

CHAPTER IV

LANDFILL SITE CHARACTERIZATION

4.1 Description of Study Area

4.1.1 General Description of Kham Bon Landfill Site and Its Vicinity

Kham Bon landfill site is located at Ban (village) Kham Bon, Muang District, Khon Kaen Province, Northeast Thailand (Figure 4.1). It is about 17 kilometers north of Khon Kaen City along the Friendship Highway, comprising an area of 0.15 square kilometers. The study area extends over some 0.32 square kilometers. The landfill is located on a ridge about 190 meters above mean sea level at the interfluves between the Huai (rivulet) Mak Ngo to the north and the Huai Kham Bon to the south. The ridge is part of the rolling terrain of the Middle terrace, a geomorphological feature of the Khon Kaen region (Eiumnoh and Osathanontha, 1982) and slopes gradually eastwards to the floodplain of the Pong River. The vicinity of the Kham Bon landfill site is enlarged. The nearest village to the site is the Kham Bon village with approximately 70 households. Another village, Sam Chan, is located to the north of the site, 2,000 metres from the landfill site. Moreover, there is the Sam Chan reservoir, on the Huai Mak Ngo, which is also located to the north of the site. It is a main water supply for Sam Chan village. Also, there is a small leachate drainage ditch discharging towards the north into the Huai Mak Ngo upstream of the Sam Chan reservoir. Another small rivulet, Huai Kham Bon, is located to the south of the study area. It flows parallel to the southern edge of the landfill site into Nong Bung oxbow lake and discharges into the Pong River. Several villages, such as Ban Bung Kae and Ban Non are located in the discharge areas of the two rivulets. The outskirts of these villages are used for growing rice, cassava and sugar cane as well as fish farming.

Kham Bon landfill site has been serviced for the disposal of municipal wastes since 1968. The landfill area is compartmentalized into 2 zones: 1 filled zone and 2 office station zone. One compartment area of the landfill has been constructed to

accept mixed wastes and a small part of infectious wastes. For the remaining area, office station and landfill treatment plant, stabilization pond, including anaerobic pond; facultative pond, and maturation pond had been constructed. Leachate generated from the landfill was collected and transferred to the leachate treatment plant.

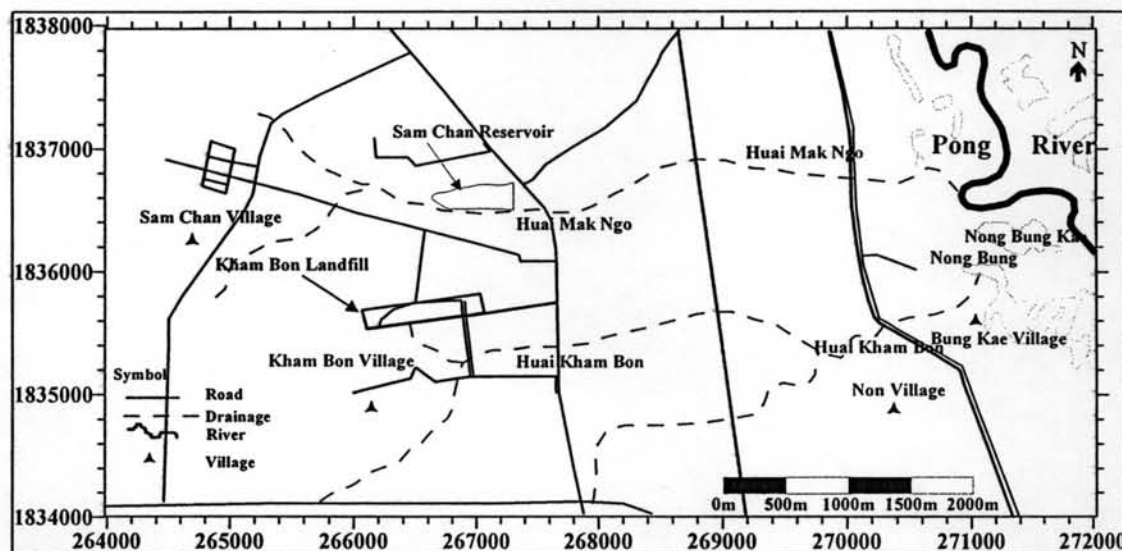


Figure 4.1 Location of study area at Kham Bon village, Khon Kaen Province, Northeast Thailand

4.1.2 Solid Wastes Disposal to Landfill Site

Solid wastes originate mainly from community area. It is mixed wastes of domestic solid and hazardous wastes. Some recyclable wastes are sorted at transfer stations before disposed to the landfill. The site is capable to accommodate approximately 200 tons per day of mixed wastes. The waste generation rate for Khon Kaen Municipality is estimated as 187 tons/day (PONRE, 2004) and the per capita rate is equal to 1.1 kg/day (Piyaprasit, 1996). The wastes disposed of to this site consist mainly of food and fruit, plastics, paper, wood, glass, metals, and other municipal garbage. Additionally, hazardous wastes, for example, batteries, fluorescent lamp tubes, and aerosol spray cans, are part of the waste stream. The proportion of different wastes at Kham Bon landfill site is shown in Figure 4.2.

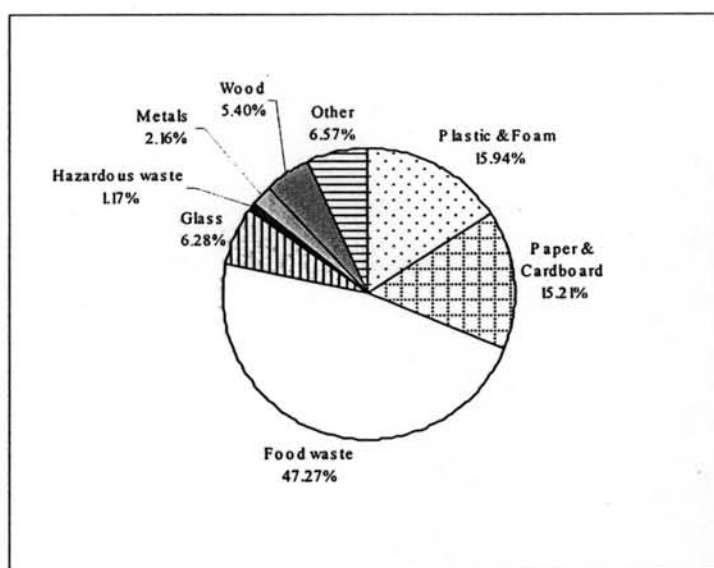


Figure 4.2 Percentage distributions of wastes deposited in Kham Bon landfill (Piyaprasit, 1996)

4.1.3 Problems of Kham Bon Landfill

Field observation indicated that the efficiency of the mixed waste disposal is likely poor. The landfill receives all types of waste materials, particularly solid and hazardous wastes. The different wastes are commingled together without a proper sorting and are piled onto the ground becoming to the decomposition. Frequently, the wastes are open dump and burnt to reduce the quantities. By such inappropriate disposal methods, the wastes have created not only a serious environmental pollution problem but also a threat to public health and safety. They are a source of houseflies and produce unpleasant odor. Moreover, they could distribute disease pathogens and generate contaminated leachate. This leachate contains various pollutants and toxic substances, especially heavy metals, which migrate, infiltrate and descend into the soil profile to contaminate the adjacent surface water and groundwater (Boonsener et al., 1994).

4.1.4 Climate and Drainage Systems

The average annual rainfall is approximately 1,750 mm, with about 80% falling between June and September. The average relative humidity is 75 % 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.

Results from the aerial photograph interpretation and the topographic map analysis confirmed that the topography of the study area plays an important role to the surface water flow directions at the landfill site. Water drains northwards from the landfill into the Sam Chan reservoir and then flows eastwards to the Huai Mak Ngo before discharging to the Pong River. Water draining southwards from the landfill enters the Huai Kham Bon and flows eastwards into an oxbow lake, Nong Bung on the Pong floodplain.

4.2 Kham Bon Landfill Site Characterizations

Soils, leachate, surface water and groundwater up and down gradient of the contaminated site were collected three times per year along the direction of the leachate movement in order to investigate the seasonal fluctuation in the concentration of contaminants from the Kham Bon landfill. The first, second and third sampling rounds were conducted on December, 2004; May, 2005; August, 2005; respectively.

4.2.1 Landfill Leachate Characterization

Figure 4.3 shows landfill leachate sampling points located at the pond treatment system, the leachate influent (INF) at the collection pond and the treated leachate effluent (EFF) at the maturation pond before discharging into the environment. Leachate samples were collected from the middle of the pond. Typical wastewater characteristics of Kham Bon landfill leachate is reported in Table 4.1.

The results of leachate analysis present the fluctuation of the studied contaminants as listed in Table 4.1. It is observed that the lower concentrations were recorded in dry season (second sampling period in May 2005) comparing with winter season (first sampling- in December 2004) and rainy season (third sampling in August 2005). It is also noted that the chemical composition of leachate significantly varied over time. Correspondingly to Tchobanoglous et al. (1993) as stated that the chemical composition of leachate would greatly vary depending on the age of landfill and the

time of sampling. Moreover, the chemical composition of leachate depends on many factors such as the initial composition of solid wastes, particle size, degree of compaction, hydrology of the site, climate (Al-Yaqout and Hamoda, 2003). These results indicated that it is not appropriate to take only one or a few sample of leachate to represent the average content of leachate. Therefore, it is essential to conduct a long-term monitoring program to obtain the representative quality of leachate. In addition, the fluctuation of leachates property might be further complicate to the removal efficiency of treatment process. This fluctuation should be considered when operating the leachate treatment plant.

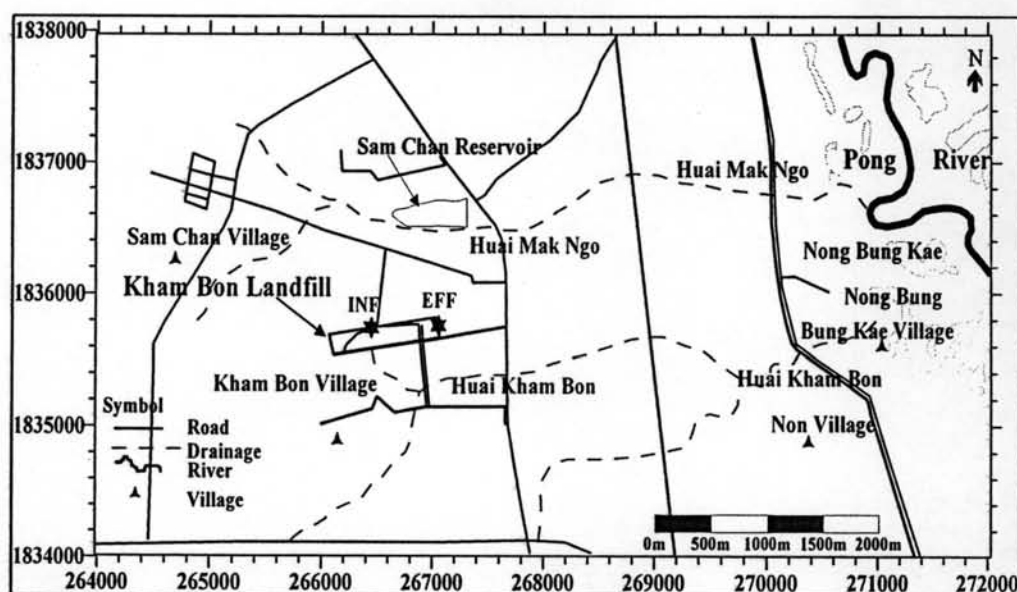


Figure 4.3 Location of landfill leachate samples collected in all periods of sampling

Considering the influent leachate samples collected in all period of sampling, pH values were between 7.7 and 8.23 due to the high alkalinity represented by bicarbonate and carbonate contents of landfill leachate. The high electrical conductivity values ($12.6\text{-}31.0\text{ mS cm}^{-1}$) recorded from the field indicates the presence of dissolved substances contained in leachate. This is also corresponded to the high TDS content, reflecting the extent of mineral contents of the leachate. COD concentration varied between $18,360$ and $27,160\text{ mg L}^{-1}$ while BOD concentration was in the range of $8,933$ to $12,500\text{ mg L}^{-1}$.

Regarding the BOD/COD ratio, it conventionally represents the biodegradable organics of leachate. BOD/COD ratio of leachate at Kham Bon landfill was in the range of 0.46-0.50, implying that this leachate was partially biodegradable. It can be treated by biological treatment process which is the most commonly used in Thailand.

Table 4.1 Chemical characteristics of landfill leachate in all samplings

Parameters	1 st Sampling		2 nd Sampling		3 rd Sampling	
	Influent	Effluent	Influent	Effluent	Influent	Effluent
pH	8.23	8.84	8.02	8.55	7.7	8.53
Conductivity (ms/cm)	14.4	9.95	12.6	7.85	31.0	16.94
TDS (mg L ⁻¹)	12,000	8,000	4550	3500	36,125	14,760
COD (mg L ⁻¹)	19,850	2,350	1,4560	1,800	27,160	2,800
BOD (mg L ⁻¹)	9,950	250	7,500	200	12,500	150
Na (mg L ⁻¹)	3,177	2,289	1,600	1,290	2,165	1,208
K (mg L ⁻¹)	2,850	2,130	1,355	1,185	2,087	1,953
Ca (mg L ⁻¹)	250	112	175	50	282	99
Mg (mg L ⁻¹)	670	430	350	130	211	115
Cl (mg L ⁻¹)	5,250	3,200	2,750	1,600	3854	2984
CO ₃ (mg L ⁻¹)	-	-	250	150	300	200
HCO ₃ (mg L ⁻¹)	-	-	3850	1,550	4,550	1,750
SO ₄ (mg L ⁻¹)	69	12	60	25	103	24
NO ₃ (mg L ⁻¹)	37	25	40	15	0	153
Fe (mg L ⁻¹)	10.1	0.4	8.60	1.69	13.6	4.70
Mn (mg L ⁻¹)	0	0	0.16	0.08	1.50	0.60
Total Cr (mg L ⁻¹)	0	0	8.63	1.59	1.40	2.20
Cd (mg L ⁻¹)	0.274	0.26	0	0	0.02	0.01
Pb (mg L ⁻¹)	0.14	0.14	0.07	0.59	0.07	0.13
Cu (mg L ⁻¹)	0.32	0.30	0.18	0.05	0.23	0.09
Zn (mg L ⁻¹)	0.45	0.12	0.32	0	2.10	0.62

Analysis results of heavy metals including Pb, Cr, Cd, Cu and Zn, present the fluctuation concentration of heavy metals (Table 4.1). Comparison of heavy metal concentration in the influent and effluent could not be made because of data fluctuation. It can be approximately stated that there were somewhat level of heavy metal contamination in leachate. Heavy metal is hardly to be treated through the biological treatment process. Leachate effluent still contained some heavy metals that can be further leaked to the environment.

Considering the effluent leachate which is a key to depict the landfill treatment efficiency, the study results reveal that the pollutants in landfill leachate could be partially removed. Comparison of the treated leachate effluent characteristics with the industrial effluent standard declared by the Announcement of Ministry of Science, Technology and Environment B.E. 2539 (1996), BOD, COD and TDS higher exceeded than the standard. Even though the studied heavy metal content in the leachate did not exceed the standard, it is not conventionally treated through biological process. It should be noted that some heavy metals were not be covered in this study, eg. Hg, it is not absolutely stated that heavy metal contaminants in leachate are within the standard. However, the effluent characteristics studied herein indicate contamination of some heavy metals, organic and non-organic substances.

4.2.2 Soil Analysis

4.2.2.1 Physical and Chemical Properties of Soil

In order to exhibit more variability in heavy metal concentrations, soil samplings were undertaken for three times per year at locations along the direction of leachate drainage, ie. at the distance of 500 to 2,000 meters westward (the potential contaminated area) as well as at the distance about 4,000 meters eastward of landfill site. At each location, soil samples were taken at different depths (Figure 4.4).

The results of grain size analysis of 108 soil samples in the study area reveal that the soils are medium to moderately fine-textured soils including coarse-textured soil. They can be classified as clay loam (CL) to silty clay loam (SCL), sandy loam (SL), loamy sand (LS) and sand (S). The fine textured soil was found only in the eastern part of the study area (Nong Bung) which is the receptor of leachate from Huai Kham Bon rivulet. The medium textured soil was deposited in the central part of the study area which is near the leachate drainage ditch. The rest of the area is covered by the coarse textured soil. Focusing on the percentage of clay content distribution in the study area, the high distribution of clay content were found along the ditch of landfill leachate flowing both north-east and south-east directions. The north-east direction, it flows northward to eastward to Huai Mak Ngo. Whereas the south-east direction, it

flows to Huai Kham Bon in the southeastern part and Nong Bung in the eastern part of the study area. Moreover, an increasing of the percentage of clay content with depth was recorded in the soil collected throughout the study area (Figure 4.5). The medium textured soil was deposited in the central part of the study area which is near the leachate drainage ditch. The rest of the area is covered by the coarse textured soil found at the leachate ditch and near Sam Chan reservoir in the central to northern parts of the study area. In contrast, slightly alkaline soil was found in the eastern part of the study area.

