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Heavy Metal Concentration and Risk Assessment of Soil and Rice in and around an Open Dumpsite in Thailand

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Abstract

This study aimed to determine the heavy metal concentration in the soil and rice in and around Nakhonluang district open dumpsite in Phra Nakhon Si Ayutthaya province of Thailand and to assess the human health risk of these metals. The soil samples demonstrated heavy metal concentrations in the following order: Fe > Mn >Zn > Cu > Cr > Ni > Pb (Cd was not detected), and the average concentrations of each metal in soil from the dumpsite area were higher than those in the surrounding area. The average concentrations of Mn in the soils exceeded the screening level for higher plant protection of the USEPA's Eco-SSL while the average Zn and Cu concentrations in the soil samples from the dumpsite exceeded the level for good soil and safety to life recommended by LDD. The rice exhibited metal concentrations in the following order: root > straw > grain. A carcinogenic human health risk assessment (R_{Total}) indicated that the values from the soil samples and the rice were at safe levels. The sum of noncarcinogenic hazard values (Cr, Cu, Mn, Ni, Pb, and Zn) indicated that exposure to the soils around the dumpsite area may pose adverse health effects (HI < 1) while exposure to the soils in the dumpsite area carries a high risk of causing adverse health effects both in children (HI = 10.5) and adults (HI = 2.18). It is suggested that suitable management measures should be applied to prevent or reduce heavy metal contamination in and around the dumpsite area.

Keywords: heavy metal; open dumpsite; soil contamination; bioaccumulation; health risk assessment

1. Introduction

In Thailand, over 13 million tons (ca. 50%) of municipal solid waste (MSW) generated each year has been disposed unsuitably, for example, through open dumping (more than 2,000 sites) and open burning (Pollution Control Department (PCD), 2016 and 2015). Open dumping sites of MSW are known to release several toxic and carcinogenic compounds such as heavy metals, volatile organic compounds/semi volatile organic compounds (VOCs/SVOCs), brominated flame retardants and phthalate esters (Huang *et al*., 2015; Eguchi *et al*., 2013; Adeniyi *et al*., 2008). Among these, heavy metal contamination has attracted more attention because heavy metals are often found in high concentration in and around dumpsites worldwide (Ajah *et al*., 2015; Alam *et al*., 2012; Nava-Martínez *et al*., 2012).

Phra Nakhon Si Ayutthaya has been ranked in the five most critical provinces in Thailand based on levels of accumulated municipal solid waste (PCD, 2015). The province generates nearly 300,000 tons of MSW per year, but only 15% of it is recycled, and the rest (85%) is dumped improperly. The province has 26 disposal sites, but none of them are designed for proper disposal. All the sites are either for open dumping or open burning. The Nakhonluang district of Phra Nakhon Si Ayutthaya is one of the medium dumpsites in Thailand. The total area of the site is about 45,600 m^2 (28.5 rai). The dump is about 7 meters in height above the ground. These days, the site receives about 25 tons a day of solid waste, 20 tons from Nakhonluang and another 5 tons from neighboring municipalities. The site has been in operation since 2002 and now has about 68,400 tons of accumulated solid waste (PCD, 2014). Without any proper leachate collection systems within the dumpsite, the runoff (leachate) from the site can flow into water supplies for agricultural use and contaminate surrounding soil and groundwater.

Leachate is water that enters the solid waste in an open dumpsite and extracts contaminants from the waste into its flow. Precipitation that infiltrates through the refuse normally results in a migration of leachate into the soil and groundwater, resulting in pollution. Leachate contains organic and inorganic pollutants, such as halogenated aliphatic compounds, aromatic hydrocarbons, phenolic compounds, pesticides and heavy metals. They are usually classified as hazardous substances that can harm the environment and human health (Toufexi *et al*., 2013).

Among these hazardous substances are heavy metals, which refer to any metallic chemical element that has a relatively high density. Some examples of heavy metals include iron, copper, chromium, nickel, lead, zinc and manganese. The major sources of heavy metals in an open dumpsite include industrial wastes, incinerator ashes, mine wastes and household hazardous substances, such as batteries, paints, dyes and inks. The concentrations of heavy metals in leachate depend on the composition of wastes. Heavy metals are dangerous because they can enter food chains and increase the concentration of chemicals in an organism over time. Heavy metals can cause serious problems because they are covert, persistent, irreversible and non-biodegradable. Heavy metals can disperse and accumulate in an ecosystem, plants and animals and can even be taken in by human beings through consumption.

There are only a few studies that directly discuss the heavy metal contamination from landfills and open dumpsites in Thailand: Uttaradit (Wachirawongsakorn and Sangyoka, 2013), Nonthaburi (Prechthai *et al*., 2008) and Khon Kaen (Chuangcham *et al*., 2008). Furthermore, risk assessments of the heavy metals from open dumpsites in Thailand have yet to be conducted and reported. A case study is necessary to provide insight into the potential risks of heavy metals to the surrounding environment and its inhabitants. Therefore, the objectives of this study were to determine the concentration of heavy metals (Cu, Zn, Cr, Cd, Ni, Fe, Mn and Pb) in soil and rice samples from in and around an open dumpsite in Phra Nakhon Si Ayutthaya and to assess the bioaccumulation factor and human health risk of the heavy metals. The results of this study are useful for waste disposal control and risk management of heavy metals in similar areas.

2. Materials and Methods

2.1 Sample collection

The open dumpsite in this study is located in the Nakhonluang district of the Phra Nakhon Si Ayutthaya province (Fig. 1). The waste in this site is mainly from residential and agricultural areas. The common waste materials are plastics, clothes, cans, food waste and hazardous wastes like batteries and light bulbs.

