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Cancer Risk Assessment around Municipal Solid Waste Incinerators

Patsiri Srivieng, Pensri Watchalayann, and Warawut Suadee

Faculty of Public Health, Thammasat University, Pathum Thani, Thailand

Corresponding author: pensri.watchalayann@gmail.com

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Abstract

Many of the pollutants emitted from municipal solid waste incinerator (MSWI) have been classified by the International Agency for Research on Cancer (IARC) as carcinogenic to humans. This study adopted the Human Health Risk Assessment (HHRA) model of the U.S. EPA to estimate both the lung and skin cancer risks contributed by arsenic, cadmium, chromium, nickel and dioxin to people living near the proposed MSWIs in Lamphun and Surat Thani Provinces in the Northern and Southern Regions of Thailand, of which both locations, waste input was 231 tons/day. The estimated lifetime of cancer risk (LCR) was based on the maximum annual average concentration of compounds of potential concern (COPCs) predicted by the Air Quality Model (AERMOD). Three potential pathways were calculated in this study, namely, inhalation, ingestion and dermal contact, with 2 scenarios of residents who were exposed from birth and during adulthood. Results show that the lung-cancer risk values exceeded the reference level (E-06) in the range of 1.06E-06 to 4.41E-06 for both scenarios and locations. For the skin-cancer risk values did not exceed the reference level in the range of 1.63E-07 to 2.43E-07. Chromium contributed a greater impact to cancer risk as compared to other pollutants. Surat Thani may be at a higher risk for cancer than Lamphun because of its meteorology and terrain. With these results, the proposed MSWIs should have the appropriate air pollution controls and monitoring system, especially for those emitting carcinogenic pollutants. Moreover, the cancer incidence surveillance system should be designed to monitor the long-term health impact of the proposed MSWIs.

Keywords: Municipal solid waste incinerators; Air-quality modeling; Heavy metals; Dioxins; Health risk assessment; Cancer risk

1. Introduction

Municipal solid waste (MSW) management has become a critical issue in Thailand because of the various serious problems arising from improper disposal. Waste management has been raised as an issue on the national agenda requiring urgent attention. The national roadmap (2016-2021) for municipal solid waste and hazardous waste management has established a driving force to all relevant sectors to solve the problem through reducing the waste generation at the sources. As the waste issue had been raised to one of the top national priorities, it must be address immediately. The government proposed making the applicable laws more lenient, such as removing the requirement for Environmental Impact Assessment (EIA) in the plant with capacity of generated electricity. Only code of practices (COPs) is compiled before developing MSWI. (PCD, 2016). Municipal solid waste incinerators (MSWIs) are typically fed with mixed waste containing hazardous substances such as heavy metals, chlorinated organic chemicals and other toxic chemicals. According to the U.S. EPA (1996), the pollutants being emitted in concentrated amounts from refuse combustors without controllers are arsenic (As), nickel (Ni), lead (Pb), cadmium (Cd), chromium (Cr) and mercury (Hg) in the form of heavy metals; mono-to-tri-chlorinated dibenzodioxin (CDD) and dibenzofuran (CDF) in the form of chlorinated organic chemicals; and particulate matter, sulfur dioxide, nitrogen oxide (NO), carbon dioxide and carbon monoxide in the form of criteria pollutants. Polycyclic aromatic hydrocarbons (PAHs) have, in addition, been found from incomplete combustion; some like Dioxin, have also been discovered in processes that have inadequate controllers (Ravindra *et al.,* 2008). The World Health Organization (WHO), in conjunction with the IARC, has recently classified 120 agents to be carcinogenic to humans (Group 1). There are cases of sufficient evidence of adverse carcinogenic health effects to humans and a causal relationship has been established between exposure to these agents and cancer in humans (Loomis *et al.,* 2013). The 5 COPCs have been selected in this study as it is having been classified as proven or suspected carcinogens by the International Agency for Research on Cancer (IARC, 2019), like As, Cd, Hg, Pb and dioxin. All chemicals effect to target organ as lung. Particularly, As and dioxin could effect to skin.

Human health risk assessment (HHRA) has been suggested as a tool for addressing health consequences from contact with multi-risk agents (e.g., chemical contaminants) and as a basis for developing risk management measures. The following major steps contribute to the risk assessment paradigm: 1. hazard identification; 2. dose response; 3. exposure assessment; and 4. risk characteristics (U.S. EPA, 2017). One of HRA tools in determining cancer risk (CR) has been defined by the U.S. EPA as “the incremental probability of an individual to develop cancer over a lifetime as a result of exposure to a potential carcinogen” (U.S. EPA, 1991).

The aim of this study was to estimate both the lung and skin-cancer risks from the stack emissions of the proposed MSWIs of Lamphun (LP) and Surat Thani (SR) Provinces and to estimate the distribution of their CRs along three exposure pathways and their significantly adverse health effects on people living near the MSWIs. It will be one of evidence that suggest to local government to mitigate for local people living near MSWIs.