The percentage of soil organic matter content ranged from 0.05 to 2.5 %. Figure 4.6 indicates that the highest organic matter values were concentrated on the central and eastern parts of the study area. Moreover, it was observed that the organic matter has been decreased descending with depth. This is because the top soil is composed of more humus obtained from decomposed of plants and animals and the humus is decreased descending with depth (Spark, 1986).

Considering individual parameters, the pH values of 6 to 8.4 displayed relatively uniform distributions throughout the study area. Slightly acidic soil was found at the leachate ditch and near Sam Chan reservoir in the central to northern parts of the study area. In contrast, slightly alkaline soil was found in the eastern part of the study area.

The cation exchange capacity of the soil samples ranged from 0.7 to 10.7 cmolc kg^{-1} of soil. As shown in Figure 4.7 the soil samples collected in the eastern part of the study area display the higher CEC values for all different levels. Moreover, it was observed that the CEC value in the disturbed zone I is lower than other zones. The reason is that the disturbed zone I is the agricultural activities zone. It is always disturbed by human activities in all seasons resulting in the fluctuation of its properties. From the observation, it can be concluded that the high organic matter and clay content are related to the high CEC in soil (Banat et al., 2005; Spark, 2005).

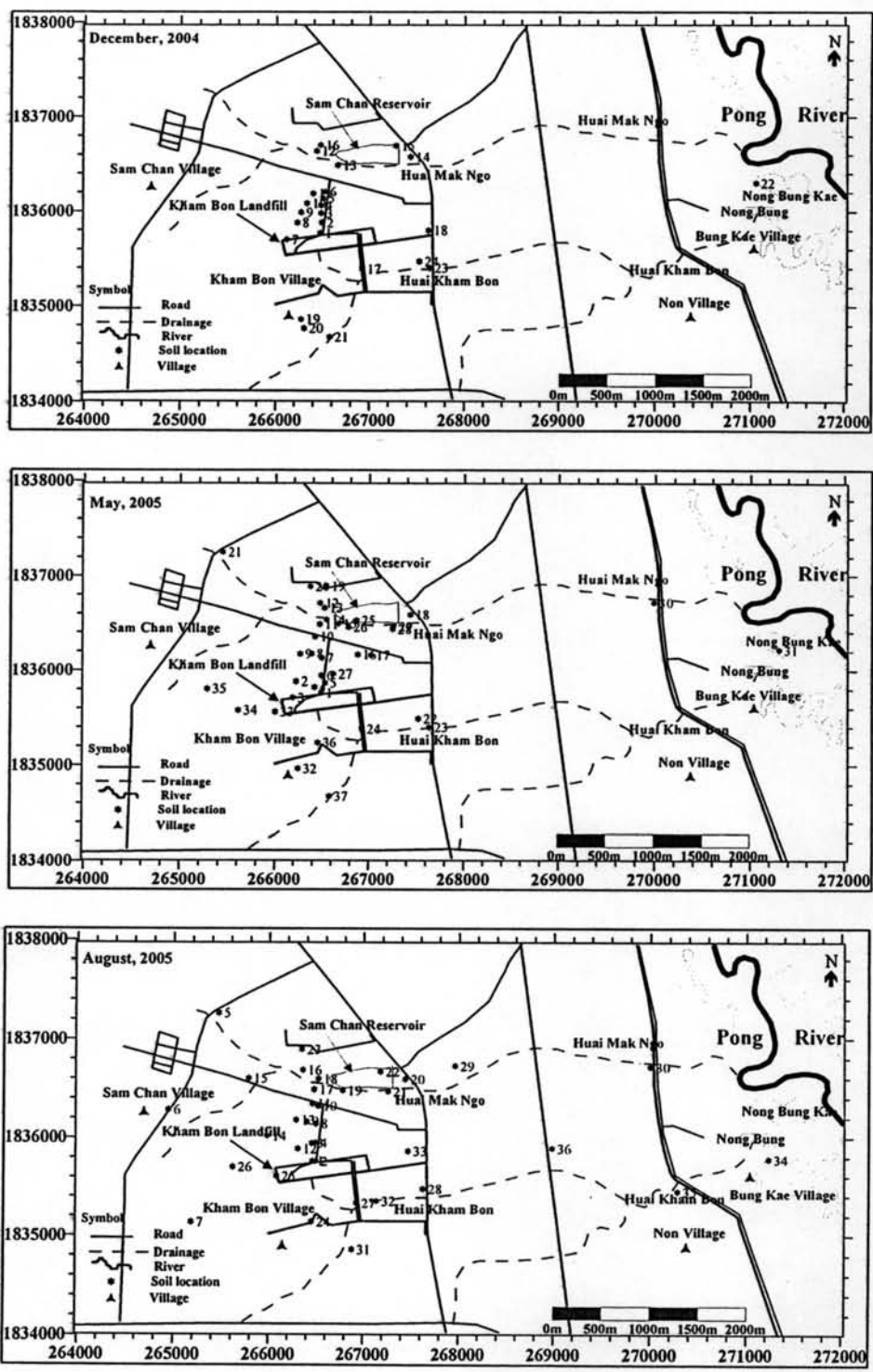


Figure 4.4 Location of soil samples taken in all sampling periods

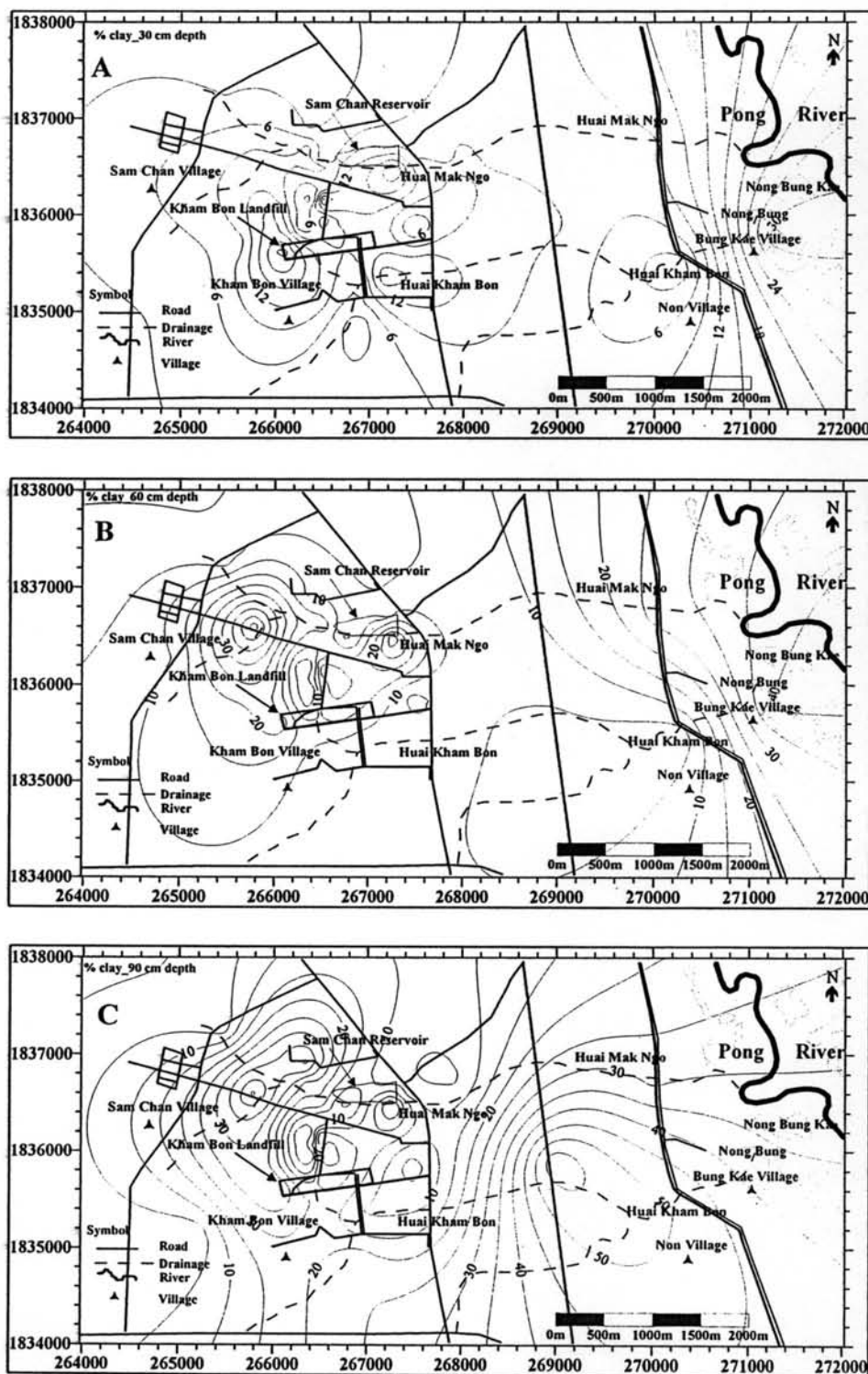


Figure 4.5 Percentage of Clay content distribution in the study area for all soil at 0-90 cm depth in the third sampling period: 0-30 cm depth (A); 30-60 cm depth (B); 60-90 cm depth (C)

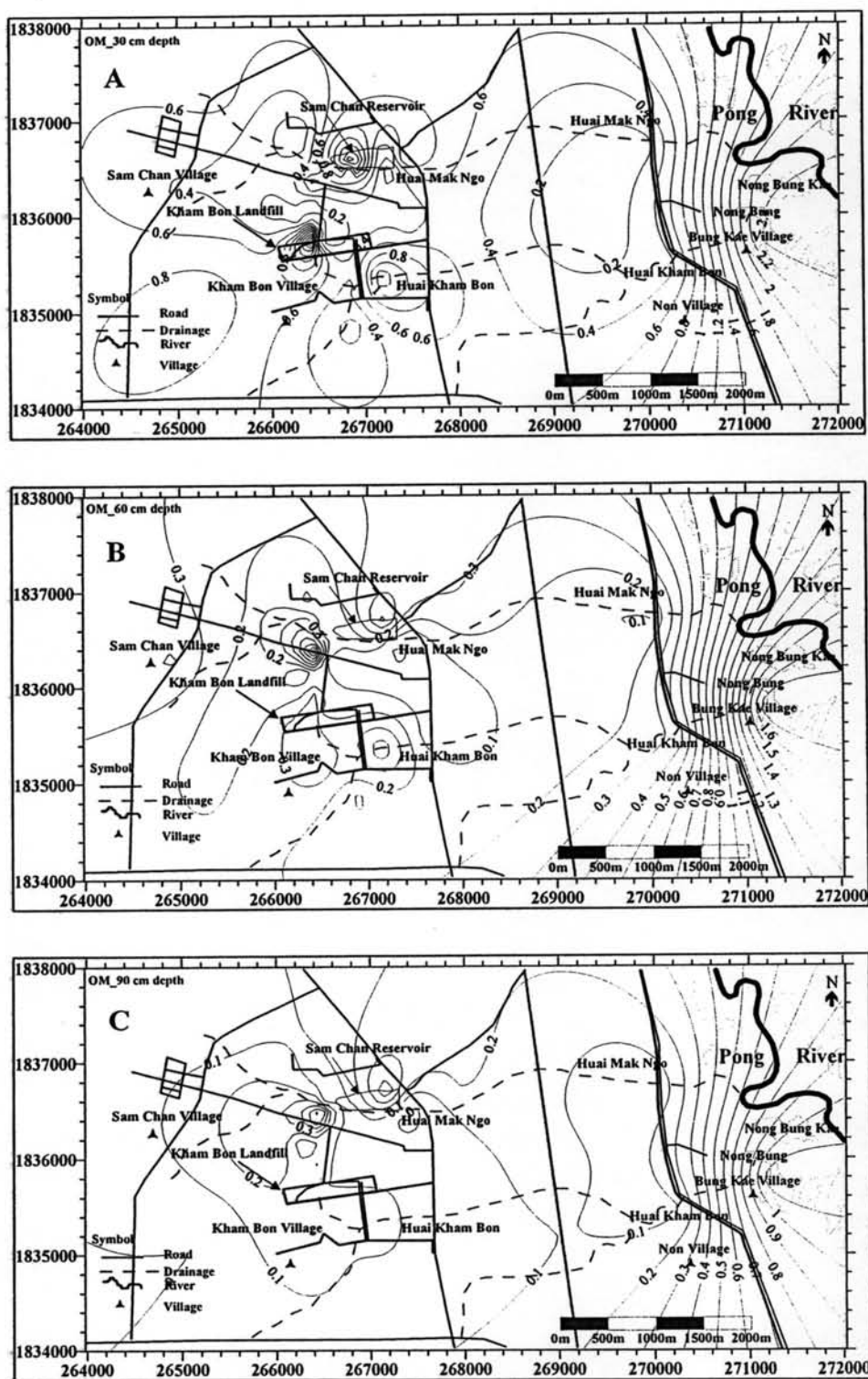


Figure 4.6 Organic matter of all soil at 0-90 cm depth in the third sampling period:

0-30 cm depth (A); 30-60 cm depth (B); 60-90 cm depth (C)

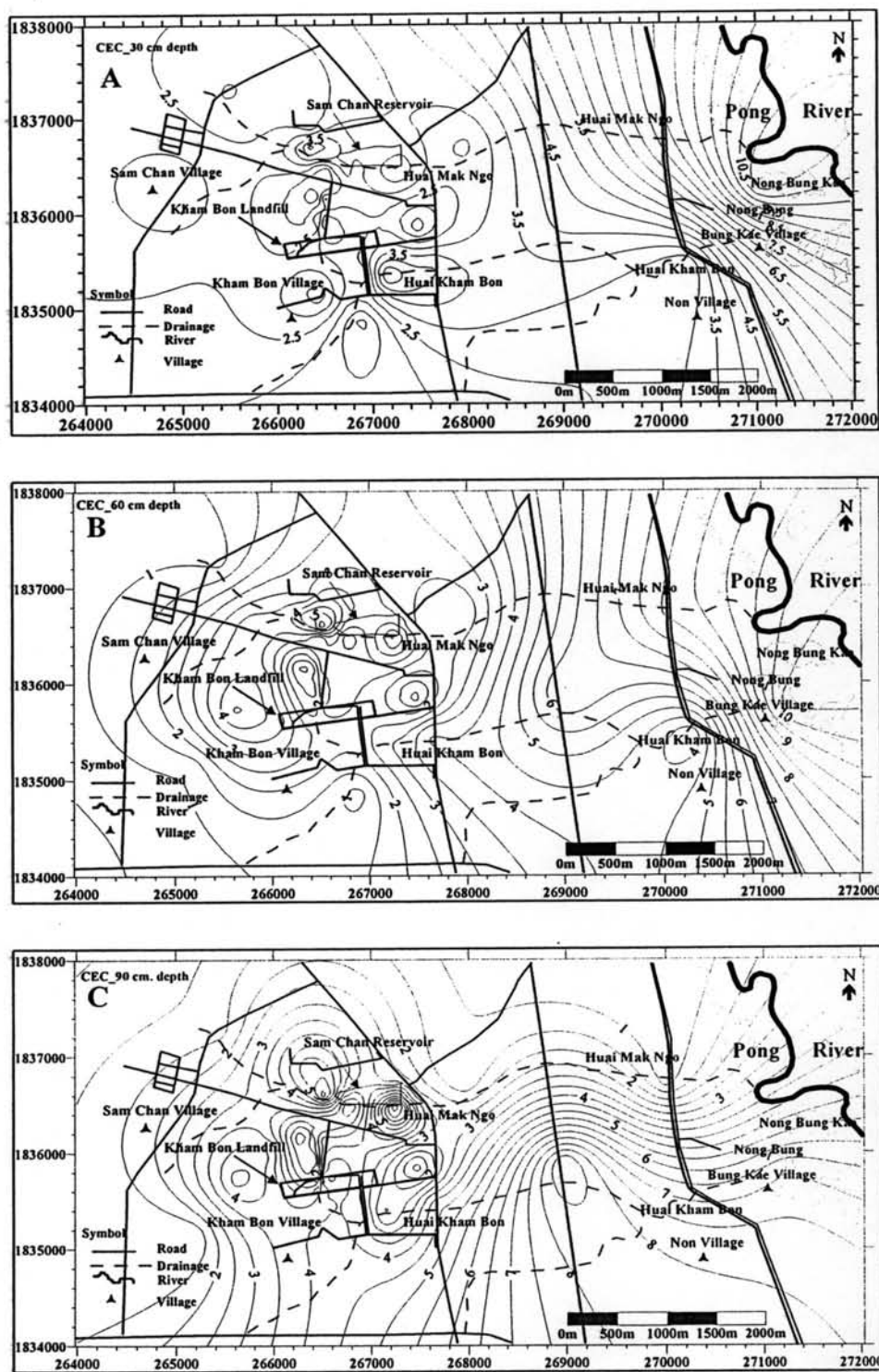


Figure 4.7 Cation exchange capacity of all soil at 0-90 cm depth in the third sampling period: 0-30 cm depth (A); 30-60 cm depth (B); 60-90 cm depth (C)

4.2.1.2 Distribution of Metals in Soil

Five heavy metals Cr, Cd, Pb, Cu and Zn in soil samples were analyzed as reported in Table 4.2 and Figures 4-8 to 4.10. Heavy metals analysis from the first sampling period as shown in Figure 4.11 points out that Cr concentration in soil varied within the range of 0.1 to 5.6 mg kg⁻¹ whereas the concentration of Pb was in the range of 5 to 23 mg kg⁻¹. Cd concentration in soil ranged from 1.8 to 3.0 mg kg⁻¹. Also, the concentration of Zn and Cu ranged from 0.9 to 55.0 mg kg⁻¹ and 0.9 to 12.7 mg kg⁻¹ respectively. Zn and Cu concentrations are typical of landfill leachate. The sources of Zn are florescent tubes, batteries and variety of food wastes whereas discarded food is the main source of Cu (Fairweathe-Tait and Hurrell, 1996). Pb, Cd and Cr ions are toxic heavy metals (Roy et al., 1991) which are found in the study area. High levels of heavy metals were encountered in the Sam Chan reservoir and along the rivulet in the Southeastern part of the study area. The highest concentration of heavy metals was recorded close to the landfill site within a radius of 500 metres, and tended to decreasing with the distance apart from the site. Focusing on the physicochemical parameters of soil that influencing the heavy metals deposition, it illustrates that the high heavy metals accumulation was agreed with the high of clay content, CEC and organic matter.