A total of eighteen soil samples and five rice samples (*Oryza sativa*) were collected in March 2016. Ten of the soil samples were collected inside the area of the dumpsite; therefore, these samples represented the soil from "inside the dumpsite" and were designated as S1-S10 (Fig. 1). Seven soil samples were collected from the surrounding agricultural area; therefore, these samples represented the soil from the "surrounding area of the dumpsite" and designated as S11-S17. A sample located further in the north of the dumpsite was collected as a reference point because the sample was in a location at an upward direction of the river and had no direct waterway from the dumpsite and no agricultural and human activities. Each soil sample was collected at a depth of ca. 30 cm for 1 kg in a plastic (zip lock) bag.

Five rice samples were collected from the surrounding area at the points where the soil samples were collected (S13-S17), and they were designated as R13-R17. Rice samples were collected as the whole tree and dirt at the root was washed out and air dried for 5 to 7 days.

2.2 Sample analysis

2.2.1 Soil samples analysis

Soil samples were air dried, ground and sieved through a 0.5-mm sieve for the analyses of physico-chemical properties and heavy metals. For the analysis of soil texture, it was sieved through a 2-mm sieve. The physico-chemical properties included temperature; soil texture, which was determined using the hydrometer method; pH, which was determined using a pH meter (O-BASF, PH-009) for soil solution (Soil: Water; 1:2); cation exchange capacity (CEC), which was determined using extraction through the ammonium acetate method; and organic matter (OM) based on the Walkley-Black dichromate wet oxidation method.

Sieved soil (0.5 g) was digested using the microwave digester (Milestone, Ethos one) method EPA3051 by adding 10 mL of 65% nitric acid and run under the following conditions: a power of 1,000 watts and an ambient temperature to 175˚C for 5 minutes and 30 seconds, then maintained at 175˚C for 10 minutes. The heavy metals Cd, Cr, Cu, Fe, Ni, Mn, Pb and Zn were identified using an atomic absorption spectrophotometer (AAS; Agilent, AA240). All glassware used for detecting heavy metals was soaked in 0.1 M nitric acid for 24 hours and rinsed with deionized water. Three replicates were used to analyze the soil samples.

2.2.2 Rice samples analysis

Rice samples were air dried, cut into 3 parts (grain, straw and root), ground and sieved through a 1-mm sieve. The samples (0.5 g) were digested in the microwave digester by adding 8 mL of 65% nitric acid and were run under the following conditions: a power of 1,000 watts and an ambient temperature to 180˚C for 25 minutes, then maintained at 180˚C for 15 minutes. The heavy metals Cd, Cr, Cu, Fe, Ni, Mn, Pb and Zn were determined using the AAS.

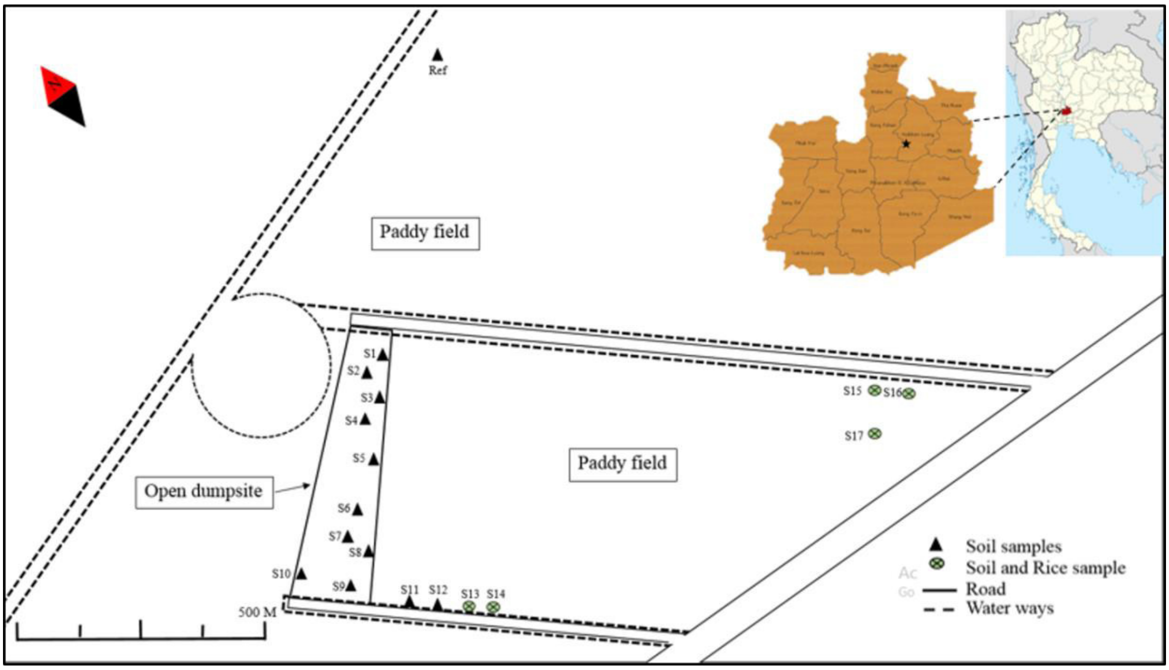

Figure 1. Territory of soil and rice sampling in the study area

2.3 Bioaccumulation Factor (BAF)

The bioaccumulation factor (BAF) was used as an index to determine the ability of a plant to accumulate a particular metal with respect to its concentration in the soil substrate (Hang *et al*., 2009). BAF was calculated as follows:

$$\mathrm{BAF} = \frac{C_r}{C_s} \quad (1)$$

C_r and C_s represent the heavy metal concentrations in each part of the rice (grain, straw and root) and soils, respectively.