2. Method and Materials

2.1 Study Area

In this study, two selected locations were Lamphun (LP; UTM: 516288, 2041580) and Surat Thani (SR; UTM: 743006, 1410505) Provinces, which their status were potential to develop MSWI. (The Secretariat of the House of Representatives, 2015). LP and SR, differing in terrain and meteorological data, were chosen as the fields of study. In LP, the proposed MSWI was located in Mae Tha District. Its topography consists of plateaus, valleys and mountains. The average temperature in Mae Tha is 35 degrees Celsius, and the weather there is mostly warm. The city occupies 751.60 square kilometers and is located in the Northern Region of Thailand. Mae Tha has a population of 39,231, and its population density is 52.19 people per square kilometer. Most of its people are agriculturists (60%), and the main agricultural products they raise include longans, rice and vegetables within an area of 52,249 rais. The natural features of the Mae Tha District include the Mae Tha River, 5 waterways, Khun Tal Natural Park and the Doi Pha Muang Wildlife Sanctuary.

In SR, the proposed MSWI located was in Phunphin District. The topography consists of plateaus and a coastline. The average temperature there is 35 degree Celsius, and it has a tropical climate. The city occupies 1,205.5 square kilometers in the Southern Region (or Peninsula) of Thailand and has a population of 89,901. Its population density is 76 people per square kilometer. Most of its people are agriculturists, and the main agricultural products they raise include rice, rubber, fruits and vegetables. The natural features of Phunphin include two waterways, the Lee Led mangrove forest and one hot spring (Department of Provincial Administration, 2017).

A cancer risk-assessment model by the U.S. EPA was applied to estimate the lifetime cancer risk from the MSWIs. The model of prediction implemented was the Air Quality Model.

The COPCs in this study were the group-1 carcinogenic chemicals, including As, Cd, Cr, Ni, the dioxins and it's like (U.S. EPA, 1996, IARC, 2019), which were being released from the stacks, as simulated in the Air Quality Model, or AERMOD.

The following major steps contribute to the risk assessment paradigm: 1) hazard identification when we know that the emission of MSWIs has occurred as described above; 2) dose response as a health problem in any scenario, especially where there are people who live near the MSWIs; 3) exposure assessment from the AERMOD on the concentration of each of the compounds of potential concern (COPCs) and how those compounds will be deposited into environmental media; and 4) risk characteristics used in the risk assessment of each of the COPCs.

2.2 Hazard Identification and Dose-Response Assessment

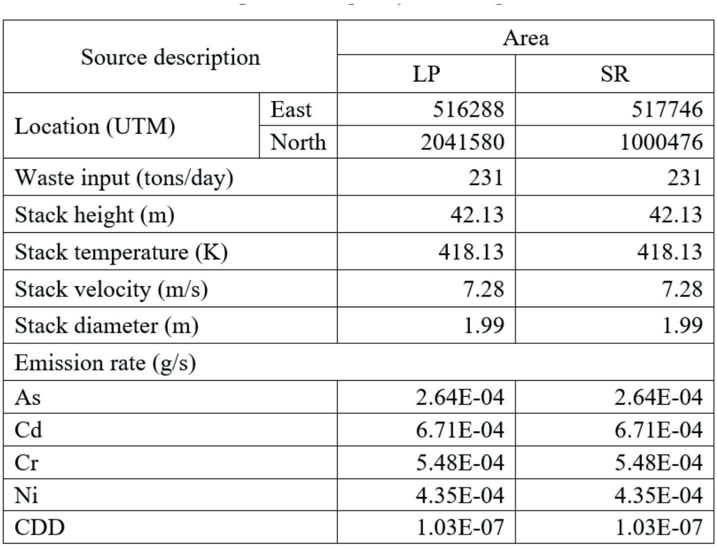
As, Cd, Cr, Ni and the dioxins are classified as carcinogens or suspected-carcinogens by the IARC (2019). Table 1 presents the target organs, the lungs and the skin, of all the COPCs that are classified as carcinogenic. Cancer assessment required the quantitative unit-risk estimate of the dose response to the potential routes of inhalation, ingestion and dermal contact.

Table 1. Characteristics of carcinogenic COPCs: target organs and unit risk

COPC	Target organ		IUR (per µg/m^3)	Reference	SF (per mg/kg-day)	Reference
	Lung	Skin				
As	✓	✓	4.30E-03	IRIS[1]	1.50E+00	IRIS[1]
Cd	✓		1.80E-03	IRIS[1]	1.50E+01	CalEPA[2]
Cr	✓		1.20E-02	IRIS[1]	5.00E-01	RSL[3]
Ni	✓		2.40E-04	IRIS[1]	9.10E-01	CalEPA[2]
CDD	✓	✓	3.30E-01	ATSDR[4]	1.50E+05	IRIS[1]

Note: 1. Integrated Risk Information System (IRIS) (U.S. EPA., 2019)
2. OEHHA Toxicity Criteria Database (CalEPA, 2019)
3. Regional Screening Levels (RSL) for Chemical Contaminants at Superfund Sites (U.S. EPA., 1989)
4. Agency for Toxic Substances and Disease Registry (ATSDR, 2005)

Table 2. Characteristic inputs in air quality modeling



Source description		Area	
		LP	SR
Location (UTM)	East	516288	517746
	North	2041580	1000476
Waste input (tons/day)		231	231
Stack height (m)		42.13	42.13
Stack temperature (K)		418.13	418.13
Stack velocity (m/s)		7.28	7.28
Stack diameter (m)		1.99	1.99
Emission rate (g/s)			
As		2.64E-04	2.64E-04
Cd		6.71E-04	6.71E-04
Cr		5.48E-04	5.48E-04
Ni		4.35E-04	4.35E-04
CDD		1.03E-07	1.03E-07

The value of unit risk of each COPC is shown in Table 1, where the inhalation unit risk (IUR) was determined by a comparison to intake by the inhalation route and the oral slope factors (SFs) were determined by comparison to intake by the ingestion route. The dermal SFs, on the other hand, were assumed to be at 100% of the oral SFs (Ong-Artborirak *et al,* 2017; U.S. EPA, 2001).