Table 4.2 Heavy metals concentration in Soil collected in three sampling times

Times of Sampling	Heavy Metals Concentration (mg kg ⁻¹ of soil)				
	Cr	Cd	Pb	Cu	Zn
1 st Sampling (December, 2004)	0.1-5.6	1.8-3.0	5.0-23.0	0.9-12.7	0.9-55
2 nd Sampling (May, 2005)	0.14-14.99	ND*	2.0-43.0	0.2-14.5	1.0-60.0
3 rd Sampling (August, 2005)	0-20.0	0-1.7	0-21.43	0-40.4	0-52.2

ND*: Not detected

The study was extended in the second sampling period to collect soil samples at two levels (0 cm to 15 cm and 15 cm to 30 cm in depth) at each point of sampling. The concentration of Cr (Figure 4.12a) in the first depth interval, 0 to 15 cm below the ground surface varied from 0.14 to 14.99 mg kg⁻¹. Figure 4.12b expresses the concentration of Pb falling in the range of 2 to 43 mg kg⁻¹. The concentrations of Cu (Figure 4.12c) and Zn (Figure 4.12d) varied from 0.2 to 14.5 mg kg⁻¹ and 1 to 60 mg

kg^{-1} , respectively. Within the second depth interval, 15 to 30 cm below ground surface, Cr concentration was in the range of 0.3 to 11.3 mg kg^{-1} , while Pb concentration was between 6 and 42 mg kg^{-1} . The concentrations of Zn and Cu ranged from 0.2 to 80 mg kg^{-1} and 0.1 to 33.8 mg kg^{-1} , respectively. It should be remarked that the concentration of Pb and Cr at the 15 cm and 30 cm depths, Pb accumulated more at the deeper depth (30 cm depth) than at the shallow depth (15 cm depth), whereas Cr was deposited in the opposite manner. These phenomena are possibly due to the immobilization of Cr with ferric oxide compound presented in the upper soil.

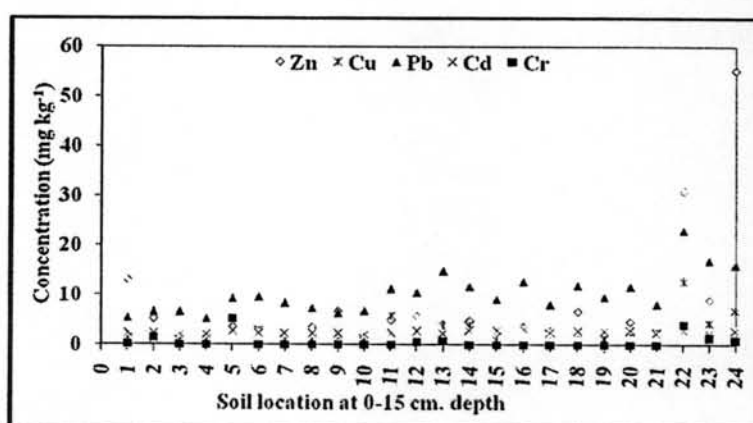


Figure 4.8 Heavy metal concentrations at 0-15 cm depth in the first sampling period

In the third round of sampling, the Spearman's rank correlation coefficient was used to calculate the significant association between soil properties and heavy metal accumulation in the study area. Pb concentration (0 to 21.43 mg kg^{-1}) was found increasing with depth (Figure 4.13a), and decreasing with distance from the site. Possible sources of lead are batteries, chemical substances from photograph processing, lead-based paints and lead pipe disposed at landfill. Correlation of Pb with clay content showed slightly positive (spearman's rank correlation, $R = 0.442$, $P < 0.007$). In contrast to Pb, Cr concentration (0 to 20 mg kg^{-1}) decreased with depth (Figure 4.13b), which is corresponding to the descending of clay content. The correlation of Cr was concerned with clay content and CEC at $R = 0.720$, $P < 0.0001$ and $R = 0.590$, $P < 0.0001$, respectively. Cd could not be detected in most parts of the surveyed area, except in some ditches and rivulets (0 to 1.70 mg kg^{-1}). The discarding of dry cell batteries and paint cans are possible sources of Cd. Pb and Cr values from

all periods of sampling are at significant concentrations in the study area. This might depend on the amount of wastes seasonally disposed of to the landfill. Cu (Figure 4.13c) and Zn (Figure 4.13d) contaminants of interest, varied from 0 to 40.4 mg kg⁻¹ and 0 to 52.2 mg kg⁻¹, respectively. For Cu, the positive correlation between clay content and CEC was statistically significant at $R = 0.723$, $P < 0.0001$ and $R = 0.671$, $P < 0.0001$, respectively. Also, Zn exhibited positively correlation with CEC, clay content and OM at spearman's rank correlation $R = 0.629$, $P < 0.0001$, $R = 0.606$, $P < 0.0001$ and $R = 0.474$, $P < 0.004$, respectively.

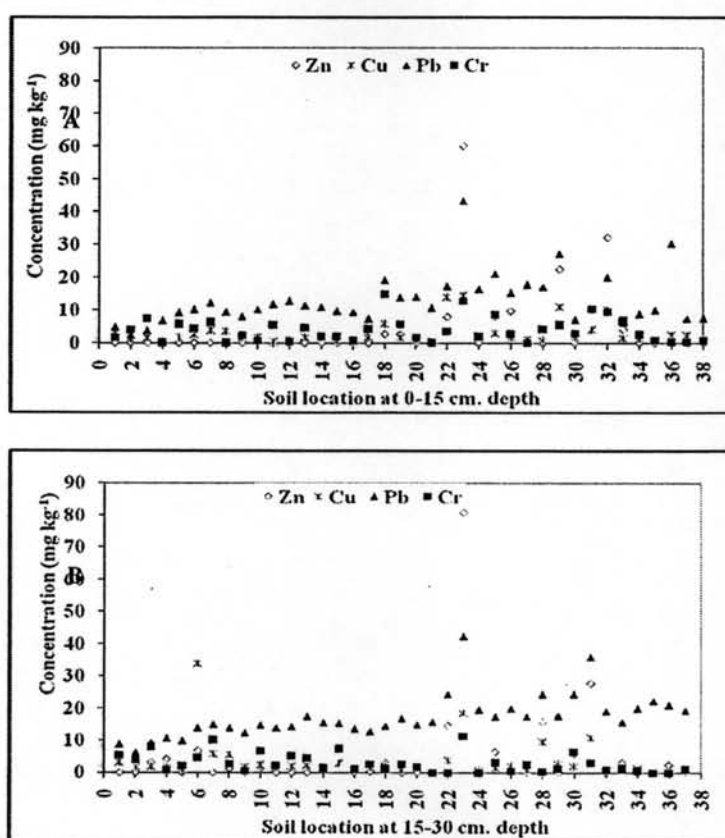


Figure 4.9 Heavy metals concentration at 0-15 cm depth (A) and 15-30 cm depth (B) in the second sampling period

According to the literature reviews, Fe and Mn oxide/ oxyhydroxides also play important role in retarding the mobility of heavy metals in soil. Thus, the concentration of Fe and Mn were recorded only in this period. Fe concentration ranged from 10 to 548 mg kg⁻¹ whereas Mn concentration varied between 3 and 3,000 mg kg⁻¹. A significant correlation was detected between Fe and clay content as well

as the CEC at spearman's rank correlation $R = 0.777$, $P < 0.0001$ and $R = 0.596$, $P < 0.0001$, respectively. It is obvious that only Mn positively correlated with pH ($R = 0.418$, $P < 0.011$) and also correlated with CEC ($R = 0.574$, $P < 0.0001$). Mn accumulation enhances with increasing pH. This is because the high pH increases hydrolysis of Mn^{2+} , Mn precipitation, and negative charge on the exchange complex (Bradl, 2004).

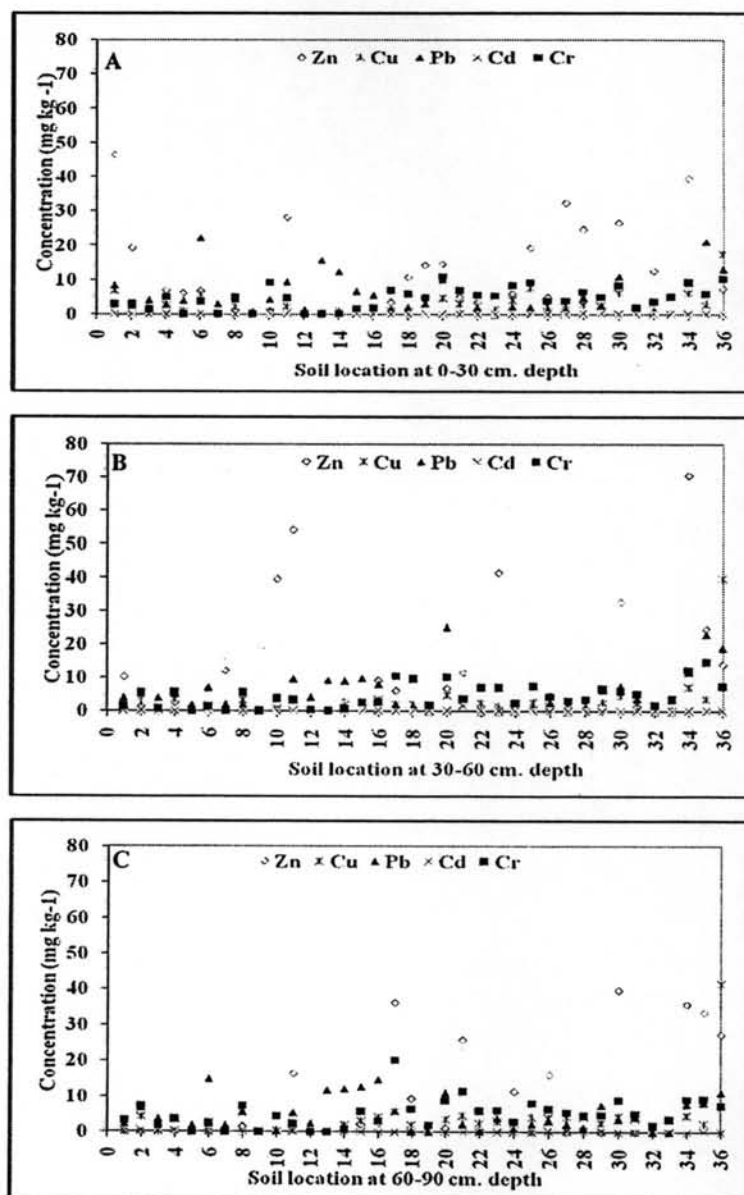


Figure 4.10 Heavy metals concentration at 0-30 cm depth (A), 30-60 cm depth (B), and 60-90 cm depth (C) in the third sampling period

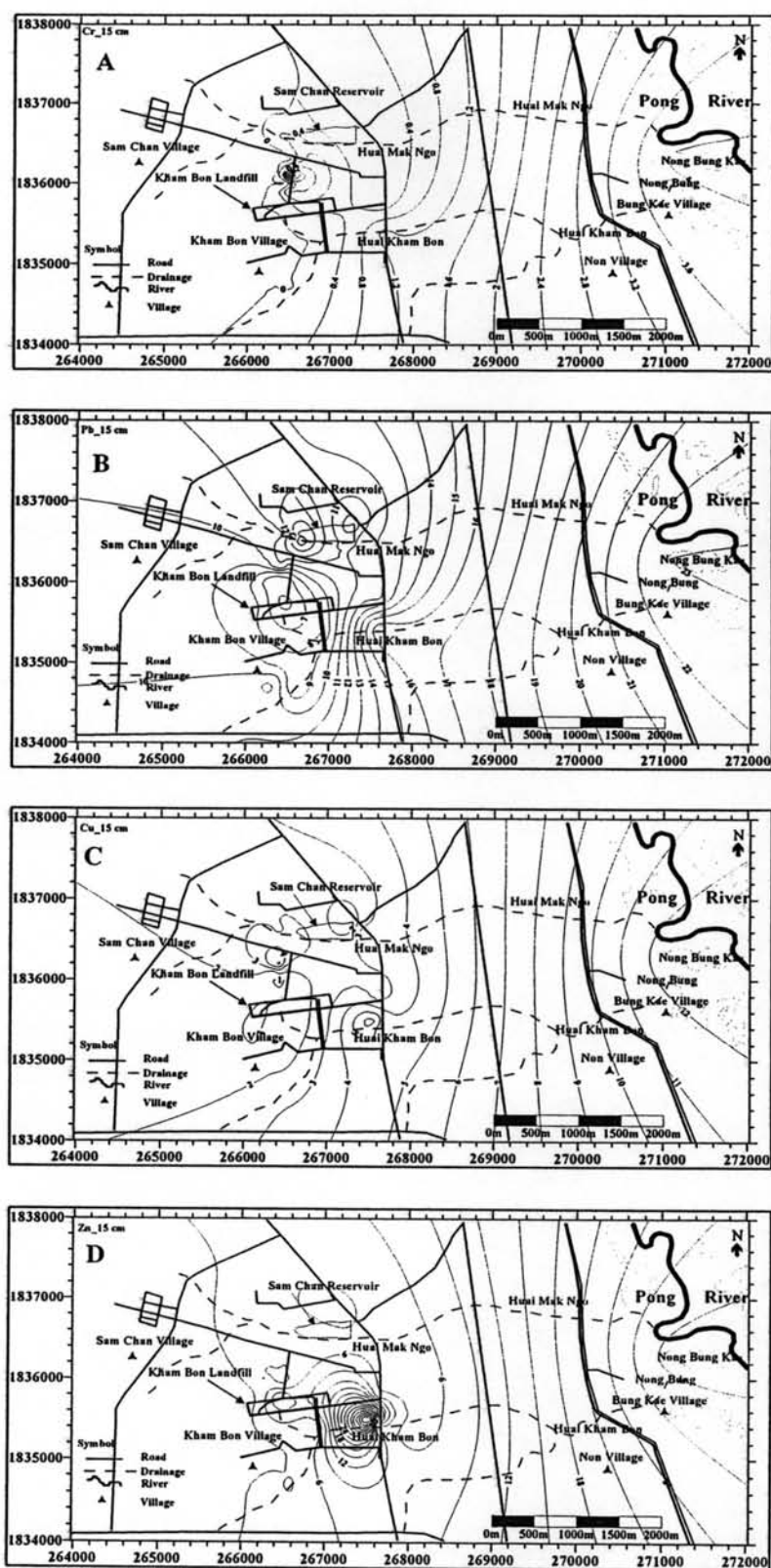


Figure 4.11 Heavy metal concentrations at 0-15 cm depth in the first sampling period: Cr (A); Pb (B); Cu (C); Zn (D)