2.4 Human health risk assessment (HI and R_{Total})

A model was used to assess health risk assessment (Huang *et al*., 2015; Hang *et al*., 2009; Ferreira-Baptista and de Miguel, 2005). The assessment procedure included four steps:

1) Risk identification was used to identify the amount of heavy metals in the soil that enter the body via three main pathways while the heavy metals in rice enter the body via the ingestion pathway only.

(a) Direct ingestion of substrate particles (D_{ing}):

$$\text{Oral dose } (D_{ing}):\ D_{ing} = \frac{C_s \times IngR \times EF \times ED \times CF}{BW \times AT}, \quad (2)$$

where *IngR* = the soil or rice ingestion rate for the receptor (mg/d)
C_s = the concentration of the pollutant in the soil or rice from the exposure point (mg/kg)
EF = the exposure frequency (days/year)
ED = exposure duration (years)
CF = conversion factor = 1.00E - 06 (kg/mg)
BW = time-averaged body weight (kg)
AT = average time of noncarcinogenic and carcinogenic risks (days)

(b) Inhalation of suspended particles through the mouth and nose (D_{inh}):

$$\text{Inhalation dose } (D_{inh}):\ D_{inh} = C_s \times \frac{InhR \times EF \times ED}{BW \times AT \times PEF}, \quad (3)$$

where InhR = the soil inhalation rate for the receptor (m^3/d)
C_s = the concentration of the pollutant in the soil from the exposure point (mg/kg)
EF = the exposure frequency (days/year)
ED = exposure duration (years)
BW = time-averaged body weight (kg)
AT = average time of noncarcinogenic and carcinogenic risks (days)
PEF = soil-to-air particulate emission factor (m^3/kg)

(c) Dermal absorption of element in particles by skin (D_{der})

Dermal dose (D_{der}): $D_{der} = \frac{C_s \times SA \times SL \times ABS \times EF \times ED \times CF}{BW \times AT}$, (4)

where SA = skin surface area available for exposure (cm^2)
C_s = the concentration of the pollutant in the soil from the exposure point (mg/kg)
SL = soil-to-skin adherence factor (mg/cm^2)
ABS = dermal absorption factor
EF = the exposure frequency (days/year)
ED = exposure duration (years)
CF = conversion factor = 1.00E - 06 (kg/mg)
BW = time-averaged body weight (kg)
AT = average time of noncarcinogenic and carcinogenic risks (days)

2) Exposure analysis was the specific approach used to determine characteristics of the heavy metals in terms of the human exposure effect of noncarcinogenic or carcinogenic hazard exposures.

3) Toxicity evaluation was calculated using the parameters of risk identification of each pathway:

(a) noncarcinogenic risk (HI)

$$HI = \sum_{i=1}^{m} \sum_{j=1}^{n} HQ_{ij} = \sum_{i=1}^{m} \sum_{j=1}^{n} \left(\frac{D}{RfD}\right)_{ij}, \quad (5)$$

Where m and n = pollutant type and number of exposure pathways, respectively

(b) carcinogenic risk (R_{Total})

$$LADD = \frac{C \times EF}{AT} \times \left(\frac{CR_{child} \times ED_{child}}{BW_{child}} \times \frac{CR_{adult} \times ED_{adult}}{BW_{adult}}\right), \quad (6)$$

where $LADD$ = the sum of average exposure dose via multiple pathways per lifecycle (1/(mg·kg·d))
AT = the average exposure time (life expectancy x 365)
CR = intake intensity (for oral ingestion and inhalation pathways, CR = IngR and CR = InhR, respectively; for dermal contact pathway, CR = SA·SL·ABS)
RfD = reference doses (mg/kg•d)

The accumulation of carcinogenic risk will be expressed as the total cancer risk (R_{Total}):

$$R_{Total} = \sum_{i=1}^{m} \sum_{j=1}^{n} R_{ij} = \sum_{i=1}^{m} \sum_{j=1}^{n} (LADD \times SF)_{ij}, \quad (6)$$

where SF = slope factors (mg•d/kg)

All parameters used for the evaluation dose are shown in Tables 1 and 2.

4) Risk assessment was assessed by comparing the HI or the obtained R_{Total} value with the following recommended values:

(a) noncarcinogenic risk
$HI > 1$ → adverse health effects unlikely to occur
$HI < 1$ → adverse health effects may occur

(b) carcinogenic risk
$R_{Total} >$ 1.00E - 04 → unacceptable
1.00E - 04 > R_{Total} > 1.00E - 06 → generally considered acceptable
$R_{Total} <$ 1.00E - 06 → not considered to pose significant health risk

Table 1. Variables used to assess human exposure to the soil and rice (Huang *et al*., 2015; Hang *et al*., 2009).

Parameters	Reference value	
	Adults	Children
IngR		
- [a]Soil (mg/d)	100	200
- [b]Rice (g/d)	389.2	198.4
InhR (m^3/d)	12.8	7.63
EF (d)	350	320
ED (yrs)	24	6
BW (kg)	59.95	23.9
AT (d)	24 x 365 = 8,760	6 x 365 = 2,190
	For carcinogenic risk, AT = 72 x 365 = 26,280	
SA (cm^2)	2,145	1,150
SL (mg/cm^2)	0.07	0.20
ABS	0.001	
PEF (m^3/kg)	1.36E + 09	

[a] Dry weight; [b] Wet weight.