Average COPCs air concentrations were obtained from the AERMOD post-processor outputs. Table 2 showed the results of all COPC concentrations in each area and its location in terms of UTM. This table shows the averaged values from the concentration predictions of a project development, and their characteristic inputs for analysis in the AERMOD of each area. The results show the typical concentrations would be basically found in these middle-sized MSWIs.

2.3 Exposure Assessment

2.3.1 Residential receptors have seemingly exposed the population to the COPCs in these two scenarios, namely, residents who were exposed from birth and residents who were exposed during adulthood. The entire exposure duration (ED) of the two scenarios at their individual locations was set at 30 years, when they reach what is considered to be break-even point of the MSWIs projects, which are expected to be in operation for at least that length of time as shown in Figure 1 (World bank, 1999). The exposure victims are as follows:

1) Residents who were exposed from birth are counted as receptors who might have been born and exposed since the MSWIs start operating. Residents in terms of duration of exposure were sub-grouped in these four stages:

- Infants 0-1 years old (ED = 1 year)
- Toddlers and pre-schoolers1-6 years old (ED = 5 years)
- Children 6-15 years old (ED = 9 years)
- Adults; i.e., people more than 15 years old (ED = 15 years)

2) Residents exposed from adulthood are counted as adult resident receptors above 16 years of age and exposed for 30 years (ED = 30) during the period of operation.

2.3.2 Exposure routes were based on the concept of multi-exposure pathways. The MSWIs emitted the COPCs from their stacks and dispersed them into the ambient air, creating what is called a ground-level concentration (GLC), the concentration in the air of a pollutant to which a human being is normally exposed. The COPCs are then deposited into the water and soil, thus contaminating the food chain, with adverse health effects on the human population, as shown in Figure 2.

There are four possible pathways, including direct inhalation and indirect exposure. These pollutants came accidentally into contact with the soil and they were ingested by the consumption of food and breast milk. Toddlers and pre-schools, children and adults, received direct exposure through inhalation because of the GLC of these pollutants. This exposure continued for entire lifetimes. During this time, they also received indirect exposure to the soil and water by contact and ingestion, and through contaminated food stuff, as shown in Table 3.

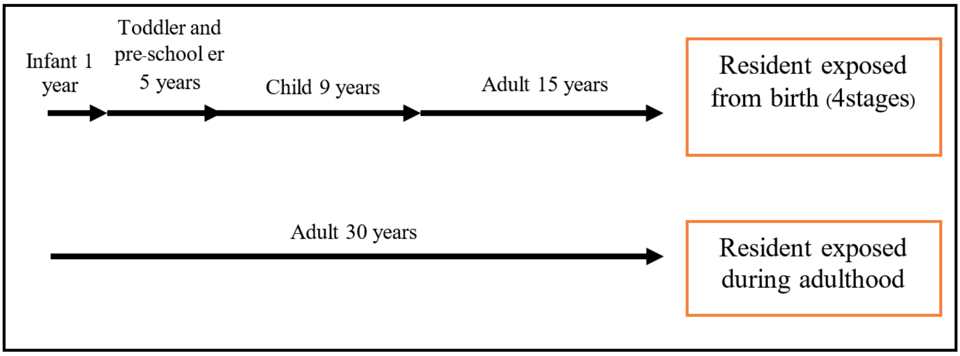


Figure 1. Scenarios of exposure stages during a potential operation period of 30 years