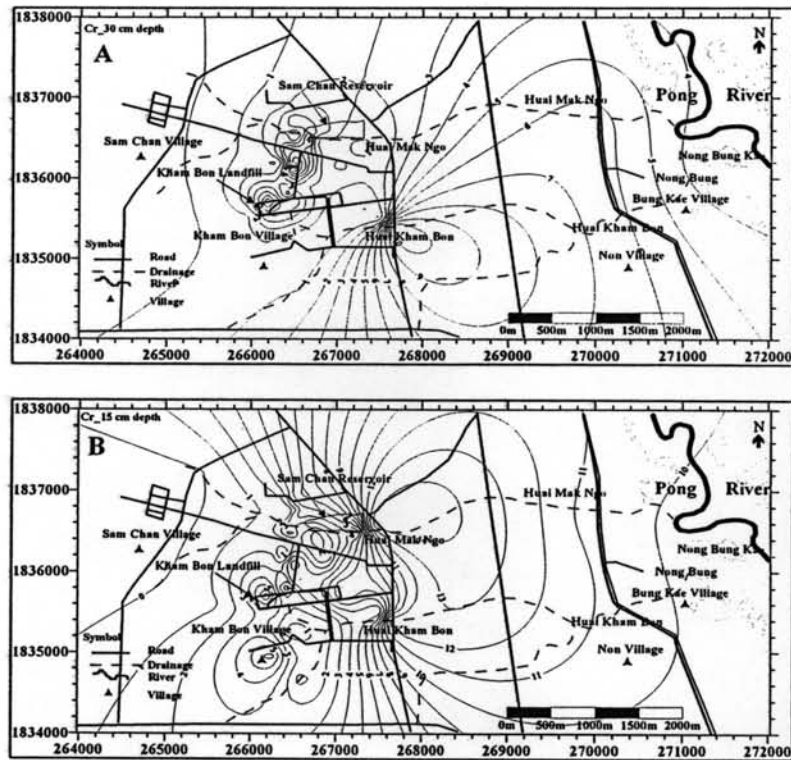


Figure 4.12a Concentration of Cr at 0-15 cm depth (A) and 0-30 cm depth (B) in the second sampling period

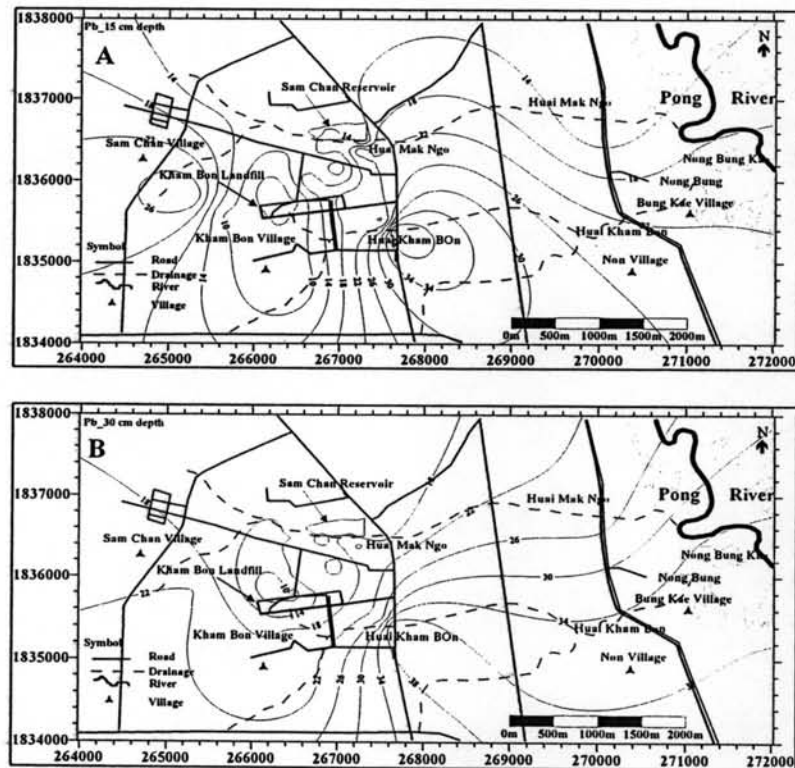


Figure 4.12b Concentration of Pb at 0-15 cm depth (A) and 0-30 cm depth (B) in the second sampling period

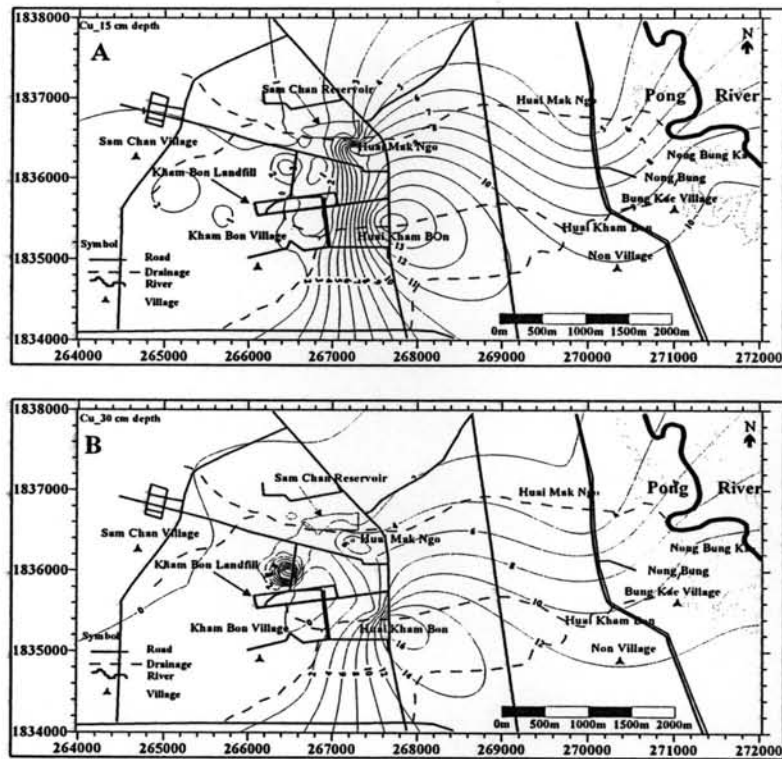


Figure 4.12c Concentration of Cu at 0-15 cm depth (A) and 0-30 cm depth (B) in the second period of sampling

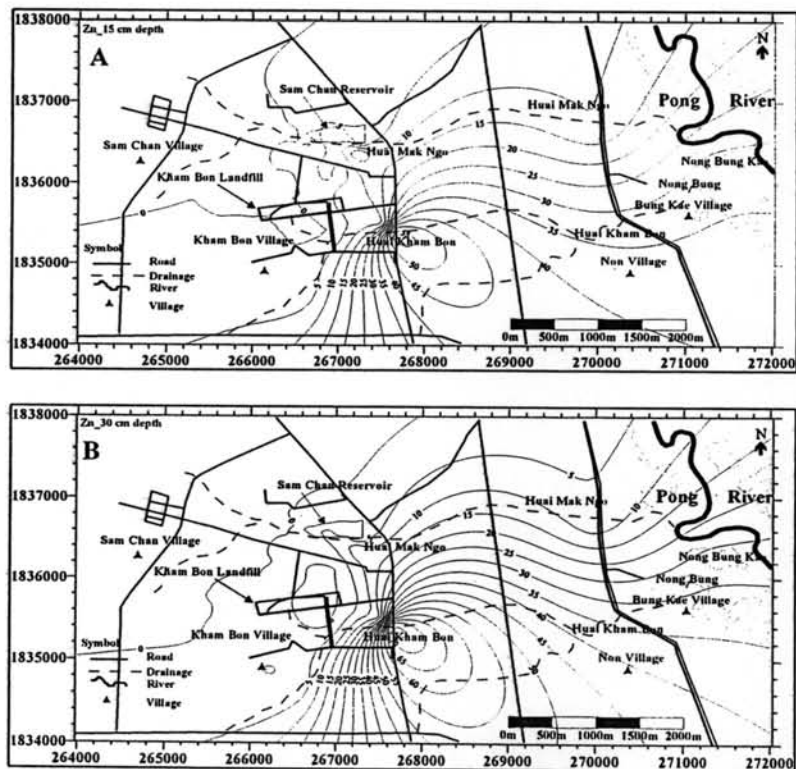


Figure 4.12d Concentration of Zn at 0-15 cm depth (A) and 0-30 cm depth (B) in the second sampling period

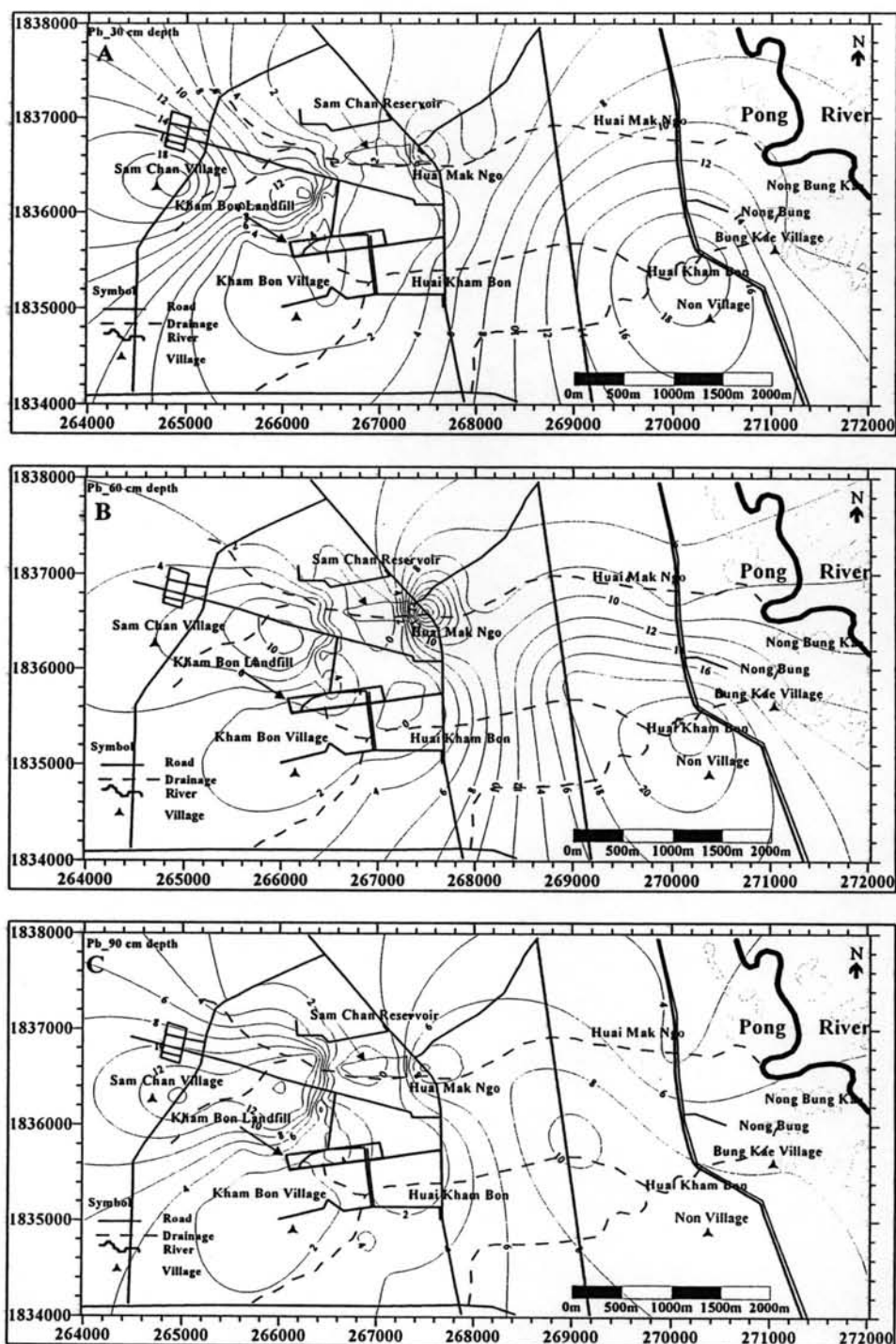


Figure 4.13a Concentration of Pb at 0-15 cm depth (A), 15-30 cm depth (B), and 60-90 cm depth (C) in the third sampling period

It is summarized that the most important factors influencing heavy metals accumulation in soils are clay mineral, CEC, metal oxides (Fe and Mn oxide) and humic substance associated with natural organic matter (Bradl, 2004). In case of metal

oxides and oxyhydroxides, the correlation of five heavy metals was calculated with the Fe and Mn. It was found that all heavy metals revealed the positive correlation with Fe ($R = 0.555-0.777$, $P < 0.0001$) and Mn ($R = 0.385-0.525$, $P < 0.0001$).

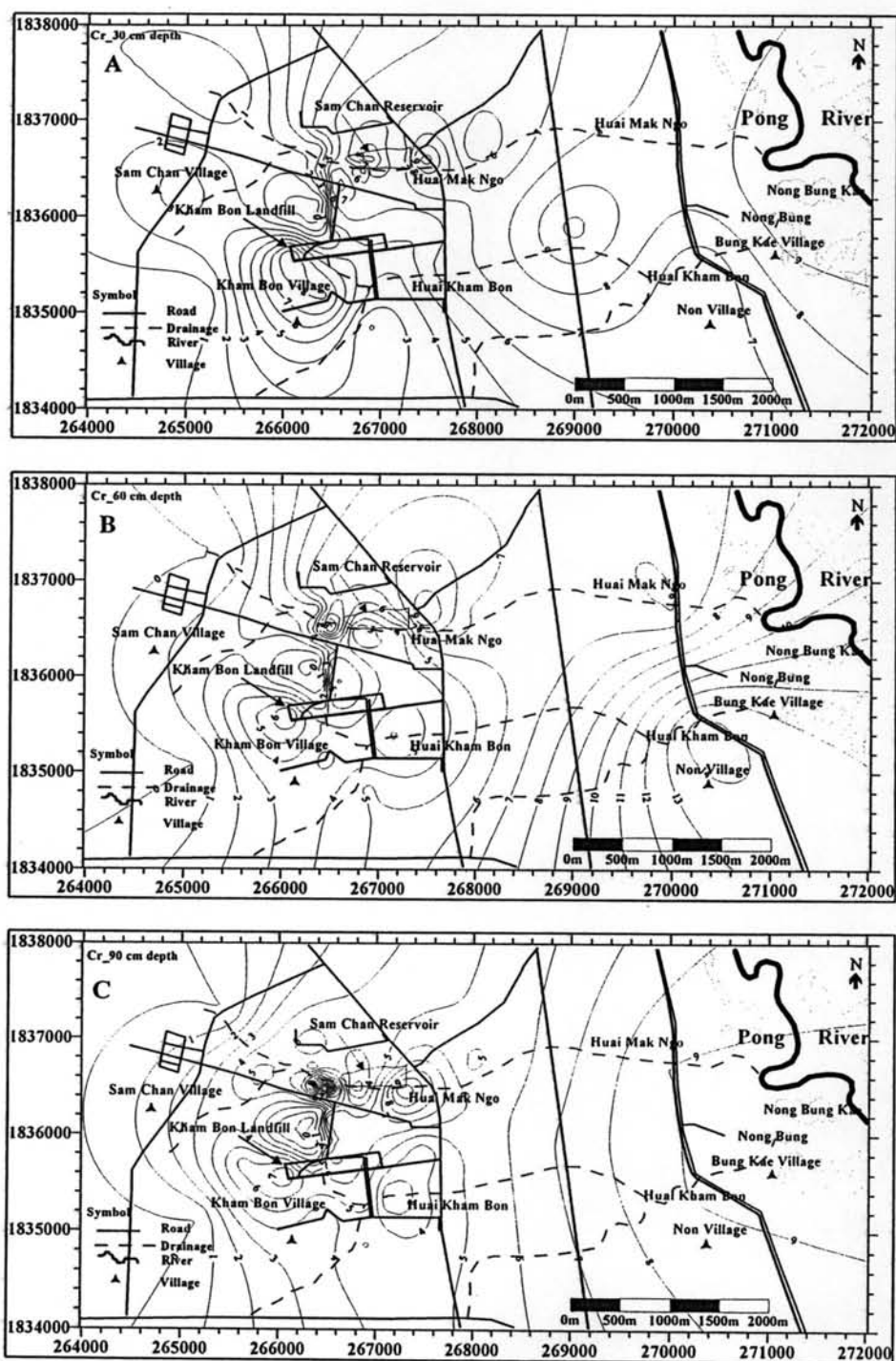


Figure 4.13b Concentrations of Cr at 0 at 0-15 cm depth (A), 15-30 cm depth (B), and 60-90 cm depth (C) in the third sampling period

Therefore, it can be pointed out that the metal oxides especially, iron oxide plays important role in controlling the heavy metals deposition in the study area. Moreover, the study area is covered by the *red loess* which composed of more iron oxide (Boonsener, 1991) which is the well source of sink for heavy metals.