3. Results and Discussion

3.1 Physico-chemical properties

All soil samples obtained from the dumpsite area and the surrounding areas had an acidic pH (4 - 6.8) and clay texture (Table 3). The varied mean composition of the soil from the open dumpsite was 31.22% sand, 14.72% silt and 54.06% clay, where the mean varied composition of sand, silt and clay in the surrounding area was 31.79%, 16.17% and 52.04% respectively. The textual class of the soils from both the dumpsite and the surrounding area was clay. The Land Development Department (LDD, 2007) has developed a database of heavy metals in agricultural soil in Thailand; soils collected from Ayutthaya (Ayutthaya series: Ay) in 2007 were acidic with a clay texture, which is the same type of soil examined in this study.

The CEC values of the soil samples were in the range of 37.42-85.92 cmol/kg, which is in accordancewith the CEC result reported from the LDD of 29.8-33.6 cmol/kg. The OM composition was between 1.10-4.58%, which fits in the same range as that of the LDD: 2.4-3.6%. The OM and CEC values reported in this study are in the same range as in the soils from other municipal solid waste from open dumpsites (Amos-Tautua *et al*., 2014).

Although the OM range of the dumpsite and the surrounding area were similar, the source of OM in the surrounding area was organic fertilizer because the land has been used for agricultural purpose while the sources of OM in the dumpsite area were organic wastes such as vegetables, wood and food.

3.2 Heavy metals in soil

Seven heavy metals were detected with the following order of abundance: Fe > Mn > Zn > Cu > Cr > Ni > Pb, and Cd was below the detection limit. The average and range of concentration of the seven heavy metals are shown in Table 4. As shown in the table, the concentrations of the five heavy metals, namely Cr, Cu, Mn, Pb and Zn, in the dumpsite area are obviously higher than those of the surrounding sites. These results confirm that the municipal waste releases a high amount of heavy metals into the soil. The concentrations of Fe were not much higher than those of the surrounding sites, these result from the fact that soil already naturally contains high levels of Fe.

Next, we compared the results with four soil quality standards from the PCD, CCME, Eco-SSL and LDD. The results showed that all heavy metal concentration levels in the soil complied with the soil quality standards for habitat and agricultural purpose in Thailand set by the Pollution Control Department (PCD, 2004). However, with regards to the standard soil quality guidelines for the protection of human health and environment from the Canadian Council of Ministers of the Environment (CCME, 2007), which is used as the standard for screening purpose in risk assessment, the concentrations of Cr in site S2; Zn in sites S2 and S4; and Cu in sites S2, S4 and S7 exceeded standard levels. Then, when the results were compared with the Ecological Soil Screening Level (Eco-SSL) from USEPA (2005), which is a standard risk for higher plants protection, the concentrations of Zn and Cu in sites S2 and S4 exceeded the standard levels

Table 2. Reference doses (RfD) for noncarcinogens and slope factors (SF) for carcinogens (Huang *et al*., 2015; Ferreira-Baptista and de Miguel, 2005)

Heavy metals	RfD (mg/kg•d)			SF (mg•d/kg)		
	RfD_{ing}	RfD_{inh}	RfD_{der}	SF_{ing}	SF_{inh}	SF_{der}
Cd	1.00E - 03		1.00E - 05		6.30E + 00	
Cr	3.00E - 03	2.86E - 05	6.00E - 05		4.20E + 01	
Cu	4.00E - 02	4.02E - 02	1.20E - 02			
Mn	4.60E - 02	1.43E - 05	1.84E - 03			
Ni	2.00E - 02	2.06E - 02	5.40E - 03		8.40E - 01	
Pb	1.40E - 03	3.52E - 03	5.25E - 05	8.50E - 03		
Zn	3.00E - 01	3.00E - 01	6.00E - 02			

as well as the average concentration of Mn. Finally, the average concentrations of Zn and Cu exceeded the recommendation level for good soil and safety life from the Land Development Department (LDD, 2006), which represents the safe level for agricultural soil in Thailand.

Zn in this study ranged from 18.11-512.67 mg/kg, and sites S2 and S4 exceeded both CCME and Eco-SSL standards (PCD standard not available). Moreover, the average value in the dumpsite was 123.56 mg/kg, which is over the LDD standard of 100 mg/kg. Zn has also been reported to contaminate soil in open dumpsites in Uttaradit, Khon Kaen and Nonthaburi provinces of Thailand (Wachirawongsakorn and Sangyoka, 2013; Chuangcham *et al*., 2008; Prechthai *et al*., 2008). The sources of Zn in the dumpsite could be batteries, pigments, galvanizing steel and iron products.

The concentration of Cu varied from 24.52-76.43 mg/kg, where sites S2 and S4 exceeded all standards (except PCD, for which the value was not available) and the LDD standard of 45 mg/kg, having an average concentration of 46.76 mg/kg. Cu has been used in electrical wiring, alloys, cooking utensils, piping and agrochemicals.

Mn ranged from 87.32-951.15 mg/kg; the averages in the dumpsite and surrounding area were 432.46 mg/kg and 289.75 mg/kg, respectively, as both amounts exceeded that of the Eco-SSL standard (220 mg/kg) considerably. This result is in agreement with the result from Prechthai *et al*. (2008), which found that Mn has the highest leaching rate compared with other heavy metals.

As shown in Table 4, the concentrations of Cr, Mn and Zn of the surrounding soils are higher than those of the reference site. These heavy metals have been reported to leach from dumpsites and contaminate adjacent soil and groundwater (Wachirawongsakorn and Sangyoka, 2013; Prechthai *et al*., 2008). It suggests that the surrounding soils in this study may have received these heavy metals from the dumpsite.