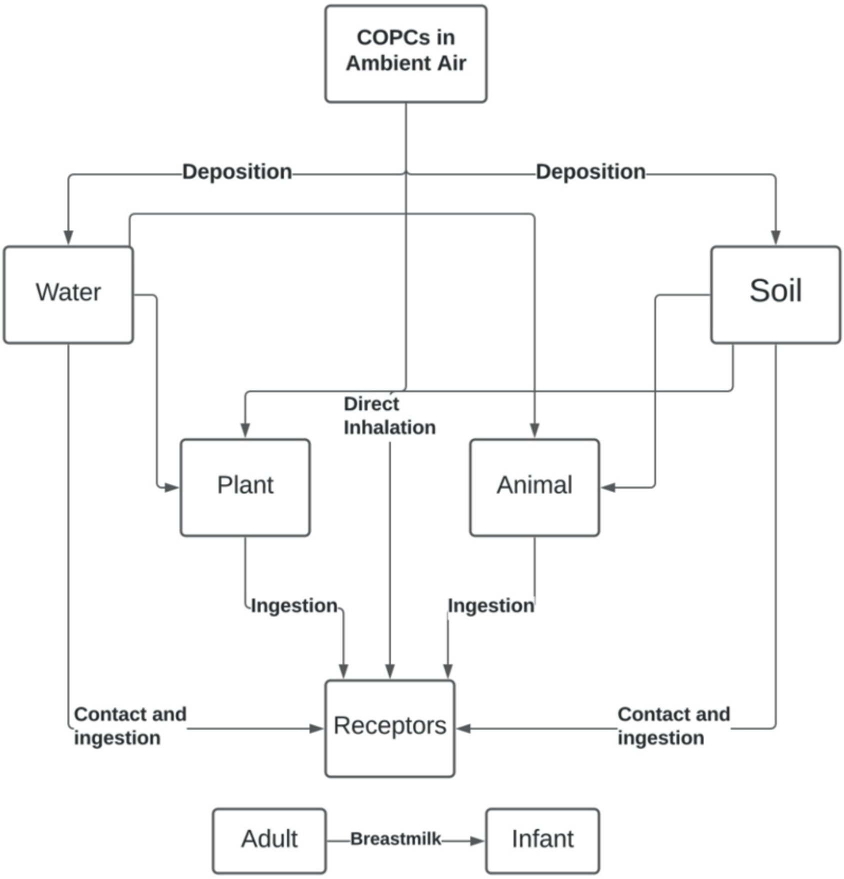


Figure 2. Route of entry of COPCs released from MSWIs stacks to receptors

Table 3. Exposure pathways, stages of life of receptor combinations evaluated (adopted from Office of Solid Waste, U.S. EPA, 2005)

Receptors	Exposure pathway								
	Inhalation	Dermal contact with surface water	Dermal contact with soil	Incident ingestion of soil	Incident ingestion of surface water	Ingestion of plant	Ingestion of animal product	Ingestion of fish	Ingestion of breast milk
Infant	✓	n/a	✓	✓	n/a	✓	✓	✓	✓
Toddler Pre-schooler	✓	n/a	✓	✓	n/a	✓	✓	✓	n/a
Child	✓	✓	✓	✓	✓	✓	✓	✓	n/a
Adult	✓	✓	✓	✓	✓	✓	✓	✓	n/a

In order to calculate CR, the average daily dose (ADD) from the exposure of each receptor is calculated by a formula modified by the Office of Solid Waste (U.S. EPA, 2005). Exposure is classified as either direct inhalation or indirect exposure (ingestion and dermal contact). The intake of COPCs into each human receptor through direct inhalation was calculated using COPC-specific air average concentrations taken from air quality model AERMOD (Lake Environment version 6.6.0) as shown in Table 4, as calculated by average the 10 values of maximum concentration of the year. All parameters substituted into the equations are shown in Table 4. Equation 1 presents the calculation procedure used to determine direct exposure through inhalation.

$$EC = \frac{C_a.EF.ED}{AT.365\ \text{days/year}}\ ;\ \mu g/m^3 \quad \text{------} \quad (1)$$

Where EC = Inhalation exposure concentration ($\mu g/m^3$)
Ca = Maximum annual average concentration (µg/m3)
EF = Exposure frequency (350 days/year)
ED = Exposure duration (year)
AT = Averaging time (days)

The highest annual average GLCs of As, Cd, Cr, Ni and CDD were obtained from an estimate based upon Air Quality Modeling: AERMOD (Lake Environment version 6.6.0). The highest annual average COPC concentrations in the soil were obtained from the AERMOD and a formulation by the U.S. EPA (Office of Solid Waste, 2005) as in Equation 2. Individual COPC concentrations in the soil were used to calculate the uptake of contaminants by soil ingestion and through dermal contact, and to estimate chemical concentrations in plant and animal products.

$$C_s = \frac{\frac{Ds.tD-Cs_{td}}{ks} + \frac{Cs_{tD}}{ks}.[1-\exp(-ks.(T_2-tD))]}{[T_2-T_1]} \quad \text{------} \quad (2)$$

Where
Cs = chemical concentration in soil (mg/kg)
Ds = deposition term (mg/kg-year)
ks = soil loss constant (per year)
tD = total time period over which deposition occurs (years)
Cs_{tD} = soil concentration at time tD (mg/kg)
T_2 = exposure duration (year)
T_1 = time at the beginning of emission (0 year)

The intake of COPCs into each human receptor through ingestion can be as shown in Table 3. Equation 3, which evaluates the total daily intake of COPCs via ingestion pathways (as described), is the summation of all the calculated indirect daily intake rates, and the cumulative ingestion exposure is the sum of the individual ingestion exposures through each of the individual ingestion routes (I_{total}), as I_{total} calculated fron the intake of food as shown in Table 3. Intake through ingestion (in units of milligrams per day) was used along with exposure frequency, ED, body weight and averaging of time to determine the total ingestion exposure in units of milligrams of COPC per kilogram of body weight per day (mg COPC/kg of body weight-day). The average daily ingestion dose ($ADD_{ingested}$) and indirect ingestion exposure concentrations can be calculated as follows:

Table 4. Maximum annual average concentration in Lamphun and Surat Thani ($\mu g/m^3$)

COPCs	Maximum annual average concentration	
	LP	SR
As	9.64E-05	1.20E-04
Cd	2.45E-04	3.05E-04
Cr	2.02E-04	2.49E-04
Ni	1.77E-04	1.98E-04
CDD	3.76E-08	4.68E-08

$$ADD_{ingested} = \frac{I_{total}.EF.ED}{BW.AT.365} \qquad \text{---------------} \quad (3)$$