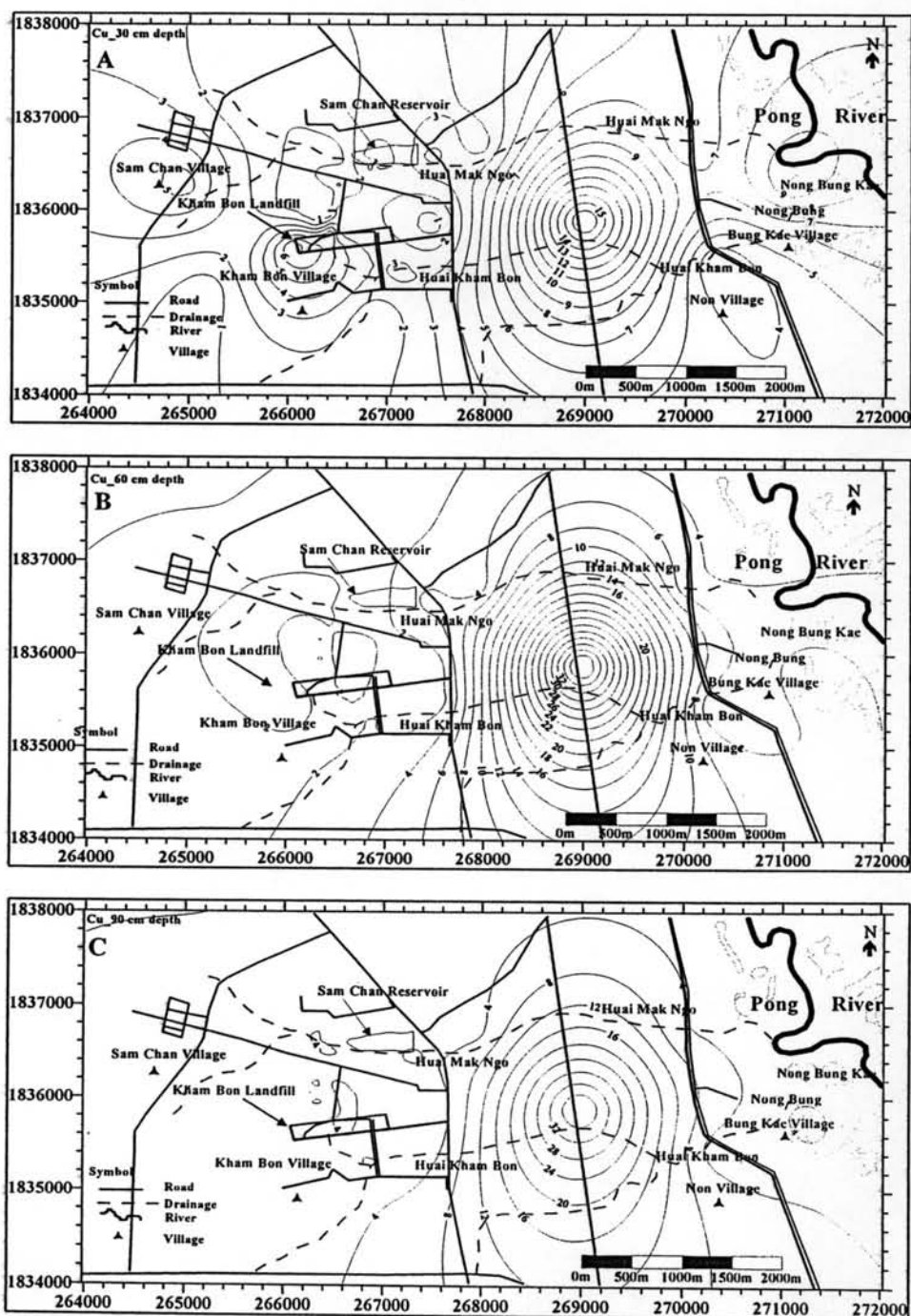


Figure 4.13c Concentrations of Cu at 0-15 cm depth (A), 15-30 cm depth (B), and 60-90 cm depth (C) in the third sampling period

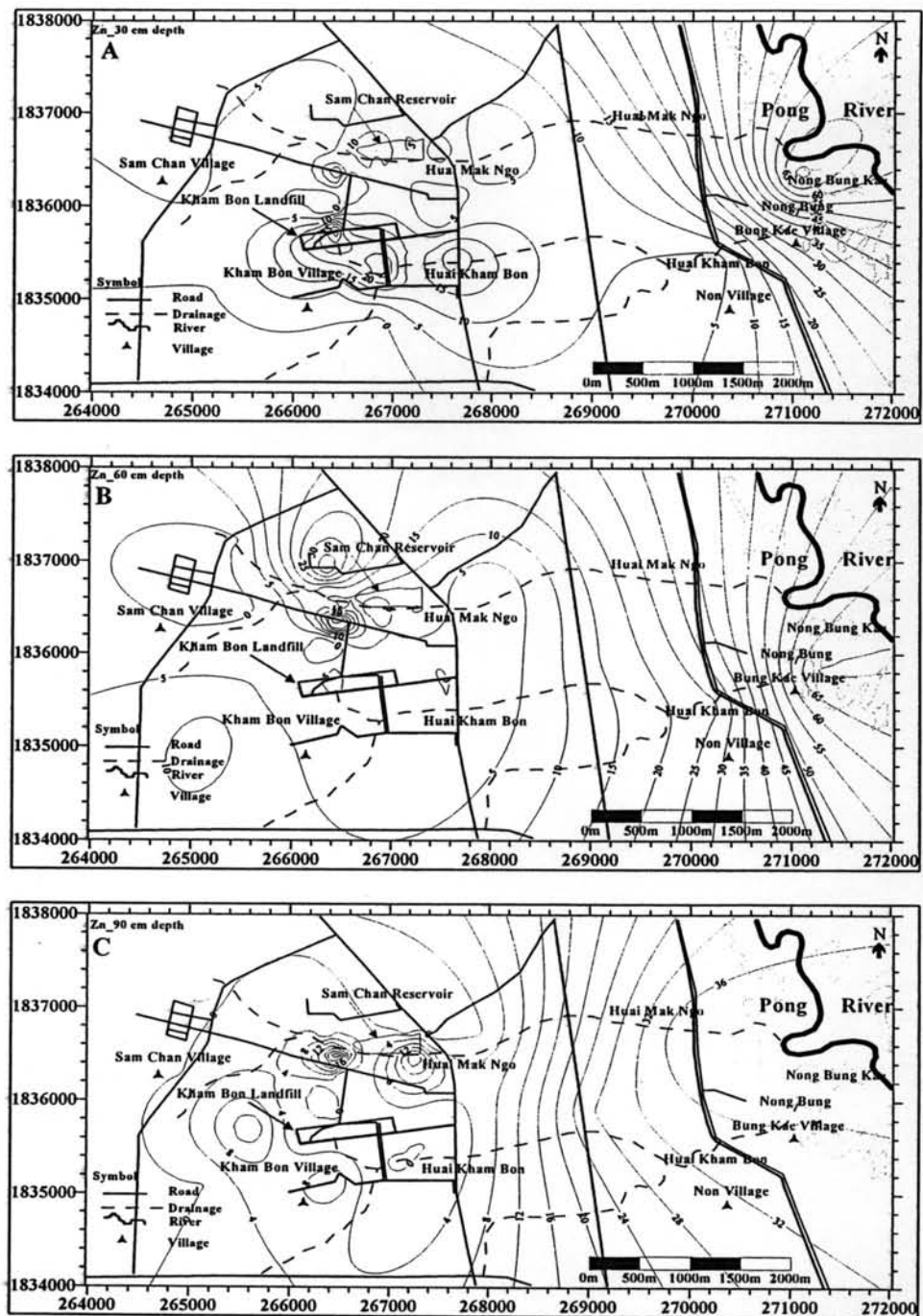


Figure 4.13d Concentrations of Zn at 0-15 cm depth (A), 15-30 cm depth (B), and 60-90 cm depth (C) in the third sampling period

Apart from physical and chemical properties controls, other factors of influencing heavy metals accumulation / mobility were taken into consideration. The lower slope gradients at the lower lying creates lower-velocity flow, consequently, dominance of the finer fraction in the soil and higher retention of heavy metals was

occurred as observed in the central part and eastern part of the study area. However, based on the Environmental Enhancement and Promotion Act B.E. 2535 (1992), the concentrations of cadmium, chromium and lead in soil **do not exceed** the standard allowable limit ($\text{Cd} \leq 37 \text{ mg kg}^{-1}$; $\text{Cr} \leq 300 \text{ mg kg}^{-1}$; $\text{Pb} \leq 400 \text{ mg kg}^{-1}$).

During all three sampling periods it was found that the zone of highest concentration of heavy metals was the ditch of leachate which flows northwards to Sam Chan reservoir. Furthermore, other zones where the concentration is high are the downstream parts of Huai Mak Ngo and Huai Kham Bon where they discharge into the Pong River through oxbow lakes. Moreover, the Pb concentration was found to be distributed both horizontally and vertically throughout the area. The field survey found that spray- paints cans, batteries, pesticide containers, iron pipes, dry cells and fluorescent tubes were widespread throughout the landfill. These mixed wastes had been burnt repeatedly in the open air within the site, in such a way that the heavy metals would also possibly be released by this action. Moreover, the Pb concentration was found to be distributed both horizontally and vertically throughout the area. The field survey found that spray-paints cans, batteries, pesticide containers, iron pipes, dry cells and fluorescent tubes were widespread throughout the landfill. These mixed wastes had been burnt repeatedly in the open air within the site, in such a way that the heavy metals would also possibly be released by this action (Chuangcham et al., 2008).

From the investigation in the second and third period of sampling, it was surprised that the significant Pb concentration was observed at Sam Chan Village in the northwestern part of the study area. In spite of the Sam Chan Village located approximately 200 metres above mean sea level which higher than the Kham Bon landfill. Moreover, it is not situated in the direction of flow pattern as reported by Chuangcham et al., 2005. The reason of this appearance is due to the uncontrolled scavenger activities. They could be the heavy metals carriers.

It should be remarked here that these physical and chemical properties of soil in the distributed zone I and II (0-60 cm depth) as reported above showed the fluctuation when comparing to the natural zone (60-90 cm depth) due to the agricultural activities.

4.2.2 Groundwater Analysis

Groundwater samples were conducted from 11 monitoring wells (Figure 4.14) within the study area in all periods of sampling to analyze physical and chemical properties as well as heavy metals contents.

4.2.2.1 Hydrogeology

Two main aquifers are identified: one shallow, unconfined and the other deep, confined (Figure 4.15). The shallow unconfined aquifer consists of alternating layers of sand and clay interbedded with sand and laterite in some places. This aquifer occurs from 2 to 8 mbgl and varies in thicknesses from 2 to 6 metres (Chuangcham, 2005). The deep confined aquifer comprises jointed sandstone, siltstone and claystone with fractures and matrix porosity. The depth of the aquifer ranges between 5 and 50 metres and it is 10 to 25 metres thick (Buaphan et al., 1998). The hydraulic conductivity of the shallow aquifer ranges from 1.5×10^{-1} to 3.93×10^{-3} m day⁻¹ and the transmissivity from 1.8 to 3.2 m² day⁻¹. Field investigation revealed that the water table is located at 1 to 5 mbgl in the shallow aquifer and is encountered from 9 m to 15 m in the deep aquifer at MW-8. There is seasonal fluctuation in water level at each monitoring well. Groundwater flows from northeastern and southeastern parts of the landfill site to the eastern boundary of the study area. The groundwater flow corresponds very well with the flow direction of surface water. Therefore, the major pathway for landfill-derived contaminants is thought to be downward to the northeast and southeast through to the Pong River (Figure 4.16).

4.2.2.2 Hydrogeochemistry

Eleven groundwater samples from all three sampling periods were analyzed for physical and chemical parameters based on the Drinking Water Standard, Groundwater Acts B.E. 2520. The results are shown in Table 4.3-4.5. The pH values were within the acceptable limits ranging between 6.5 and 8.0 according to those permissible by the Groundwater Acts, B.E. 2520. The electrical conductivity varied within the range of 60 to 3,300 $\mu\text{S cm}^{-1}$ and was found to be high, especially in MW-4 and MW-5 which are situated within a radius of 500 metres down gradient from the

dump site. The TDS within the landfill site varied from 100 to 4,000 mg L⁻¹, some values were much higher than the permissible upper limit of 1,500 mg L⁻¹.

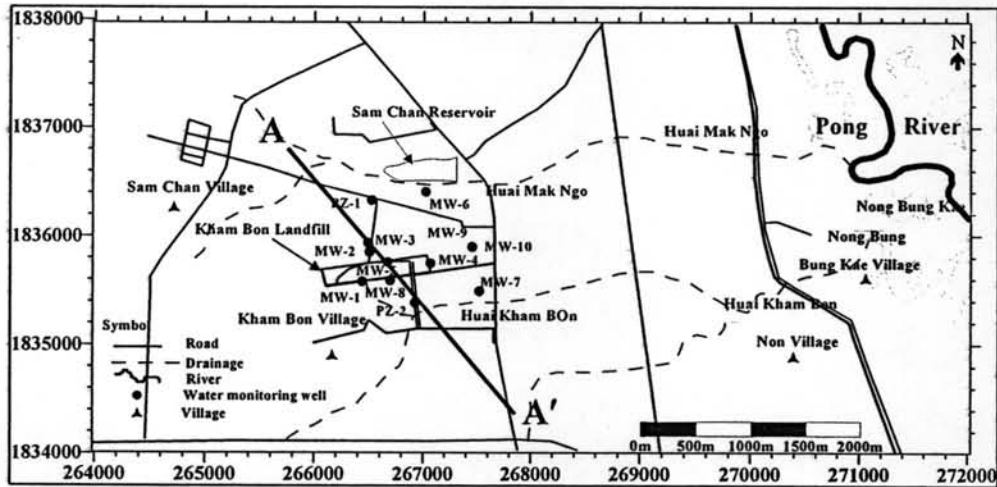


Figure 4.14 Location of groundwater monitoring wells in the study area

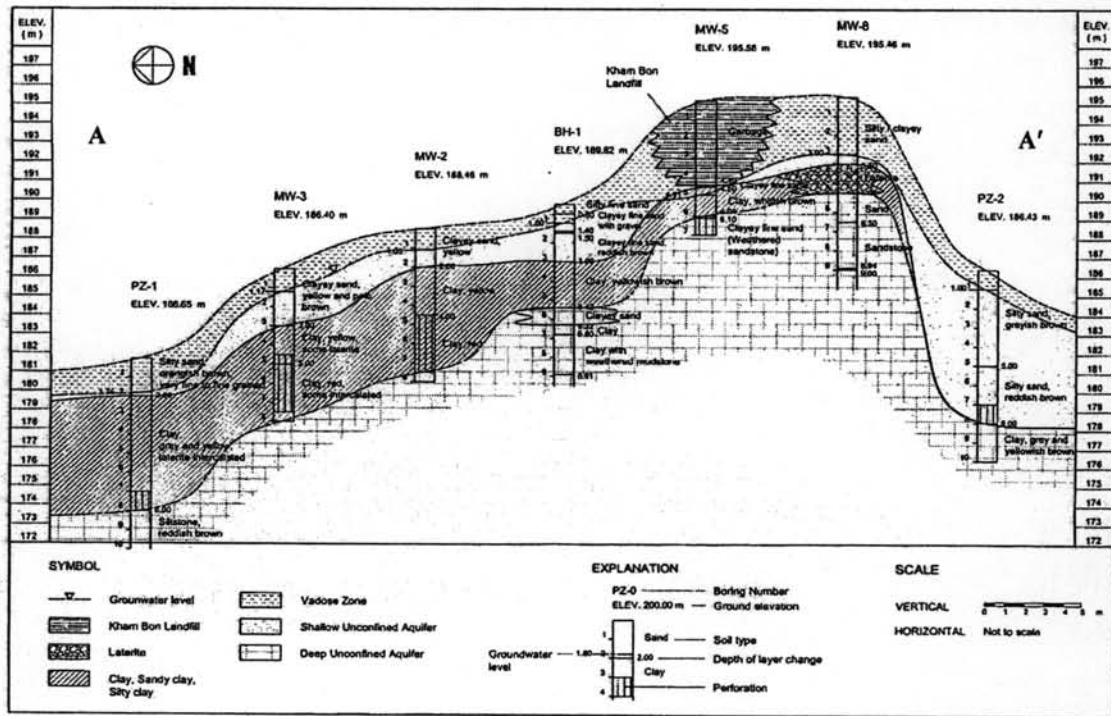


Figure 4.15 Geologic section along A-A' (see Fig. 4.14) showing stratigraphy and hydrogeology of the Kham Bon landfill, Khon Kaen

These high conductivity values and high TDS were measured in boreholes near the landfill site which have been affected by landfill leachate. The total hardness reported as CaCO_3 were within the range of 40 to 480 mg L^{-1} . It is within the acceptable limits and being classified as moderately hard to hard (Sawyer et al, 1994). The range of sodium concentration was from 2 to 430 mg L^{-1} , whereas the potassium concentration varied from 1 to 130 mg L^{-1} . The multivalent, calcium and magnesium often present at a significant concentration in natural water. The concentrations of calcium and magnesium ranged from 1 to 170 mg L^{-1} and 1 to 40 mg L^{-1} , respectively. These ions are easily precipitated and in particular react with soap to form scum which is difficult to remove (Driscoll, 1986). Moreover, the concentrations of calcium and magnesium ions are related to the hardness of the water.