It is noted that Cd was not detected in this study. This result aligns with those of Pongpom *et al*. (2014), who studied agricultural soils in Ayutthaya and found no Cd in all 17 samples. Moreover, other concentrations of heavy metal found by Pongpom *et al*. (2014) correspond to those found in the surrounding soils of the current study as well.

From this study, we find that the concentrations of Cu, Mn and Zn in the dumpsite area exceed the CCME and Eco-SSL standards. This finding generates some concerns for ecological and human health, which can be adversely affected by the toxicity of these heavy metals. Cd, Cr and Pb have a high degree of toxicity, and they are classified as human carcinogens (known or probable) according to the USEPA and IARC. These metals are considered systemic toxicants that are known to induce multiple organ damage even at low levels of exposure (Tchounwou *et al*., 2012; Järup, 2003).

3.3 Bioaccumulation factor

In this study, we measured the accumulation of heavy metals in rice sampled from the fields around the dumpsite to determine how much heavy metal accumulated in the plant tissue. We determined the concentration of heavy metals by dividing the plant into three parts: root, straw and grain. The rice exhibited metal concentrations in the following order: root > straw > grain. This was in accordance with the finding of Singh *et al*. (2011), who reported that heavy metals (i.e. Cd, Cr, Cu, Pb, Zn, As, Mn and Hg) accumulated in the root more than other parts of rice. In the current study, the value of the bioaccumulation factor (BAF) appeared in the following order: root > straw > grain (Table 5). A BAF value greater than 1 indicates that the pollutant is absorbed and accumulated in the plant tissue. If the BAF is less than 1, the pollutant is not retained in the plant tissue. From Table 5, we found that all heavy metals are absorbed and accumulated in root samples. However, only Mn, Zn and Ni are accumulated in straw. For grain, we found that all BAF values are less than 1, indicating that all heavy metals are not accumulated in grain.

3.4 Human health risk assessment of heavy metal in soil and rice samples

Heavy metals are known to cause negative, often chronic or carcinogenic, health effects to humans. Risk assessment is a process of assessing the risk of heavy metals in soil and rice samples entering into the human body and causing adverse noncarcinogenic or carcinogenic health effects. Estimation of human exposure to a substance can be carried out by monitoring three main pathways of exposure including oral, inhalation and dermal contact.

For soil samples, exposure was evaluated in three pathways: oral (D_{ing}), inhalation (D_{inh}), and dermal (D_{der}). But for rice samples, the evaluation was performed in one pathway, oral (D_{ing}), because humans usually intake rice orally. Average concentrations of heavy metals found in the soil and rice were used to calculate the human exposure and by comparing the amount of exposure to the safe level of each heavy metal element, risk was calculated.

Table 3. Physico-chemical properties of the soil samples

	Code	pH	Sand (%)	Silt (%)	Clay (%)	Soil texture	CEC (cmol/kg)	OM (%)
Soil from the open dumpsite area	S1	4.00	26.92	20.36	52.72	clay	64.00	1.25
	S2	6.00	36.36	13.44	50.20	clay	59.50	3.72
	S3	5.60	30.36	17.44	52.20	clay	69.80	2.12
	S4	5.20	31.08	2.72	66.20	clay	50.99	3.68
	S5	5.00	35.08	18.42	46.50	clay	65.53	1.15
	S6	5.20	35.40	18.00	46.60	clay	37.42	1.44
	S7	5.40	26.36	10.92	62.72	clay	58.00	1.10
	S8	6.80	28.24	14.16	57.60	clay	75.24	2.38
	S9	6.20	32.40	9.72	57.88	clay	55.22	1.10
	S10	5.80	30.00	22.00	48.00	clay	62.69	1.68
	Average	5.52	31.22	14.72	54.06	clay	59.84	1.96
	Range	4.00-6.80	26.36-36.36	2.72-20.36	46.5-66.2	clay	37.42-75.24	1.10-3.72
Reference point	Ref	5.00	31.08	14.16	54.76	clay	57.43	1.20
Soil from the surrounding area	S11	5.00	32.36	11.00	56.64	clay	56.43	3.20
	S12	5.20	32.68	12.08	55.24	clay	60.18	4.31
	S13	5.40	29.80	22.16	48.04	clay	50.75	3.95
	S14	6.00	29.80	14.16	56.04	clay	61.94	1.63
	S15	5.40	25.24	18.16	56.60	clay	85.92	3.78
	S16	5.10	40.42	13.54	46.04	clay	81.50	4.58
	S17	5.10	32.24	22.08	45.68	clay	71.11	2.79
	Average	5.31	31.79	16.17	52.04	clay	66.83	3.46
	Range	5.00-6.00	25.24-40.42	11.00-22.16	45.68-56.64	clay	50.75-85.92	1.63-4.58

Table 4. Heavy metal contamination at the open dumpsite and surrounding area (mg/kg)