Where

$ADD_{ingested}$ = The average daily ingestion dose (mg COPC/kg of BW-day)

I_{total}= Total ingestion exposure of COPC (mg/kg)

BW = Body weight (kg)

The final pathway is described in equation 4, which, in this study, is dermal exposure. Humans can be exposed to COPCs by absorption through the skin when it comes into contact with them. Daily intake of COPCs via dermal uptake from surface water was calculated for adults and children. Manual contact via dermal uptake from the soil was counted for three scenarios. Absorption through the skin in units of (mg/[kg of body weight]-day) was used along with the number of dermally absorbed doses per event (DAevent); event including swimming and accidental contact to soil, skin surface area, exposure frequency, ED, body weight and average time to determine the total ingestion exposure in units of milligrams of COPC per kilogram of body weight per day (mg COPC/[kg of body weight]-day). The parameters used to assess ingestion and dermal-exposure doses are shown in Table 5.

Table 5. All scenario-specific exposure parameters

Parameter	Infant	Toddler/ preschooler	Child	Adult	Reference
Body weight (kg)	7	10.48	24.18	68.83	SizeThailand[1]and U.S. EPA[2]
ED for direct/indirect pathways (yr)	1	5	9	15*, 30**	PCAPP[3]
Exposure frequency (day/yr)	350	350	350	350	U.S. EPA[2]
Exposure time (hr/day)	24	24	24	24	U.S. EPA[2]
Average life time for carcinogenic effects (yr)	75.3	75.3	75.3	75.3	World Bank[4]
Average time for carcinogenic effects of MSWI operation (yr)	30	30	30	30	U.S. EPA[2]
Ingestion rate:					
soil (kg/day)	0.0002	0.0002	0.0002	0.0001	U.S. EPA[2]
exposed fruit and vegetables (kg/day)	0.0138	0.0138	0.0342	0.0514	MOAC[5]
protected fruit and vegetables (kg/day)	0.0138	0.0138	0.0342	0.0514	MOAC[5]
below-ground vegetable (kg/day)	0.0138	0.0138	0.0342	0.0514	MOAC[5]
beef (kg/day)	0.0080	0.0080	0.0197	0.0247	MOAC[5]
pork (kg/day)	0.0080	0.0080	0.0197	0.0247	MOAC[5]
poultry (kg/day)	0.0080	0.0080	0.0197	0.0247	MOAC[5]
eggs (kg/day)	0.0189	0.0189	0.0478	0.0399	MOAC[5]
milk (kg/day)	0.0219	0.0219	0.0587	0.1310	MOAC[5]
fish (kg/day)	0.0125	0.0125	0.0444	0.0936	MOAC[5]
incidental surface water (ml/hr)	n/a	n/a	120	71	U.S. EPA[2]
skin surface area available for contact soil (cm^2)	2625	2625	4100	5700	U.S. EPA[2]
skin surface area available for contact water (cm^2)	n/a	n/a	8970	18000	U.S. EPA[2]

Note: *Residents exposed from birth
** Residents exposed during adulthood

[1] SizeThailand.org, 2017
[2] Office of Solid Waste, U.S. EPA, 2005
[3] Pueblo Chemical Agent-Destruction Pilot Plant, 2016
[4] World Bank, 2019
[5] Ministry of Agriculture and Cooperatives, 2011

$$ADD_{dermal} = \frac{DA_{event}.SA.EF.ED}{BW.AT.365} \quad \text{---------} \quad (4)$$

Where

ADD_{dermal} = The average daily ingestion dose (mg/kg-day)

DAevent = Dermally absorbed dose per event (mg/cm^2-event)

SA = Skin surface area (cm^2)

2.4 Risk Characterization

As shown in Table 1, this study considers two types of potential cancers, specifically those which affect the lungs and the skin.

The totality of lung cancer risk will be calculated in terms of the toxic metals targeting the lungs, namely, As, Cd, Cr and Ni, while As also affects the skin, and the dioxins impact all sites. Consequently, both of the latter two carcinogens will be considered in the calculation of cancer risk. The calculation of lifetime exposure via all possible pathways is shown in equations 4 and 5, of which the equation 5 is for cancer risk with the inhalation pathway, while the equation 6 is for the indirect pathway of dermal contact and ingestion. Total cancer risk from direct exposures was calculated as the sum of the direct exposure cancer risks for each individual COPC. Similarly, total cancer risk from indirect exposures was calculated as the sum of the indirect exposure cancer risks for each individual COPC. Total direct and indirect cancer risks were then summed to determine the overall cancer risk.

$$\text{Cancer risk}_{direct} = EC.IUR \quad \text{---------------} \quad (5)$$

where

EC = inhalation exposure concentration of chemicals (μg/m^3)

IUR = inhalation unit risk ([μg/m^3]$^{-1}$)

$$\text{Cancer risk}_{indirect} = ADD_{\text{ingested or dermal}} \cdot SF \quad \text{--} \quad (6)$$

where

ADD = indirect exposure to chemicals (via ingestion or dermal contact) (mg/kg of body weight-day)

SF= cancer slope factor (oral/dermal) for chemicals ([mg/kg of body weight-day]$^{-1}$)

3. Results and Discussion

3.1 Quantification of Multi-Exposures

3.1.1 Soil Concentrations of COPCs

Table 6 presents the individual COPC concentrations in the soil (mg/kg). The results showed that all of the COPCs soil concentrations in both areas did not exceed “soil-quality standards for living and agriculture” of the Thai Pollution Control Department (PCD, 2020), which might imply that the concentration of COPCs in the soil affected both contact and ingestion only incidentally, while the uptake to plant and animal life was very limited in extent.