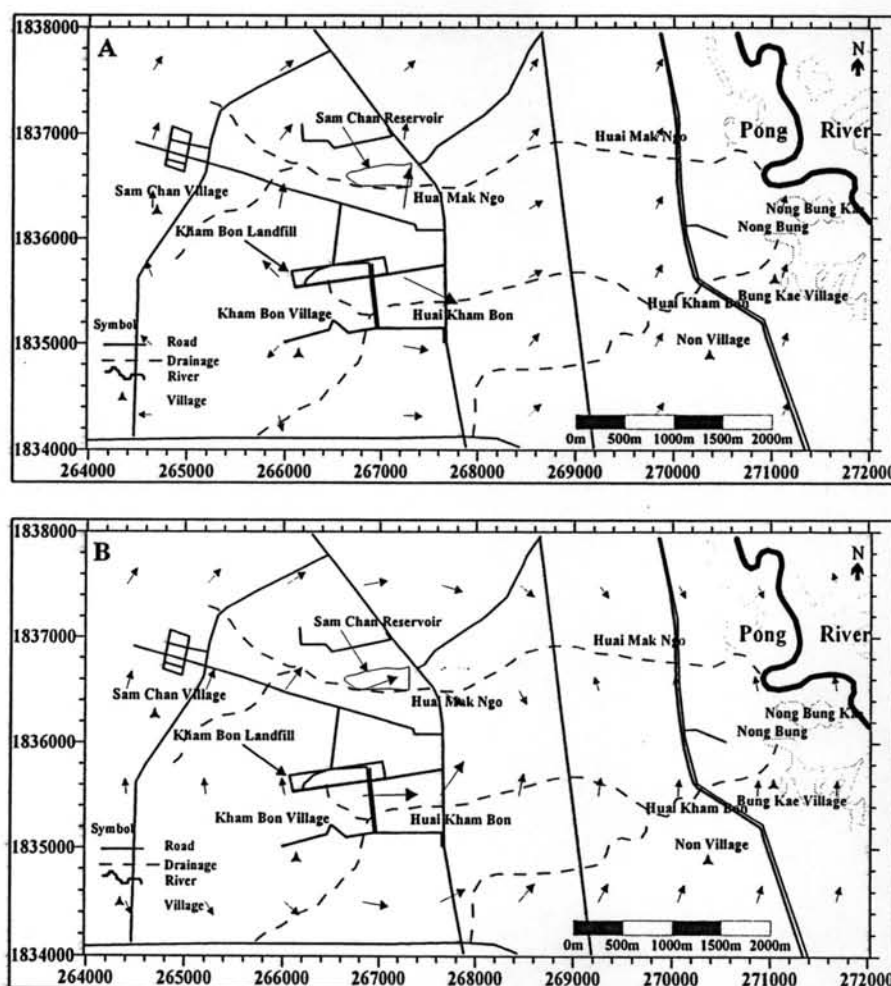


Figure 4.16 Groundwater flow direction in shallow aquifer (A) and deep aquifer (B) in the study area

Chloride concentration varied widely from 5 to 880 mg L⁻¹ exceeding the allowable maximum of 600 mg L⁻¹ in the eastern part of the landfill site at MW-4 in the down gradient direction. Relevantly, chloride content in the leachate was in the range of 2,700 to 5,200 mg L⁻¹ (see Table 4.3) and the soil in the study area is not saline soil, it is believed that the source of chloride ion was from infiltration of leachate into the groundwater. This phenomenon is similar to the study of Lyngkilde & Christensen, 1992. Considerably, bicarbonates and carbonates are the most important anions in natural water as they play role on the pH and alkalinity of water.

Table 4.3 Chemical properties of groundwater collected in the first sampling period

Sample ID	MW-2	MW-3	MW-4	MW-5	MW-6	MW-7	MW-8	MW-9	MW-10	PZ-1	PZ-2
pH	6.77	6.59	6.51	6.66	5.82	8.07	6.57	7.17	6.99	6.77	6.88
EC ($\mu\text{S cm}^{-1}$)	815	134.3	3.36 mS	526	57	585	676	744	553	475	731
TDS (mg L ⁻¹)	560	160	1940	4000	20	370	1000	480	190	2000	1520
Na ⁺ (mg L ⁻¹)	44.8	6.1	432.2	6.1	0.4	45.0	57.6	37.7	30.2	2.6	1.6
K ⁺ (mg L ⁻¹)	7.6	1.0	130.3	0.0	0.0	3.9	0.6	3.1	0.0	0.0	5.7
Ca ²⁺ (mg L ⁻¹)	141.1	20.2	167.2	22.4	1.1	92.6	74.2	116.1	114.1	67.5	138.9
Mg ²⁺ (mg L ⁻¹)	26.7	3.3	42.0	2.6	0.1	12.5	6.3	24.2	20.5	7.9	11.6
Cl ⁻ (mg L ⁻¹)	37	6.06	879.8	5.1	6.1	12	127.4	13.8	8.6	36.8	50.9
HCO ₃ ⁻ (mg L ⁻¹)	385	70	390	90	35	315	440	300	135	330	210
CO ₃ ²⁻ (mg L ⁻¹)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
NO ₃ ⁻ (mg L ⁻¹)	0.2	19.2	5.6	26.4	0.0	0.0	2.6	0.7	1.3	24.6	10.9
SO ₄ ²⁻ (mg L ⁻¹)	1.7	5.8	22.3	7.6	2.9	2.2	7.3	1.1	0.9	8.4	2.8
Fe (mg L ⁻¹)	0.259	1.936	4.982	0.202	1.345	0.370	0.053	0.017	0.341	0.486	1.937
Mn (mg L ⁻¹)	0.052	0.188	0.373	0.697	0.085	0.335	0.000	0.000	0.680	0.133	0.548
Cu (mg L ⁻¹)	0.026	0.030	0.031	0.031	0.024	0.025	0.029	0.036	0.051	0.023	0.037
Zn (mg L ⁻¹)	0.247	0.146	0.312	0.072	0.082	0.193	0.066	0.112	1.105	0.015	1.697
Cr (mg L ⁻¹)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Cd (mg L ⁻¹)	0.028	0.027	0.028	0.024	0.025	0.027	0.028	0.027	0.027	0.028	0.028
Pb (mg L ⁻¹)	0.131	0.117	0.155	0.167	0.125	0.139	0.173	0.181	0.208	0.144	0.162
Ionic Balance	2.1	4.0	18.0	57.8	-11.5	-3.1	-0.2	-17.7	-14.9	-4.6	-10.1

ND : Not Detected

The bicarbonate concentrations ranged from 30 to 460 mg L⁻¹ and the carbonate values ranged from 0 to 35 mg L⁻¹. Accordingly, pH of groundwater was in the range of 6-7. The nitrate concentrations ranged from 0 to 75 mg L⁻¹, of which the high nitrate content exceeded the maximum allowable limit (< 45 mg L⁻¹) located in the southern part of the landfill site. The important sources of nitrate are not only leachate from landfill leaching into the shallow aquifer but also fertilizers, manure and possible plant decomposition from agricultural fields surrounding the site. The range of

sulphate concentration of 1 to 22 mg L⁻¹ fell within the permissible level (<250 mg L⁻¹).

Table 4.4 Chemical properties of groundwater collected in the second period of sampling time

Sample ID	MW-2	MW-3	MW-4	MW-5	MW-6	MW-7	MW-8	MW-9	MW-10	PZ-1	PZ-2
EC ($\mu\text{S cm}^{-1}$)	803	107.70	1,677	22	187.4	774	500	199.9	712	678	892
TDS	446	85	1,460	840	115	502	400	486	456	422	640
TH	347	39	343	337	35	318	190	329	327	265	410
Na ⁺ (mg L ⁻¹)	36.3	4.8	120.2	119.6	2.8	50.1	18.6	43.4	36.1	62.2	21.8
K ⁺ (mg L ⁻¹)	2.2	1.1	45.1	91.5	6.6	0.5	4.6	2.2	3.5	0.9	3
Ca ²⁺ (mg L ⁻¹)	103.1	15	142.8	59.3	13.4	65.8	79.3	139.4	69.7	99.9	140.1
Mg ²⁺ (mg L ⁻¹)	22.8	0.9	12	30.3	0.3	13.3	5.8	26.1	20.7	9.4	16.1
Cl ⁻ (mg L ⁻¹)	43.8	7.0	427	196.8	5.1	11.3	63.1	6.4	10.7	44	58.8
HCO ₃ ⁻ (mg L ⁻¹)	35.0	30.0	30.0	465	185	240	80	265	255	195	210
CO ₃ ²⁻ (mg L ⁻¹)	15.0	ND	ND	35.0	ND	15.0	15.0	15.0	25.0	30.0	30.0
NO ₃ ⁻ (mg L ⁻¹)	ND	ND	14.4	0.1	0.2	0.8	4.0	0.7	0.8	ND	17.3
SO ₄ ²⁻ (mg L ⁻¹)	0.1	0.6	3.1	9.1	0.6	0.7	0.7	3.0	0.7	0.9	1.8
Fe (mg L ⁻¹)	ND	0.205	0.170	10.129	12.653	3.546	0.512	ND	0.069	1.546	3.054
Mn (mg L ⁻¹)	0.064	0.189	0.112	1.260	0.222	1.360	0.638	0.153	0.370	0.313	1.153
Cu (mg L ⁻¹)	0.011	0.011	0.006	0.008	0.012	0.018	0.026	0.017	0.012	0.021	0.055
Zn (mg L ⁻¹)	0.053	0.048	0.170	0.056	0.011	0.000	0.978	0.024	0.140	0.442	0.460
Cr (mg L ⁻¹)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Cd (mg L ⁻¹)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Pb (mg L ⁻¹)	0.059	0.035	0.054	0.051	0.036	0.051	0.129	0.073	0.074	0.069	0.119
Ionic Balance	-21.3	3.3	-3.4	13.2	81.2	-16.4	24	-28.1	-55.6	25.3	-23.1

ND : Not Detected

The Piper Trilinear Diagram (Piper, 1944) is employed herein to classify groundwater based on the dominant cations and anions. Almost all the data in all three sampling periods fall within the diamond-shaped area labeled *I* on the diagram, thus classifying the hydrochemical facies of the groundwater in the study area as Ca-Mg-HCO₃-CO₃ type (Figure 4.20). This area of the diagram is called “carbonate hardness facies” or “hydrochemical facies type *I*”. The carbonate hardness exceeds 50 percent, showing the chemical properties of the groundwater which are dominated by alkaline earths and weak acids. These properties are temporary hardness and low salinity. The December 2004 samples from MW-4 plots in the area labeled *IV* on the diagram, demonstrating the hydrochemical facies of the groundwater as Na-K-Cl-SO₄ type.

Table 4.5 Chemical properties of groundwater collected in the third period of sampling time

Sample ID	MW-2	MW-3	MW-4	MW-5	MW-6	MW-7	MW-8	MW-9	MW-10	PZ-1	PZ-2
pH	6.65	5.74	3.78	6.38	6.11	7.27	6.59	6.84	6.8	6.49	6.51
EC ($\mu\text{S cm}^{-1}$)	708	69.9	1,313	1,129	137.4	459	674	629	576	559	646
TDS (mg L^{-1})	530	99	1,448	550	102	425	834	598	463	550	687
TH (mg L^{-1})	371	49	302	349	80	247	355	357	347	263	386
Na^+ (mg L^{-1})	23.4	7.4	81.2	77.2	5.2	54.0	20.2	29.5	24.1	38.6	12.6
K^+ (mg L^{-1})	0.5	0.6	26.6	24.7	5.1	0.5	7.9	1.2	0.7	0.2	1.6
Ca^{2+} (mg L^{-1})	78.6	7.0	89.8	72.5	13.1	107.9	170.9	120.5	100.3	83.4	111.7
Mg^{2+} (mg L^{-1})	11.1	0.5	5.7	12.9	1.4	16.5	23.0	20.1	18.0	8.0	10.6
Cl^- (mg L^{-1})	44.8	9.4	385.8	133	2.5	18.8	314.6	8.8	9.5	41.4	54.4
HCO_3^- (mg L^{-1})	295	30	15	340	50	220	115	330	310	230	255
CO_3^{2-} (mg L^{-1})	ND	ND	ND	ND	ND	20	ND	ND	ND	ND	ND
NO_3^- (mg L^{-1})	ND	ND	158.7	ND	ND	ND	50.8	47.6	17.5	74.9	0.0
SO_4^{2-} (mg L^{-1})	1	1.5	0.6	1107	0.2	0.2	2.3	0.8	0.9	1.7	1.3
Fe (mg L^{-1})	ND	0.752	4.922	10.314	13.322	0.098	ND	ND	0.36	0.629	0.876
Mn (mg L^{-1})	0.111	0.052	0.042	1.0	0.205	0.201	0.5365	0.51	0.341	0.186	0.348
Cu (mg L^{-1})	0.007	0.002	0.007	0.011	0.017	0.011	0.013	0.012	0.058	0.011	0.012
Zn (mg L^{-1})	0.985	0.034	0.456	0.087	0.376	0.009	ND	ND	0.027	ND	0.3
Cr (mg L^{-1})	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Cd (mg L^{-1})	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Pb (mg L^{-1})	0.013	0.005	0.01	0.015	0.017	0.011	0.004	0.018	0.032	0.018	0.017
Ionic Balance	-57.9	-20.6	-6.3	5.4	52.6	-16.2	-19.1	-36.9	-12.4	-21.8	-19.2

ND : Not Detected

This area is called “*noncarbonate alkali facies*” or “*hydrochemical facies type IV*”. The noncarbonate alkali exceeds 50 percent, so the groundwater is dominated by alkali earths and strong acids. The water is brackish to salty, corresponding to the high electrical conductivity and high chloride content of this station during sampling periods. The MW-4 sample from the second sampling plots in the area labeled *III* on the diagram, indicating the Ca-Mg-Cl-SO₄ type. It means the noncarbonate hardness is in excess of 50 percent, and the chemical properties of the groundwater are dominated by alkali earths and strong acids. This area is called “*noncarbonate hardness facies*” or “*hydrochemical facies type III*”. The water quality is expressed as hard water. Moreover, the MW-5 sample plots in the area labeled *V* on the diagram which indicates mixing water in which the groundwater type is neither cation nor anion dominant. Therefore, the water quality cannot be specified as soft or hard. The

chemical properties of samples from MW-4 and MW-5 were unchanged between the second and third samplings. In contrast, the chemical property of groundwater at MW-8 changed from the hydrochemical facies type indicating temporary hardness to *hydrochemical facies type III* classified as hard water. It means that the Na and K ions were replaced by the Ca and Mg ions in this period corresponding to the increasing total hardness in this borehole.