Code	Cd [e]	Cr	Cu	Fe	Mn	Ni	Pb	Zn
S1	ND	27.10 ± 4.92	33.91 ± 1.38	26432.55 ± 854.40	597.67 ± 6.75	10.08 ± 0.25	4.71 ± 0.06	58.60 ± 0.18
S2	ND	74.95 ± 0.07	76.43 ± 11.46	25924.50 ± 285.67	355.51 ± 21.79	14.38 ± 3.75	10.74 ± 0.52	512.67 ± 7.76
S3	ND	31.80 ± 2.10	36.14 ± 5.02	23852.97 ± 602.12	253.39 ± 27.98	32.45 ± 11.10	4.60 ± 0.73	44.18 ± 0.09
S4	ND	40.60 ± 3.03	74.53 ± 1.58	24034.73 ± 1990.74	333.54 ± 10.20	27.53 ± 9.16	7.52 ± 0.99	296.45 ± 11.73
S5	ND	25.63 ± 4.12	52.47 ± 11.85	30109.70 ± 249.95	951.15 ± 44.45	32.85 ± 6.41	5.25 ± 2.61	68.03 ± 2.24
S6	ND	27.63 ± 5.69	26.08 ± 0.06	17979.65 ± 1828.51	206.24 ± 9.88	23.55 ± 8.98	7.08 ± 0.60	38.31 ± 3.74
S7	ND	40.67 ± 2.41	69.02 ± 3.84	25168.63 ± 1376.53	716.37 ± 15.33	30.63 ± 12.27	9.39 ± 1.60	103.29 ± 6.03
S8	ND	29.35 ± 6.01	27.45 ± 1.87	8739.63 ± 636.82	131.26 ± 11.55	25.45 ± 9.12	5.63 ± 2.11	49.61 ± 1.31
S9	ND	18.73 ± 5.99	36.92 ± 3.98	25611.75 ± 2736.01	592.01 ± 0.33	27.30 ± 12.30	27.07 ± 5.09	18.11 ± 2.11
S10	ND	23.17 ± 2.25	34.61 ± 1.48	21967.50 ± 3415.48	187.43 ± 35.61	5.45 ± 0.47	5.81 ± 1.65	46.31 ± 5.54
Average	ND	33.96 ± 3.66	46.76 ± 4.25	22982.16 ± 1397.62	432.46 ± 18.39	22.97 ± 7.38	8.78 ± 1.60	123.56 ± 4.07
Range	ND	18.73 - 74.95	26.08 - 76.43	8739.63 - 30109.70	131.26 - 951.15	5.45 - 32.85	4.60 - 27.07	18.11 - 512.67
S11	ND	24.10 ± 2.11	24.70 ± 1.73	21112.30 ± 2569.21	87.32 ± 3.28	5.05 ± 0.08	5.69 ± 1.71	27.70 ± 1.08
S12	ND	23.90 ± 1.61	25.96 ± 1.40	21325.53 ± 783.13	133.93 ± 2.35	20.83 ± 4.99	5.91 ± 1.37	35.61 ± 3.28
S13	ND	27.07 ± 1.89	28.54 ± 2.19	20756.50 ± 2537.96	145.06 ± 6.91	25.50 ± 1.84	5.97 ± 1.22	36.60 ± 2.73
S14	ND	21.97 ± 1.23	24.94 ± 0.83	20321.33 ± 1456.86	312.84 ± 13.72	26.30 ± 6.08	5.35 ± 1.29	30.21 ± 8.55
S15	ND	29.80 ± 2.16	26.42 ± 0.49	25772.80 ± 109.09	536.41 ± 8.27	9.86 ± 2.24	4.21 ± 1.48	55.60 ± 1.24
S16	ND	21.67 ± 1.82	24.52 ± 0.58	22939.29 ± 2348.62	402.09 ± 17.9	19.23 ± 4.8	4.51 ± 1.47	47.00 ± 4.9
S17	ND	22.12 ± 1.78	24.94 ± 1.22	23030.32 ± 1138.31	410.62 ± 12.1	18.8 ± 1.84	5.31 ± 0.91	42.42 ± 2.67
Average	ND	23.38 ± 1.80	25.72 ± 1.20	22179.72 ± 1563.31	289.75 ± 9.22	17.94 ± 3.12	5.28 ± 1.35	39.30 ± 3.49
Range	ND	21.67 - 29.80	24.52 - 28.54	19806.34 - 25772.80	87.32 - 536.41	5.05 - 26.30	4.21 - 5.97	27.70 - 55.60
Ref	ND	15.25 ± 0.05	26.33 ± 1.17	19806.35 ± 2176.97	109.16 ± 3.58	12.25 ± 0.64	5.47 ± 1.31	34.65 ± 5.63
PCD [a]	37	300	NA	NA	1800	1600	400	NA
CCME [b]	1.4	64	63	NA	NA	50	70	200
Eco-SSL [c]	32	NA	70	NA	220	38	120	160
LDD [d]	0.5	NA	45	NA	NA	NA	55	100

[a] Soil quality standard for habitat and agricultural purposes in Thailand (PCD, 2004); [b] Soil quality guidelines for the protection of human health and environmental (CCME, 2007); [c] Ecological soil screening level for the protection of higher plants (USEPA, 2005); [d] Recommendation level for good soil and safety life for agricultural soil in Thailand (LDD, 2006); [e] Limit of detection = 1 mg/kg; ND: some pollutants are not detected; NA: some pollutants are nonexistent in one standard.

