		Thickness (m.)	Geologic log	Description
from	to			
0	5	5.0	Sand	Yellowish brown, medium
				grained, well sorted ,well
				roundness, loose, nonplastic
5	13	8.0	Clayey Sand	Light reddish brown, medium to
				coarse grained ,moderately
				sorted, well roundness,
				compacted, slightly to
				moderately plastic.
13	15	2.0	Sandstone	Maroon, medium to course
				grained, well sorted,
				well roundness , siliceous
				cemented, moderately hard

Borehole identification: KK_2

Type of drilling: Down the hole hammer

Location: 17 km. North of KhonKaen Town along the Friendship Road

Diameter: 102.6 mm.

Site description: Kham Bon Landfill Site

Borehole Elevations: 182.399 m.

Groundwater level: 1.35 m.

UTME: 0266119

UTMN: 1836284

Map sheet: 5542II

Perforation interval: 14.4 – 18.4m.

Total depth: 19.90m.

Perforation range: 4 m

Depth (m.)		Thickness (m.)	Geologic log	Description
from	to			
0	1	1	Sand	Pinkish gray, medium grained,
				well sorted, well roundness,
				loose, nonplastic
1	10	9	Clayey Sand	Light brown, medium grained,
				well sorted, well roundness,
				moderately plastics, loose and
				Soft
10	21	11	Sandstone	Dark maroon (Dark reddish
				brown), very fine to fine grain
				well sorted, well roundness,
				calcareous cemented, composed of micas, moderately hard

Borehole identification: KK3

Type of drilling: Down the hole hammer

Location: 17 km. North of KhonKaen Town along the Friendship Road

Diameter: 102.6 mm.

Site description: Kham Bon Landfill Site

Borehole Elevations:185.103 m.

Groundwater level: 2.24 m.

UTME: 0266113

UTMN: 1836087

Map sheet: 5542II

Perforation interval: 9.6-13.6 m.

Total depth: 15.10m.

Perforation range: 4 m

Depth (m.)		Thickness (m.)	Geologic log	Description
from	to			
0	5	5.0	Sand	Yellowish orange, fine to very
				fine grained, well sorted, well
				roundness, loose, nonplastic.
5	12	6.0	Clayey Sand	Yellow, fine to medium grained
				sand ,moderately sorted, well
				roundness, compacted, slightly
				to moderately plastic.
12	15	3.0	Sandstone	Maroon, (Reddish brown),
				medium to course grained, well
				sorted, well roundness, siliceous
				cemented, moderately hard.

Borehole identification: KK_4

Type of drilling: Down the hole hammer

Location: 17 km. North of KhonKaen Town along the Friendship Road

Diameter: 102.6 mm.

Site description: Kham Bon Landfill Site

Borehole Elevations: 190.393 m.

Groundwater level: 7.55 m.

UTME: 0266192

UTMN: 1836060

Map sheet: 5542II

Perforation interval: 39.5-43.5 m.

Total depth: 45 m.

Perforation range: 4 m.

Depth (m.)		Thickness (m.)	Geologic log	Description
from	to			
0	1	1	Sand	Light reddish brown, medium,
				grained ,well sorted, well
				roundness, loose, nonplastic
1	9	8	Clayey Sand	Brown, medium to coarse
				grain, well sorted, well
				roundness, moderately plastics,
				loose and compacted
9	11	3	Sand	Brownish gray, medium to
				coarse grained, well sorted
				well roundness, nonplastic to
				slightly plastic, loose and soft
11	45	34	Sandstone	Dark brown, medium to coarse
				grained, well sorted, well
				roundness, siliceous cemented,

Borehole identification: KK5

Type of drilling: Down the hole hammer

Location: 17 km. North of KhonKaen Town along the Friendship Road

Diameter: 102.6 mm.

Site description: Kham Bon Landfill Site

Borehole Elevations: 192.507 m.

Groundwater level: 4.70 m.

UTME: 0266317

UTMN: 1836110

Map sheet: 5542II

Perforation interval: 39.5-43.5 m.

Total depth: 25.00 m.

Perforation range: 4 m.

Depth (m.)		Thickness (m.)	Geologic log	Description
from	to			
0	2	2	Sand	Brown, medium grained, well
				sorted, well roundness, loose,
				nonplastic
2	9	7	Clayey Sand	Yellowish brown, medium
				grained, moderately to well
				sorted, well roundness, loose
				and compacted, compose of
				Limonite
9	12	3	Sand	Brownish grey, medium grained
				well sorted, well roundness,
				nonplastic, loose
12	25	13	Sandstone	Dark brown, medium to coarse
				grained, well sorted, well
				roundness, siliceous cemented,

Borehole identification: KK6

Location: 17 km. North of KhonKaen Town along the Friendship Road

Site description: Kham Bon Landfill Site

UTME: 0265911

UTMN: 1835899

Total depth: 25.70 m.

Type of drilling: Down the hole hammer

Diameter: 102.6 mm.

Borehole Elevations: 192.876 m.

Groundwater level: 7.30 m.

Map sheet: 5542II

Perforation interval: 20.2-24.2m.

Perforation range: m.

Depth (m.)		Thickness (m.)	Geologic log	Description
from	to			
0	1	1	Sand	Pinkish grey, medium to coarse
				grained, well sorted, well
				roundness, loose, nonplastic
1	6	5	Clayey Sand	Brown, medium to coarse
				grained, well sorted, well
				roundness, moderately to
				highly plastic, soft.
6	12	6	Sand	Brown, medium to coarse
				grained, well sorted, well
				roundness, loose, nonplastic
12	16	4	Clayey Sand	Brown, medium to coarse
				grained, well sorted, well
				roundness, highly plastic, soft
16	20	4	Sandstone	Greenish grey, fine to coarse
				grained, poorly sorted, well
				roundness, calcareous
				cemented, moderately hard.

20	25	5	Sandstone	Dark maroon(Dark reddish
				brown) , very fine to fine
				grained, well sorted, well
				roundness, calcareous
				cemented, moderately hard,
				composed of mica.

Borehole identification: KK7

Type of drilling: Down the hole hammer

Location: 17 km. North of KhonKaen Town along the Friendship Road

Diameter: 102.6 mm.

Site description: Kham Bon Landfill Site

Borehole Elevations: 187.702 m.

Groundwater level: 3.25 m.

UTME: 0266185

UTMN: 1835931

Map sheet: 5542II

Total depth: 19.90 m.

Perforation interval: 14.4-18.4m.

Perforation range: m.

Depth (m.)		Thickness (m.)	Geologic log	Description
from	to			
0	1	1	Sand	Light brown, medium grained,
				well sorted, well roundness,
				loose, nonplastic.
1	16	15	Clayey Sand	Pinkish brown, medium grained,
				well sorted, well roundness,
				siliceous cemented, compose
				of micas, moderately hard
16	21	5	Sandstone	Reddish brown, fine to medium
				grained, well sorted, well
				roundness, siliceous cemented,
				moderately hard, composed of
				Micas.

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