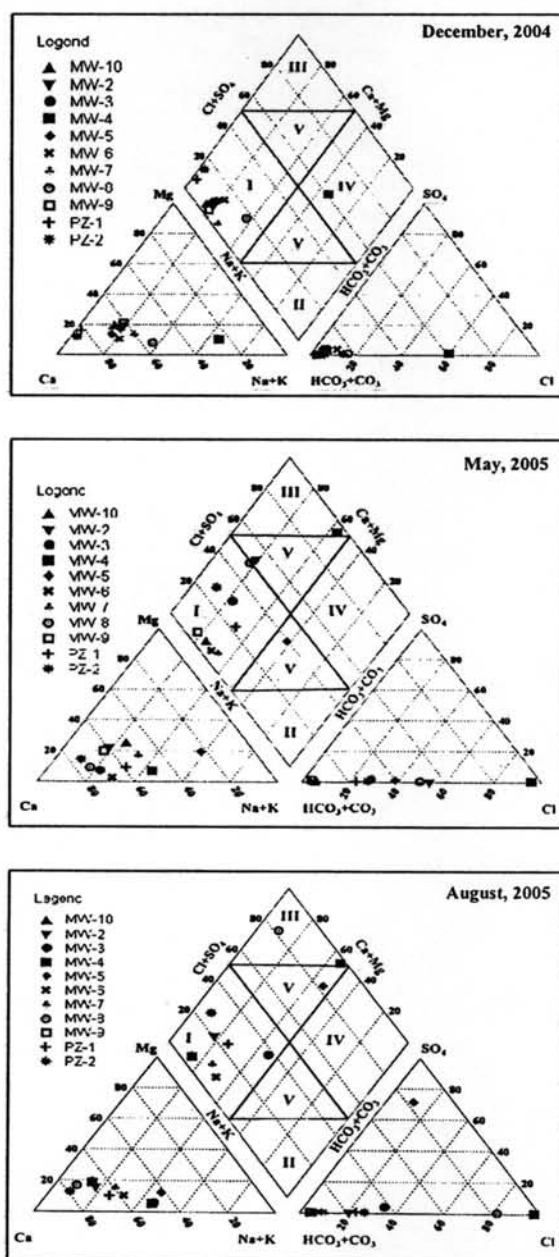


Figure 4.17 Hydrochemical facies of groundwater in all sampling periods in the study area

The results of the cation and anion analyses in all sampling periods revealed that the fluctuation of ion concentrations occurred in the shallow monitoring wells in the down gradient direction. It indicates that the shallow wells might be contaminated from the landfill leachate in the surrounding area. In the deep aquifer, the groundwater quality was poor at MW-8. Its chemical property changed from temporary hardness to hard water. Furthermore, throughout the sampling, the piezometric level in MW-8 declined from 8 to 15 mbgl. In comparison, the other deep wells, MW-9 and MW¹⁰, showed a slight decline from 2 to 4 mbgl. This might be due to the heavy groundwater extraction. In this situation, the variation in the concentration of ions could be induced by groundwater flow from the shallow aquifer, eventually leading to contamination of the deep aquifer. The variability of cation and anion concentrations in all periods of sampling is due to several factors: the volume of landfill leachate, surface runoff overflow from solid waste pile, rainfall, depth of the aquifers, and the distance of the wells from the pollution source.

In conclusion for water quality of groundwater, chloride is seemed to be the indicator of landfill leachate contamination. Chloride content in leachate and in groundwater was relatively high compared to other parameters. This is possible because chloride is non-reactive ion which can infiltrate to groundwater directly. While other ions, carbonate, noncarbonated ions are reactive ions which potentially react with other substances in soil. For nitrate content, the concentration in leachate was low comparing to the concentration in groundwater, implying that nitrate ion was from other sources rather than leachate.

4.2.2.3 Heavy Metals in Groundwater

Eleven groundwater samples from 3 new monitoring wells and 8 existing ones were taken in all periods of sampling. The concentrations of heavy metals showed a significant fluctuation during the entire monitoring period, which could not be clearly characterized for any trends (Tables 4.3 to 4.5). In the first sampling, the following ranged were observed (Figure 4.18A): Cd 0.02-0.03 mg L⁻¹, Mn 0.09-0.69 mg L⁻¹; Fe 0.05-1.94 mg L⁻¹; Pb 0.1-0.2 mg L⁻¹; Cu 0.02-0.05 mg L⁻¹ and Zn 0.07-1.69 mg L⁻¹.

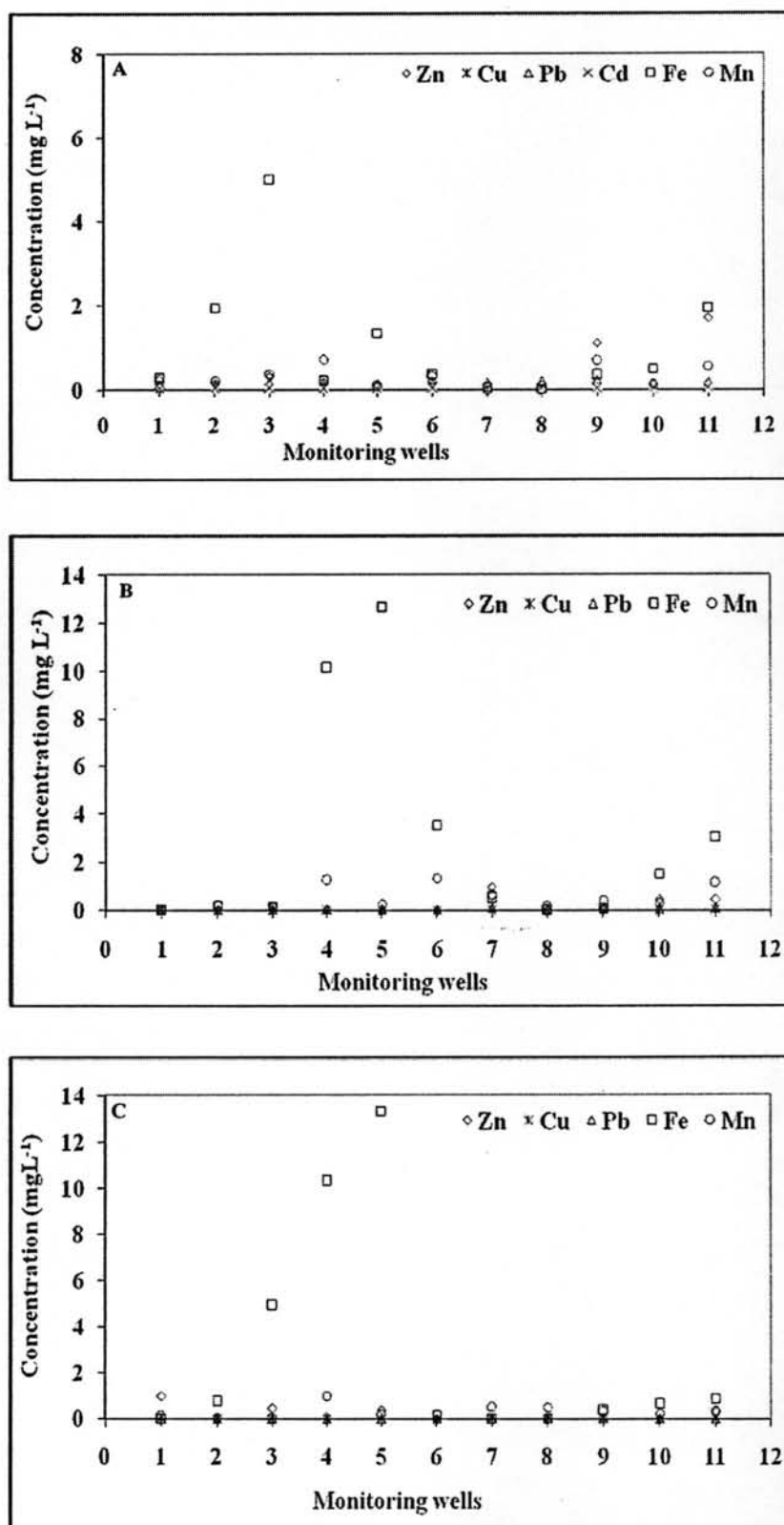


Figure 4.18 Heavy metals concentration of groundwater monitoring wells in the first period of sampling (A), the second sampling period (B) and the third sampling period (C) in the study area

Based on the Enhancement and Conservation of National Environmental Quality Act B.E. 2535, Cd, Mn, Fe and Pb exceeded the allowable limit ($\text{Cd} \leq 0.003 \text{ mg L}^{-1}$; $\text{Mn} \leq 0.5 \text{ mg L}^{-1}$; $\text{Fe} \leq 1.0 \text{ mg L}^{-1}$; $\text{Pb} \leq 0.01 \text{ mg L}^{-1}$) while Cu and Zn concentrations were within the standard allowable limit ($\text{Cu} \leq 1.0 \text{ mg L}^{-1}$, $\text{Zn} \leq 5.0 \text{ mg L}^{-1}$). The zone of higher heavy metals concentration was located near landfill sites in the northern and southeastern pathway down gradient of the landfill site. The second sampling revealed significant concentrations of Pb, Fe and Mn. The concentration of these and other heavy metals are as follows (Figure 4.18B): Pb 0.03-0.13 mg L^{-1} ; Fe 0.07-2.65 mg L^{-1} ; Mn 0.06-0.36 mg L^{-1} ; Cu 0.01-0.05 mg L^{-1} ; and Zn 0.05-0.5 mg L^{-1} . Only the concentrations of Pb, Fe and Mn were higher than the allowable limit. Cd and Cr were not detected in any monitoring wells. The zone of higher heavy metals concentration is situated near the landfill site through the northern and southeastern pathway of the study area corresponding with the direction of drainage.

In addition, MW-8 in the deep aquifer presented the highest Pb concentration in the southern part of the study area. MW-8 is the pumping well serving for 10 households located nearest the landfill site. Due to the heavy pumping for water consumption, the contaminants could possibly be drawn from the shallow aquifer into this deep well. In the third sampling period, the concentration of heavy metals was as follows: Pb 0.03-0.05 mg L^{-1} ; Zn 0.01-0.98 mg L^{-1} ; Fe 0-5.98 mg L^{-1} and Mn 0.02-2.11 mg L^{-1} . Again, Pb, Fe and Mn concentrations exceeded the allowable maximum limit whereas Cu concentration was below the detection limits. It is also noted that in this period (Figure 4.18C), the concentration of most heavy metals in the southern part of the study area were below the detection limits, while Cd and Cr concentrations could not be detected. The third sampling period is about mid-May (summer ending to winter beginning), the contents of heavy metals possibly retained onto soil, lacking of water flow brought heavy metals to the ground water. In the mean time, in the rainy season dilution take place leading to low concentration as well.

In summary, heavy metals contamination could be found in the shallow aquifer. However, the concentrations of heavy metals were likely very low not exceeding the allowable standard, except Fe and Mn and Pb at some period. Fe and Mn are metal ions found naturally in soil which is in conformance with the red-loess

soil in this study area. For Pb contamination, it is possible to be found in the groundwater as the leachate always contain of Pb, and it can be infiltrated to groundwater as mentioned previously. Regarding the contamination of Cr, it is potentially adsorbed by soil due to immobilization of Cr by ferric oxide as earlier explanation.

4.2.3 Surface water Analysis

4.2.3.1 Hydrochemistry

Surface water samples were taken from all three sampling periods (Figure 4.19). Physical and chemical properties were analyzed based on the National Primary Drinking Water Regulations (www.epa.gov/safewater/contaminants/index.html) applied for public water system. The study results are reported in Tables 4.6 to 4.8. All samples were taken around the Sam Chan reservoir, divided into the new Sam Chan (SW-1) reservoir and old Sam Chan (SW-2) reservoir, located at the north of the study area. The new Sam Chan reservoir has been used as water supply for Ban Sam Chan, whereas the old Sam Chan reservoir has been no longer used.

In the first sampling period, pH values were recorded within the standard limit about 7 to 8. The electrical conductivity varied within the range of 60 to 530 $\mu\text{S cm}^{-1}$. The conductivity value of SW-1 exceeded allowable limit ($\text{EC} \leq 500 \mu\text{S cm}^{-1}$). TDS content varied from 280 to 2,000 mg L^{-1} . TDS were higher in SW-1 than SW-2. The allowable limit of TDS does not exceed 2,000 mg L^{-1} . However, if TDS is higher than 1000 mg L^{-1} , it implies an inferior source of water. The concentration of sodium and potassium ranged from 2 to 60 mg L^{-1} and 1 to 45 mg L^{-1} , respectively. The concentration of calcium and magnesium varied from 1 to 30 mg L^{-1} and 0.2 to 5 mg L^{-1} respectively. No maximum levels have been established for sodium, potassium, calcium, and magnesium. The chloride concentration varies within the allowable limit from 3 to 80 mg L^{-1} . The concentration of bicarbonate varies within the range of 20 to 325 mg L^{-1} . The nitrate concentrations range from 2 to 25 mg L^{-1} . The permissible limit of nitrate concentration not exceeds 10 mg L^{-1} . The high nitrate concentration was found at the new Sam Chan and old Sam Chan reservoirs. This anion indicated

the contamination from agriculture area where use fertilizer and livestock manure. The range of sulphate concentration within the acceptable limit was found between 1 and 14 mg L⁻¹.

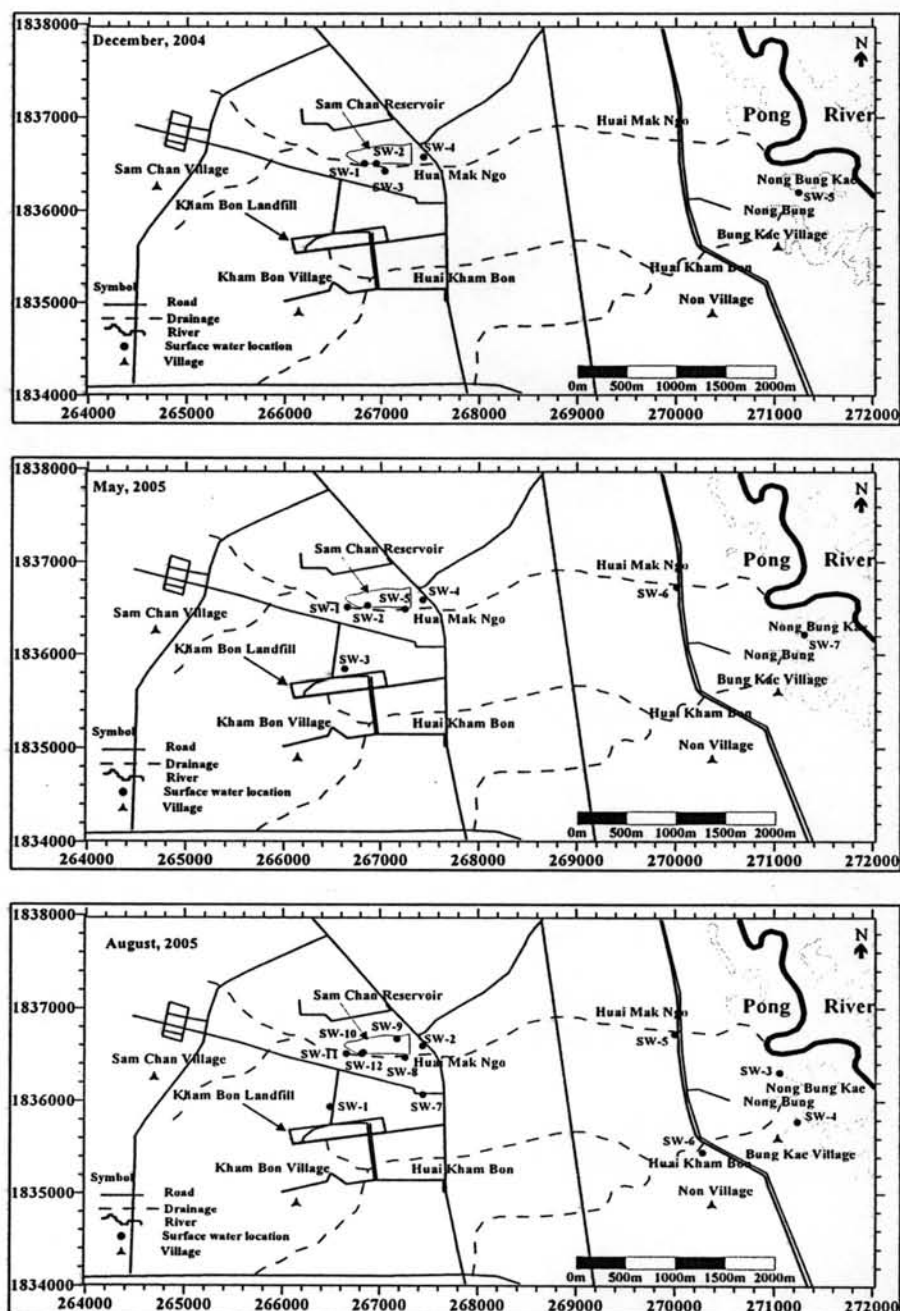


Figure 4.19 Location of surface water samples taken in all periods of sampling

In the second sampling period, the pH values were found within the standard limit about 7.1 to 8.54. The electrical conductivity ranged from 60 to 480 $\mu\text{S cm}^{-1}$

Table 4.6 Chemical properties of surface water collected in the first period of sampling time