Table 5. Concentration and bioaccumulation factor (BAF) of heavy metals in rice

Code	Heavy metal	Concentration of heavy metal (mg/kg)				BAF		
		Soil	Root	Straw	Grain	Root	Straw	Grain
R13	Cr	27.07	27.56	6.23	5.62	**1.02**	0.23	0.21
	Cu	28.54	23.35	20.62	7.4	0.82	0.72	0.26
	Fe	20,756.50	22,989.14	681.39	174.43	**1.11**	0.03	0.01
	Mn	145.06	22,1.39	242.96	21.77	**1.53**	**1.67**	0.15
	Ni	25.5	21.1	20.36	7.32	0.83	0.80	0.29
	Pb	5.97	7.44	1.73	1.48	**1.25**	0.29	0.25
	Zn	36.6	47.2	26.25	24.66	**1.29**	0.72	0.67
R14	Cr	21.97	18.33	16.63	0.97	0.83	0.76	0.04
	Cu	24.94	27.66	12.04	5.63	**1.11**	0.48	0.23
	Fe	20,321.33	27,316.57	4112.4	881.85	**1.34**	0.20	0.04
	Mn	312.84	234.45	280.35	26.97	0.75	0.90	0.09
	Ni	26.3	21.27	11.38	2.52	0.81	0.43	0.10
	Pb	5.35	5.7	1.49	1.49	**1.07**	0.28	0.28
	Zn	30.21	53.18	33.65	1.3	**1.76**	**1.11**	0.43
R15	Cr	29.8	25.34	7.24	2.48	0.85	0.24	0.08
	Cu	26.42	23.78	5.46	7.45	0.90	0.21	0.28
	Fe	25,772.80	17,630.36	548.12	165.4	0.68	0.02	0.01
	Mn	536.41	544.88	312.88	18.5	**1.02**	0.58	0.03
	Ni	9.86	16.6	10.82	2.15	**1.68**	**1.10**	0.22
	Pb	4.21	4.47	1.24	2.72	**1.06**	0.29	0.65
	Zn	55.6	51.73	21.2	16.19	0.93	0.38	0.29
R16	Cr	21.67	23.46	6.96	1.89	**1.08**	0.32	0.09
	Cu	24.57	19.74	7.04	8.16	0.81	0.29	0.33
	Fe	22,939.29	17,338.71	554.7	141.89	0.76	0.02	0.01
	Mn	402.09	293.86	374.16	18.35	0.73	0.93	0.05
	Ni	19.23	14.12	10.2	2.59	0.73	0.53	0.13
	Pb	4.51	4.46	3.24	1.74	0.99	0.72	0.39
	Zn	47	55.57	24.39	15.9	**1.16**	0.51	0.33
R17	Cr	22.12	36.66	4.71	3.3	**1.66**	0.21	0.15
	Cu	24.94	21.13	6.96	12.53	0.85	0.28	0.50
	Fe	23,030.32	23,842.76	482.24	554.99	**1.04**	0.02	0.02
	Mn	410.62	176.99	363.54	24.09	0.43	0.89	0.06
	Ni	18.8	21.31	7.28	3.54	**1.13**	0.39	0.19
	Pb	5.31	8.91	2.73	3.97	**1.68**	0.51	0.75
	Zn	42.42	47.08	25.87	19.87	**1.11**	0.61	0.47

3.4.1 Noncarcinogenic risk

In this study, we performed a human health risk assessment of heavy metals in both soil and rice. For soil samples, the risk assessment was evaluated using three exposure pathways: oral (HQ_{ing}), inhalation (HQ_{inh}) and dermal (HQ_{der}). For rice samples, only the oral (HQ_{ing}) pathway was used for evaluation. Risks derived from all exposure pathways were summed up, and risks from all heavy metals were also summed up to yield an HI (Hazard index) value. The results of risk assessment of soil and rice samples are shown in Table 6.

The hazard level of the soil samples could be described as follows: oral > inhalation > dermal. HI value indicates the risk level to human health. If the HI is greater than 1, this indicates a risk hazard to humans. We found that the HI of the soil samples in the dumpsite was greater than 1 for both children (HI = 10.5) and adults (HI = 2.18). The HI value for children was 5 times higher than that of adults because children weigh less than adults. However, in the surrounding area, the soil samples did not indicate a hazard to both children and adults. We also found that rice in surrounding sites do not cause a hazard to both children and adults, as the HI values for children and adults were both less than 1.

Table 6. Noncarcinogenic risks of heavy metals from soil and rice samples

	Group	Heavy metals	Noncarcinogenic hazard			HI
			HQ_{ing}	HQ_{inh}	HQ_{der}	
Soil from the open dumpsite area (S1-S10)	Children	Cr	8.31E - 01	2.44E - 04	4.78E - 02	8.79E - 01
		Cu	8.58E - 03	2.39E - 07	3.29E - 04	8.90E - 03
		Mn	6.90E - 02	6.22E - 03	1.98E - 02	9.50E - 02
		Ni	8.42E - 03	6.75E - 10	3.59E - 04	8.78E - 03
		Pb	4.60E - 02	5.13E - 07	1.41E - 02	6.01E - 02
		Zn	3.02E - 03	6.20E - 08	4.95E - 06	3.03E - 03
		Sum	**9.66E + 00**	6.47E - 02	8.23E - 01	**1.05E + 01**
	Adult	Cr	1.81E - 01	1.79E - 04	1.36E - 03	1.83E - 01
		Cu	1.87E - 03	1.75E - 07	9.36E - 06	1.88E - 03
		Mn	1.50E - 02	4.55E - 03	5.64E - 04	2.02E - 02
		Ni	1.84E - 03	4.94E - 10	1.02E - 05	1.85E - 03
		Pb	1.00E - 02	3.75E - 07	4.02E - 04	1.04E - 02
		Zn	6.59E - 04	6.20E - 08	4.95E - 06	6.64E - 04
		Sum	**2.11E + 00**	4.73E - 02	2.35E - 02	**2.18E + 00**
Soil from the surrounding area (S11-S17)	Children	Cr	5.62E - 01	1.65E - 04	3.23E - 02	5.94E - 01
		Cu	4.69E - 03	1.31E - 07	1.80E - 04	4.87E - 03
		Mn	4.71E - 02	4.25E - 03	1.35E - 02	6.48E - 02
		Ni	6.45E - 03	5.17E - 10	2.75E - 04	6.72E - 03
		Pb	2.74E - 02	3.05E - 07	8.40E - 03	3.58E - 02
		Zn	9.76E - 04	2.74E - 08	5.61E - 05	1.03E - 03
		Sum	6.49E - 01	4.42E - 03	5.47E - 02	7.07E - 01
	Adult	Cr	1.22E - 01	1.21E - 04	9.19E - 04	1.23E - 01
		Cu	1.02E - 03	9.58E - 08	5.12E - 06	1.03E - 03
		Mn	1.03E - 02	3.11E - 03	3.85E - 04	1.37E - 02
		Ni	1.41E - 03	3.78E - 10	7.82E - 06	1.41E - 03
		Pb	5.97E - 03	2.23E - 07	2.39E - 04	6.21E - 03
		Zn	2.13E - 04	2.00E - 08	1.60E - 06	2.14E - 04
		Sum	1.41E - 01	3.23E - 03	1.56E - 03	1.46E - 01
Rice (R13-R17)	Children	Cr	6.92E - 02	NC	NC	6.92E - 02
		Cu	1.50E - 03	NC	NC	1.50E - 03
		Mn	3.47E - 03	NC	NC	3.47E - 03
		Ni	1.32E - 03	NC	NC	1.32E - 03
		Pb	1.19E - 02	NC	NC	1.19E - 02
		Zn	4.32E - 04	NC	NC	4.32E - 04
		Sum	8.78E - 02	NC	NC	8.78E - 02
	Adult	Cr	5.92E - 02	NC	NC	5.92E - 02
		Cu	1.28E - 03	NC	NC	1.28E - 03
		Mn	2.97E - 03	NC	NC	2.97E - 03
		Ni	1.13E - 03	NC	NC	1.13E - 03
		Pb	1.01E - 02	NC	NC	1.01E - 02
		Zn	3.70E - 04	NC	NC	3.70E - 04
		Sum	7.51E - 02	NC	NC	7.51E - 02