3.1.2 Multi-Exposure to Receptors

The lifetime exposure was calculated as the most probable value, assuming the incinerator plant was operating for 8 hours per day, 365 days per year, for 30 years. The calculation was performed in equations 1-3, with results as shown in Table 7. This table lists concentrations for both direct and indirect exposure in two scenarios for each location, from which both values are then calculated and summed to equal the total cancer risk (using equations 4-5). Table 6 presents the major exposure concentration as inhalation in both scenarios, and as a result, it implies that the trend in the risk from all of the chemicals can increase, so that the risk becomes higher. The deposition terms of Ni and dioxins are not available, so that neither total indirect-exposure value occurred. Only the breast-milk intake of carcinogen exposure was found.

From a comparison of area, it was found that the exposure of COPCs in SR was higher than LP, since the GLC of the COPCs was higher. The direct exposures at each stage of life showed that people in the adult stage had the highest exposure, which was affected by the inhalation route. On the other hand, infants experienced their highest intake of COPCs via indirect exposure, i.e., though breast milk from their mothers. Infant exposure was also associated with the age levels of their mothers, since there were increasing dioxin levels for residents living near the incinerators (Reis *et al.,* 2007). In addition, the lower weights of the infants also resulted from the exposure values. The effect of indirect exposure on toddlers/pre-schools, children and adults varied with consumption rate, surface area and weight.

Table 6. Highest annual average soil concentrations (mg COPC/kg soil) of individual COPCs in each area

COPC	Highest annual average soil concentration		Standard (PCD, 2020)
	LP	SR	
As	5.50E-21	5.51E-21	3.9
Cd	1.14E-18	1.14E-18	37
Cr	5.95E-16	4.29E-16	300
Ni	n/a	n/a	1,600
CDD	n/a	n/a	n/a

Note: Values shown do not include background values.

Table 7. Calculated direct inhalation and indirect exposures to carcinogenic COPCs for all exposure scenarios

Area	COPC	Exposure	Resident exposure from birth					Resident exposed during adulthood
			Infant	Toddler/ pre-school	Child	Adult	Total	
LP	As	Direct inhalation exposure concentration (µ g COPC/m^3)	1.23E-06	6.14E-06	1.10E-05	1.84E-05	3.68E-05	3.68E-05
	Cd		3.12E-06	1.56E-05	2.81E-05	4.68E-05	9.36E-05	7.77E-05
	Cr		2.57E-06	1.29E-05	2.31E-05	3.86E-05	7.72E-05	6.40E-05
	Ni		5.63E-07	1.13E-05	1.58E-05	2.80E-05	5.57E-05	5.60E-05
	CDD		4.79E-10	2.39E-09	4.31E-09	7.18E-09	1.44E-08	1.44E-08
SR	As		1.53E-06	7.64E-06	1.37E-05	2.29E-05	4.58E-05	4.58E-05
	Cd		3.88E-06	1.94E-05	3.49E-05	5.82E-05	1.16E-04	9.67E-05
	Cr		3.17E-06	1.59E-05	2.85E-05	4.76E-05	9.52E-05	7.90E-05
	Ni		6.29E-07	1.26E-05	1.77E-05	3.13E-05	6.22E-05	6.27E-05
	CDD		5.96E-10	2.98E-09	5.36E-09	8.94E-09	1.79E-08	1.79E-08
LP	As	Total Indirect Exposure (mg COPC/kg body weight - day)	2.13E-08	2.02E-14	4.52E-15	5.51E-15	2.13E-08	1.10E-14
	Cd		7.63E-07	1.60E-13	3.02E-14	3.79E-14	7.63E-07	7.46E-14
	Cr		1.65E-06	5.67E-13	1.10E-13	1.35E-13	1.65E-06	1.52E-12
	Ni		5.50E-07	n/a	n/a	n/a	5.50E-07	n/a
	CDD		2.71E-11	n/a	n/a	n/a	2.71E-11	n/a
SR	As		2.65E-08	8.08E-14	1.82E-14	2.22E-14	2.65E-08	4.43E-14
	Cd		9.49E-07	4.41E-13	8.35E-14	1.05E-13	9.49E-07	2.06E-13
	Cr		2.85E-06	9.49E-13	1.84E-13	2.26E-13	2.85E-06	2.54E-12
	Ni		6.15E-07	n/a	n/a	n/a	6.15E-07	n/a
	CDD		3.38E-11	n/a	n/a	n/a	3.38E-11	n/a

3.2 Cancer Risk Asssessment

Total cancer risk from direct and indirect exposures was calculated as the sum of each direct and indirect cancer risk exposure for each individual COPC. Total direct and indirect cancer risks were then summed to determine the overall cancer risk. All stages of receptors were contributed a portion of the total risk to the cumulative lifetime subsistence risk. The type of cancer risk was defined by the target organ, as shown in Table 1. All scenarios showed the greatest cancer risk values. Cancers typically appear in lungs because of the fact that all COPCs can bring about lung cancer, according to the IARC (2019).