Sample ID	SW-1	SW-2	SW-3	SW-4	SW-5
pH	7.98	7.68	5.48	7.94	8.08
EC ($\mu\text{S cm}^{-1}$)	529	182	57.3	525	147.8
TDS (mg L^{-1})	2000	570	1000	570	280
Na^+ (mg L^{-1})	59.6	12.1	1.5	55	5.2
K^+ (mg L^{-1})	46	4.5	0.8	44.6	1.7
Ca^{2+} (mg L^{-1})	30.2	16.4	0.9	22.8	7.1
Mg^{2+} (mg L^{-1})	5.2	3.5	0.2	5.0	1.6
Cl^- (mg L^{-1})	78.7	15.0	2.6	78.1	5.3
HCO_3^- (mg L^{-1})	325.0	165.0	20.0	305.0	125.0
CO_3^{2-} (mg L^{-1})	0.0	0.0	0.0	0.0	0.0
NO_3^- (mg L^{-1})	25.5	20.8	1.7	4.0	1.4
SO_4^{2-} (mg L^{-1})	13.6	4.9	1.0	7.0	6.3
Fe (mg L^{-1})	0.895	0.129	0.354	0.985	0.296
Mn (mg L^{-1})	0.120	0.032	0.000	0.122	0.000
Cu (mg L^{-1})	0.033	0.026	0.033	0.031	0.029
Zn (mg L^{-1})	0.010	0.010	0.012	0.011	0.009
Cr (mg L^{-1})	ND	ND	ND	ND	ND
Cd (mg L^{-1})	0.025	0.027	0.029	0.028	0.026
Pb (mg L^{-1})	0.118	0.159	0.181	0.185	0.143

Table 4.7 Chemical properties of surface water collected in the second period of sampling time

Sample ID	SW-1	SW-2	SW-3	SW-4	SW-5	SW-6	SW-7
TDS (mg L^{-1})	160	740	294	814	458	420	140
TH (mg L^{-1})	78	90	92	159	86	39	29
Na^+ (mg L^{-1})	1.8	9.5	6.9	13.5	8.4	5.2	1.2
K^+ (mg L^{-1})	4.8	64.1	24.9	57.0	51.0	38.0	2.8
Ca^{2+} (mg L^{-1})	35.7	17.0	19.8	28.0	14.1	3.9	6.7
Mg^{2+} (mg L^{-1})	4.4	6.2	8.3	21.8	4.2	1.8	1.3
Cl^- (mg L^{-1})	18.4	102	88	213.7	107.7	58.8	6.6
HCO_3^- (mg L^{-1})	65	130	50	190	85	60	35
CO_3^{2-} (mg L^{-1})	30	ND	10	25	20	ND	ND
NO_3^- (mg L^{-1})	ND	ND	0.2	0.4	0.4	0.1	0.1
SO_4^{2-} (mg L^{-1})	0.5	8.4	2.7	3.2	13.1	3.9	9.3
Fe (mg L^{-1})	0.080	0.980	0.000	2.210	1.267	3.089	0.959
Mn (mg L^{-1})	0.281	0.228	0.037	1.763	0.277	1.051	0.128
Cu (mg L^{-1})	0.003	0.007	0.015	0.008	0.006	0.008	0.014
Zn (mg L^{-1})	ND	ND	ND	ND	ND	ND	ND
Cr (mg L^{-1})	ND	ND	ND	ND	ND	ND	ND
Cd (mg L^{-1})	ND	ND	ND	ND	ND	ND	ND
Pb (mg L^{-1})	0.053	0.046	0.044	0.068	0.080	0.087	0.086

Table 4.8 Chemical properties of surface water collected in the third period of sampling time

Station ID	SW-1	SW-2	SW-3	SW-4	SW-5	SW-6	SW-7	SW-8	SW-9	SW-10	SW-11	SW-12
pH	7.32	8.22	7.54	7.36	7.35	7.27	7.24	8.51	8.51	8.53	8.99	8.55
EC ($\mu\text{S cm}^{-1}$)	2980	739	104.8	154.7	423	225	79.2	3400	578	236	601	245
TDS (mg L^{-1})	2950	858	265	263	567	517	75	3572	867	248	910	265
Na^+ (mg L^{-1})	126	83.7	18.2	23.5	74.2	25.2	1.4	178.1	80.0	27.2	80.8	29.6
K^+ (mg L^{-1})	174	16.5	14.8	11.8	36.9	13.8	3.1	263.9	97.4	10.5	110.1	13
Ca^{2+} (mg L^{-1})	134.1	67.5	12.7	29.0	24.8	34.2	16.0	66.0	20.8	35.6	26.3	38.4
Mg^{2+} (mg L^{-1})	54.3	9.7	5.1	5.7	7.1	4.9	2.5	34.6	6.8	5.7	5.7	5.7
Cl^- (mg L^{-1})	2011.9	66.2	18.2	4.7	58.1	11.6	1.1	758.8	81.4	18.7	85.6	18.7
HCO_3^- (mg L^{-1})	100	300	10	25	20	60	35	540	75	75	85	85
CO_3^{2-} (mg L^{-1})	15	60	ND	ND	ND	ND	ND	40	20	10	50	15
NO_3^- (mg L^{-1})	ND	ND	142.0	0.0	4.8	0.0	13.9	350.5	28.8	0.0	ND	ND
SO_4^{2-} (mg L^{-1})	8	4.4	18.9	4	1.4	0.9	ND	0.8	12.6	0.1	14.6	0.5
Fe (mg L^{-1})	1.606	1.229	1.942	1.621	1.298	4.108	ND	5.977	1.445	0.271	1.66	0.308
Mn (mg L^{-1})	0.276	0.027	0.058	0.171	0.452	2.105	0.018	0.678	0.209	0.293	0.166	0.216
Cu (mg L^{-1})	0.013	0.009	0.006	0.004	0.004	0.002	0.002	0.016	0.003	0.002	0.009	0.004
Zn (mg L^{-1})	ND	ND	ND	0.19	ND	ND	ND	ND	ND	ND	ND	ND
Cr (mg L^{-1})	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Cd (mg L^{-1})	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Pb (mg L^{-1})	0.038	0.038	0.013	0.032	0.051	0.047	0.035	0.061	0.046	0.038	0.062	0.075

while the TDS varied within the standard limit between 140 to 800 mg L^{-1} . For nitrate and sulfate values were reported within the allowable maximum limit of 10 and 200 mg L^{-1} , respectively.

In the third sampling period, pH value fell within the range of acceptable limit whereas the electrical conductivity was reported higher than the standard limit at the SW-1, SW-2 and SW-8 (2,980, 739, and 3,400 mS cm^{-1} , respectively). Again, the TDS values and chloride concentration (Table 4.7) of SW-1 (2,950 mg L^{-1}); SW-2 (860 mg L^{-1}), and SW-8 (3,572 mg L^{-1}) were much higher than the allowable maximum limit. SW-1 (new Sam Chan) is a small pond located near Kham Bon landfill site, whereas SW-8 is a small ditch of landfill leachate drainage joining to the natural rivulet namely Huai Mak Ngo, SW-2 located at Huai Mak Ngo before discharging into the Pong River. When considering water quality of SW-5 (Huai Mak Ngo branch); SW-6 (Huai Kham Bon branch); SW-4 (Nong Bung), it is found that the studied parameters were met the allowable maximum level. From this finding, it can be concluded that the high impact of landfill leachate was occurred at the area located nearby the site and decreasing along the distance far from the site. Reasonably, it is due to the dilution of rainwater in rainy season, as well as the precipitation of ions

with colloidal particles along the pathway of landfill leachate to such surface water receptors. Considering source of water supply (Sam Chan reservoir), it was appeared that the values of electrical conductivity, TDS, and chloride of old Sam Chan reservoir was higher than the allowable maximum limit while such concentrations in the new Sam Chan reservoir were presented within the range of the allowable maximum limit. It implies that there was some accumulation of these saline contents in the old Sam Chan reservoir.

Results from the surface water study indicated that water quality of the new Sam Chan reservoir and old Sam Chan had slight problem with the saline content in terms of TDS, EC and chloride. As mentioned earlier, chloride content in leachate was high as well as high chloride content was found in some wells. The higher saline content in surface water of both reservoirs could possibly be induced by leachate.

4.2.3.2 Heavy Metals in Surface Water

The results of heavy metals analysis of surface water samples are reported in Tables 4.6 to 4.8. Pb was found in all sampling analysis. Its concentration in the first, second and third samplings were reported as 0.14-0.18 mg L⁻¹, 0.04-0.08 mg L⁻¹ and 0.01-0.08 mg L⁻¹, respectively. These concentrations exceeded the allowable maximum limit (Pb ≤ 0.05 mg L⁻¹) in all periods. Zn and Cr concentrations (respectively as 0.07-0.04 mg L⁻¹ and 0.06-0.07 mg L⁻¹) which are higher than the allowable maximum limit (Zn ≤ 1.0 mg L⁻¹; Cr ≤ 0.05 mg L⁻¹) were detected only at a trench and channel along the drainage flow direction in the north toward the northeast of the area. On the other hand, Cu content was below the detection limit. However, Fe and Mn concentrations (0.08-3.09 mg L⁻¹ and 0.03-0.8 mg L⁻¹, respectively) were still found in all seasons and exceeded the allowable maximum limits (Mn ≤ 1.0 mg L⁻¹) in the north toward the northeast of the study area.

4.3 Landfill Leachate Production

Leachate generation is a result of climatological factors, biological and chemical properties of wastes being disposed of at the landfill. Estimation of leachate

rate in a landfill site is of considerable importance in the design of an appropriate collection system or the treatment alternatives to reduce the offsite migration that might pollute both surface water and groundwater resources.

Estimation of outflow quantity is a preliminary study step for transport of contaminants from landfill to the environment. Water balance analysis of landfill is undertaken for the maximum infiltration case; water inflowing into the landfill is lost as evaporation, either percolates below the landfill or is stored in the landfill. In the course of landfill modeling, the cover layer and waste layers are modeled as a vertical percolation layer and soil below the landfill as a barrier layer.

Water balance analysis was done for twenty four years. The data of: precipitation; temperature, and solar radiation obtained from the Meteorological Department of Thailand were input into the model for all simulations. The first simulation expressed the water balance of the unlined landfill operation at beginning. The profile structure is shown in Figure 4.20. The results presented that leachate generation, which was summation of lateral drainage through layer 3 and percolated through layer 4 is within the range of 20 and 44 percentage of annual precipitation. These values have been found out to be agreed with the FS&DD Project (1998) as well as corresponded to the literature value of 25 to 50 percentage of precipitation for such a less compacted landfill (Campbell, 1983). The leachate generation rate is 0.12 to 0.38 m³/m² / year. The evapotranspiration rate was found to be significant activity.

Layer	Top (cm)	Bottom (cm)	Thickness (cm)
Loamy Fine Sand ¹	0.0000	-0.6000	0.6000
Municipal Waste (312 kg/cub.m)	-0.6000	-3.1000	2.5000
Sand	-3.1000	-3.4000	0.3000
Silty Clay Loam	-3.3985	-3.6985	0.3000

Figure 4.20 Profile structure for the first of simulations

It is in the range of 46 to 68 percentages of annual precipitation. This is mainly due to the absence of vegetation as well as the root cannot store the moisture resulting in the amount of moisture is lost through the evaporation. Moreover, almost of

percolation flowing through layer 4 (silty clay loam barrier) was observed. It can be pointed out that the polluted groundwater might occur beneath and the natural barrier which can be available from the surrounding area is not suitable to be a soil barrier due to its hydraulic properties.

In the second simulation, the water balance was simulated for the additional of HDPE as liner material (Figure 4.21). The leachate generation was found ranging from 26 to 50 percentage of annual precipitation. The lateral drainage (layer 3) was found to be 23 to 41 percentages as compared to annual precipitation and rate of production is with the range of 0.16 to 0.27 $\text{m}^3 / \text{m}^2 / \text{year}$. The generation of leachate in this simulation was found in the rate of 0.18 to 0.32 $\text{m}^3 / \text{m}^2 / \text{year}$. In this simulation, it can be seen that the percolation through layer was still appear. Even though the HDPE liner was added, the rate of percolation was occurred in the range of 0.02 to 0.07 $\text{m}^3 / \text{m}^2 / \text{year}$ and is 3 to 9 percentage of annual precipitation. This situation has to be taken into account. It might danger the landfill design and possibly polluted groundwater underneath. However, the effective of HDPE liner can be observed. The leachate generated in this simulation can be almost collected in the lateral drainage.

Layer	Top (cm)	Bottom (cm)	Thickness (cm)
Loamy Fine Sand ¹	0.0000	-0.6000	0.6000
Municipal Waste (312 kg/cub.m)	-0.6000	-3.1000	2.5000
Sand	-3.1000	-3.4000	0.3000
High Density Polyethylene (HDPE)	-3.3985	-3.3995	0.0010
Silty Clay Loam	-3.3990	-3.6990	0.3000

Figure 4.21 Profile structure for the second of simulations

In the last simulation, the water balance simulation was done for a total height of 9.3 m with three lift; HDPE liner and barrier soil. Figure 4.22 displays the profile structure of this simulation. The percolation through the barrier soil liner is found to be in the order of 0.07 to 1.06 percentage of annual precipitation and amount of percolation can be neglected. For the lateral drainage layer, the component varied from 7 to 53 percentage of annual precipitation whereas the rate of generation is 0.05

to $0.32 \text{ m}^3 / \text{m}^2 / \text{year}$. Therefore, the generation of leachate ranged between 0.05 and $0.33 \text{ m}^3 / \text{m}^2 / \text{year}$. It can be observed clearly that the percolation through the barrier disappeared in this assumption. This is due to low hydraulic conductivity ($K \leq 10^{-7} \text{ cm sec}^{-1}$) which corresponding to the theory. Moreover, results from all simulations reveal that the amount of leachate production on an annual basis is not different in significant level. However, the percolation through the barrier soil would be concentrated instead. The barrier soil should be met the regulations ($K \leq 10^{-7} \text{ cm sec}^{-1}$) and HDPE liner should be taken into a consideration in all cases.

Layer	Top (cm)	Bottom (cm)	Thickness (cm)
Loamy Fine Sand1	0.0000	-0.6000	0.6000
Municipal Waste (312 kg/cub.m)	-0.5995	-3.0995	2.5000
Loamy Fine Sand	-3.0990	-3.3990	0.3000
Municipal Waste (312 kg/cub.m)1	-3.3985	-5.8985	2.5000
Loamy Fine Sand2	-5.8980	-6.1980	0.3000
Municipal Waste (312 kg/cub.m)2	-6.1975	-8.6975	2.5000
Sand	-8.6970	-8.9970	0.3000
High Density Polyethylene (HDPE)	-8.9965	-8.9975	0.0010
Barrier Soil	-8.9970	-9.2970	0.3000

Figure 4.22 Profile structure for the third of simulations

4.4 Kham Bon Landfill Circumstance

Based on the experimental outcomes from both field and laboratory analyses, it is evident that soil, surface water and groundwater at the Kham Bon landfill and its surroundings have been contaminated by leachate migration within a radius of 2,000 metres from the landfill. The soil analysis reveals that some heavy metals have accumulated at least 90 cm below the ground surface. Moreover, the observed groundwater levels at approximately 1 to 2 mbgl in some monitoring wells show seasonal fluctuation. This combination of fluctuating groundwater levels just below high concentrations of heavy metals poses a pollution risk to groundwater. The groundwater chemistry of the shallow aquifer was characterized by high concentrations of some ions, especially heavy metals. Furthermore, the single pumping well penetrating to the deep aquifer in the southern part of the study area

showed significant concentrations of heavy metals. The zone of high heavy metal concentration was distributed between the Sam Chan Reservoir in the north and the Huai Mak Ngo in the eastern part of the study area which joins the Pong River. Also, a similar distribution was found in the Huai Kham Bon in the southeast where it flows through the Nong Bung to the Pong River.

Evidently, the soil composition underlying the landfill and the presence of a small drainage ditch are both very important factors to explain the behavior of the landfill as a source of groundwater pollution. Although the heavy metals seem to be scattered throughout the area without controlling factors in fact, there are patterns of distribution and controls. The first pattern is that the heavy metals distribution follows the drainage patterns within the area whereas the second pattern is controlled by the scavenger activities. They will be the heavy metals carriers.

Other major factors controlling leachate production and migration at the landfill in this area are the seasonal variations in precipitation, the site topography which controls the runoff patterns and the soil type which affects infiltration and solute transport to the water table. Accordingly, groundwater samples should be collected seasonally to assess the fluctuations of major ion concentrations.

In addition, results of study also revealed that these heavy metals of interest might be well adsorbed by soils rather than be percolated into water. It is increasingly important to understand the long-term behaviour of contaminants in the subsurface. This will require a proper understanding of the contaminant plume in the subsurface environment through knowledge of the sorption and transport properties of the soil and contaminants.

Therefore, batch and column experiments were conducted to study behaviors of heavy metals including adsorbed, released and transported through Kham Bon landfill soil. Data of physical and chemical properties of soil obtained from the study area was designed to perform batch and column experiments.