NC = not calculated.

3.4.2 Carcinogenic risk

We then proceeded to assess the risk of carcinogenic hazards to human health through exposure to heavy metals in soil and rice. Because the reference value and relevant data was still not enough for assessing carcinogenic risk from dermal exposure to heavy metals, this study could assess only the risk from oral and inhalation exposures of three heavy metals: Cr, Ni and Pb.

For the soil samples, the carcinogenic risk of the soils from an open dumpsite and its surrounding area were between 1.45E - 07 and 2.26E - 07, respectively (Table 7) and could be described as follows: Cr > Pb > Ni. These values were under the safety level (R_{Total} < 1E - 04), and the R_{Total} value of the soils in the open dumpsite was higher than that of the dumpsite's surrounding area.

For the rice samples, only the ingestion pathway was used, and with the availability of the SF value, only Pb could be evaluated. The carcinogenic risk (R_{Total}) of all rice samples was 5.31E - 08, which was below the safety level of 1E - 04; therefore, all of the rice samples were deemed safe to consume.

The results of the health risk assessment complied with those of Huang *et al*. (2015), which determined that there was no carcinogenic risk in the China open dumpsite.

4. Conclusions

The Cr, Cu, Mn, Pb and Zn concentrations in soil from the open dumpsite area were higher than the surrounding area. Heavy metal contaminations in the soil can enter plants and animals in the food chain capable of bioaccumulation and cause adverse health effects. Rice growing in soil near the Phra Nakhon Si Ayutthaya open dumpsite accumulated all the heavy metals in their roots except for Mn, which accumulated the most in the rice plant's straw parts. However, no accumulation was found in the rice grain.

Four standards were used for the screening for risk assessment in the soil samples. All heavy metals in the soils were below the soil quality standard for habitat and agricultural purpose in Thailand from PCD; however, some of the soil samples (S2, S4 and S7) in the dumpsite exceeded both standards from the Canadian soil quality guidelines for the protection of environmental and human health from CCME and the Ecological soil screening levels (Eco-SSLs) from USEPA except for Mn (S1, S2, S3, S4, S5, S7, S9 and S14), which exceeded the standard level. Zn and Cu in soil from the dumpsite were above the safe soil level put forth by LDD.

Based on the human health risk assessment, the heavy metal concentrations of soil from the open dumpsite pose a high noncarcinogenic risk to adults and children while the risk of heavy metal concentrations in the surrounding area to both adults and children were below the safe threshold. In terms of carcinogenic risk, all of the soil samples were below the safe threshold, and the risk value to adults was higher than to children. Finally, rice samples focused on grain were evaluated for human health risk by the ingestion pathway, and the results of the human health risk assessment showed that the risk value could be acceptable .

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Table 7. Carcinogenic risks of heavy metals from soil and rice samples

	Heavy metals	Carcinogenic risk			R_{Total}
		R_{ing}	R_{inh}	R_{der}	
Soil from	Cr	N/A	1.34E - 07	N/A	1.34E - 07
the open	Ni	N/A	1.81E - 09	N/A	1.81E - 09
dumpsite area	Pb	8.97E - 08	N/A	N/A	8.97E - 08
(S1-S10)	Sum	8.97E - 08	1.36E - 07	N/A	2.26E - 07
Soil from	Cr	N/A	9.04E - 08	N/A	9.04E - 08
the surrounding	Ni	N/A	1.38E - 09	N/A	1.38E - 09
area	Pb	5.34E - 08	N/A	N/A	5.34E - 08
(S11-S17)	Sum	5.34E - 08	9.18E - 08	N/A	1.45E - 07
Rice	Cr	N/A	NC	NC	NC
(R13-R17)	Ni	N/A	NC	NC	NC
	Pb	5.31E - 08	NC	NC	5.31E - 08
	Sum	5.31E - 08	NC	NC	5.31E - 08

N/A = slope factor not available; NC = not calculated.

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