Table 8 showed the 5 COPCs contributing lifetime lung cancer risks to both receptors. The results showed that the CRs of the scenario of residents exposed from birth in LP and SR are 3.24E-06 and 4.41E-06, respectively, while the CRs of the scenario of residents exposed during adulthood in LP and SR are are 1.06E-06 and 1.30E-06, respectively. The lung-cancer risk value exceeded the reference level (E-06) defined by the U.S. EPA (1991). Cr contributed the greatest effect and over E-06 in the SR, where residents were exposed from birth. As found in the same as the study by Li *et al.* (2017), there were significantly high blood concentrations of Cr in the local residents, according to comparisons made in China. The CDD found a small contribution, which the study of Vilavert *et al.* (2012) showed is lower than the maximum recommended guidelines, while the dioxin concentrations showed a decreasing trend in plants, but were still the same in GLC. The values of CRs from direct exposure are also five-times higher than from indirect exposure for the scenario of exposure from birth and the continued effect of exposure by the breast-milk consumption of infants. These values are E + 07 times higher for the scenario of exposure during adulthood, for which the major pathway was inhalation. Thus, the air-monitioring program was important in order to conduct any future MSWI project. In the study of Rovira *et al.* (2015), a sampling of dioxins was found, which confirmed the fact that inhalation is a major route for the ingestion of dioxins.

Two COPCs, As and CDD, combined to contribute to the lifetime skin cancer risk to all receptors. The results in Table 7 showed that skin CRs of the scenario of the residents exposed from birth in the LP and SR are 1.90E-07 and 2.37E-07, respectively, while the CRs of the scenario of the residents exposed during adulthood in LP and SR are 1.58E-07 and 1.97E-07, respectively. In point of fact, none of the scenarios exceeded the reference level (E-06).

Results demonstrate that Cr in all areas might produce the greatest percentage of cancer risk from direct and indirect pathways with apoximately 50% in the scenario of exposure from birth and 70% in the scenario of exposure during adulthood, while the smallest percent of cancer risk for CDD was found with almost 0% when considering all scenarios. The reason might be that the deposition of CDD in the soil could not be calculated and would not lead to a direct exposure estimation. This explanation might be used for Ni, too. Although the presence of CDD in breast milk was estimated, the contribution to cancer risk was very small when compared with other exposure routes.

It is apparent that cancer risk for Cr and Cd exceeds the reference level (E-06) for the scenario of the residents exposed from birth, and for the total cancer risk of all scenarios, it exceeded the reference level. Cr had the greatest effect toward risk of cancer risk value in all senarios. Cd had the second greatest effect toward the total toward risk of cancer in main the scenario of exposure from birth, affecting infants who ingested breast milk from their mothers. Meanwhile, the study of Scungio *et al.* (2016) of heavy metals (As, Cd, Ni) and PCDD/Fs (polychlorinated dibenzodioxins/furans) released from MSWIs in Italy found that the lungs could be affected by those emissions at levels below the WHO target (E-05).

Table 8. Individual COPCs contribute to carcinogenic risk for all scenarios

Scenario		Carcinogenic risk of COPCs (dimensionless)							
		Exposure from birth				Adulthood			
		Direct exposure	Indirect exposure	Total	Percent of risk	Direct exposure	Indirect exposure	Total	Percent of risk
LP	As	1.58E-07	3.19E-08	1.90E-07	5.86	1.58E-07	1.65E-14	1.58E-07	14.92
	Cd	1.40E-07	1.14E-06	1.28E-06*	39.58	1.17E-07	1.12E-13	1.17E-07	10.98
	Cr	9.26E-07	8.27E-07	1.75E-06*	54.00	7.68E-07	7.59E-13	7.68E-07	72.39
	Ni	1.34E-08	0.00E+00	1.34E-08	0.41	1.34E-08	0.00E+00	1.34E-08	1.27
	CDD	4.74E-09	0.00E+00	4.74E-09	0.15	4.74E-09	0.00E+00	4.74E-09	0.45
	Total lung CR	1.24E-06	2.00E-06	3.25E-06*	-	1.06E-06	8.87E-13	1.06E-06*	-
	Total skin CR	1.53E-06	1.65E-14	1.95E-07*	-	1.31E-06	1.64E-12	1.63E-07	-
SR	As	1.97E-07	3.97E-08	2.37E-07	5.36	1.97E-07	6.65E-14	1.97E-07	15.04
	Cd	1.75E-07	1.42E-06	1.60E-06*	36.16	1.45E-07	3.10E-13	1.45E-07	11.07
	Cr	1.14E-06	1.42E-06	2.56E-06*	58.01	9.47E-07	1.27E-12	9.47E-07	72.30
	Ni	1.49E-08	0.00E+00	1.49E-08	0.34	1.50E-08	0.00E+00	1.50E-08	1.15
	CDD	5.90E-09	0.00E+00	5.90E-09	0.13	5.90E-09	0.00E+00	5.90E-09	0.45
	Total lung CR	1.53E-06	2.89E-06	4.42E-06*	-	1.31E-06	1.64E-12	1.31E-06	-
	Total skin CR	2.03E-07	3.97E-08	2.43E-07	-	2.03E-07	6.65E-14	2.03E-07	-

* Exceeds the reference level

Both CR of direct and indirect exposure were similar to each other as breastmilk could significantly effect to carcinogenic risk from oral exposure, in the scenario of exposure from birth. On the other hand, CR of direct exposure was higher than CR of indirect exposure, which can be described as inhalation was major route of exposure, in the scenario of exposure during adulthood.

In SR it was found that the cancer risk was higher than the LP values, possibly because SR is located near the Gulf of Thailand and the meteorological south of Thailand, where the climate is mostly rainy and windy. LP, by contrast, is located in the Northern Region of Thailand, where it is permeated with forest which is buffeted by the winds, while during the summer season there may be a lack of rain and occasional droughts. With these results, the geographical and meteorological conditions can both affect the existing risks (Nouwen *et al.,* 2001; Jose *et al.,* 2002). However, the study of Elliott *et al.* (1996) mentioned that risk as a function of distance from the MSWIs declined. In this current study, it was found that the distances from the MSWIs with the highest concentrations are 230 and 300 meters for LP and SR, respectively. As predicted, both skin and lung cancers exceeded the U.S. EPA reference level (E-06). In the study of Salerno *et al.* (2017), meanwhile, it was found that the MSWIs were located a few meters from the city and the agricultural areas, elevating the risk of total cancer in women. The level of cancer risk was found to be 4.34 times greater from the larger-size MSWIs in both areas. While the L size receives the input waste at the rate of 1000 tons per day, the M size receives only 231 tons per day, which is compatible with the study of Porta et al. (2009). There have been two investigations that are considered vital and need to be examined because of the approach taken and because of the large sizes of the landfills. The study of Goldberg *et al.* (1999) also found people related to one another that were living near MSW landfills, where they were at risk of cancer, including cancer of the lungs and skin. Because of these results, air-control devices should be considered, like, for example; Wet Scrubber, Electrostatic Precipitator, etc. (Vehlow, 2015) to decrease the concentrations of pollutants.

3.3 Risk Distribution Contour

From the results shown in Table 6, the risk distribution of carcinogenic substances was generated. People who were likely to have been exposed were those living near the MSWIs. The risk distribution for both pollutants shows higher levels in areas within a radius of approximately 0.30 and 0.41 km radius of the plants in LP and SR, respectively, as based on the meteorological data and geographic (terrain) data that was applied to the AERMOD. The value of total multi-chemical cancer risk can be plotted in terms of isopleths to explain the distribution of cancer risk in each area. SR has a lowland terrain with contours that are quite round and arranged in series. In LP, on the other hand, which has a mostly high-elevation, the contours are not ordered, and high-level areas could have a higher cancer risk. With these results, the geographical data can affect both risk results.

Figure 3 shows that the lung-cancer risk in LP covered an area of 1.13 km2 in the scenario of exposure from birth, while, on the other hand, the scenario of adulthood covered 1 km². Figure 4 shows that the lung-cancer risk (E-06) in SR covered an area of 0.88 km² in the scenario of exposure from birth, while, on the other hand, the scenario of adulthood covered 0.5 km². The results from meteorological and terrain data show that the excessive level of risk in LP covered a greater area than in SR. The nearest place to a MSWI in LP is the Ban Doi Kaew School (mark 1; 1.2 km from source), which is the location of a primary school with students aged 3-11 years, and the Mae Tha Wittayakhom School (mark 1; 2.6 km from source), which is a high school with students aged 12-18 years. Likewise, in the vicinity of a MSWI in SR (mark 1; 0.75 km from source), there is both a primary school and the Tha Rong Chang Hospital (mark 2; 3 km from source), which is the community hospital for that area.

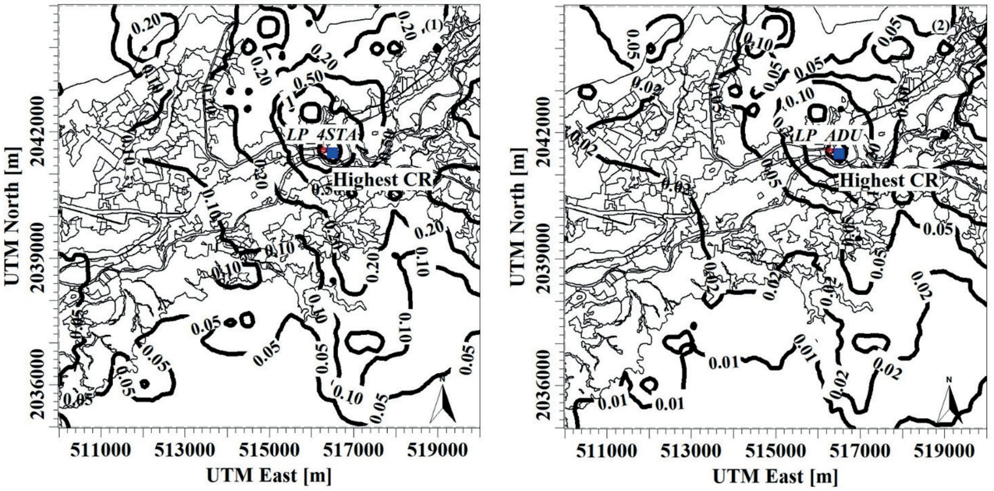


Figure 3. Lung cancer risk distribution of the multi-chemical emissions from the LP MSWIs: (1) from exposure at birth and (2) from adulthood (E-06).

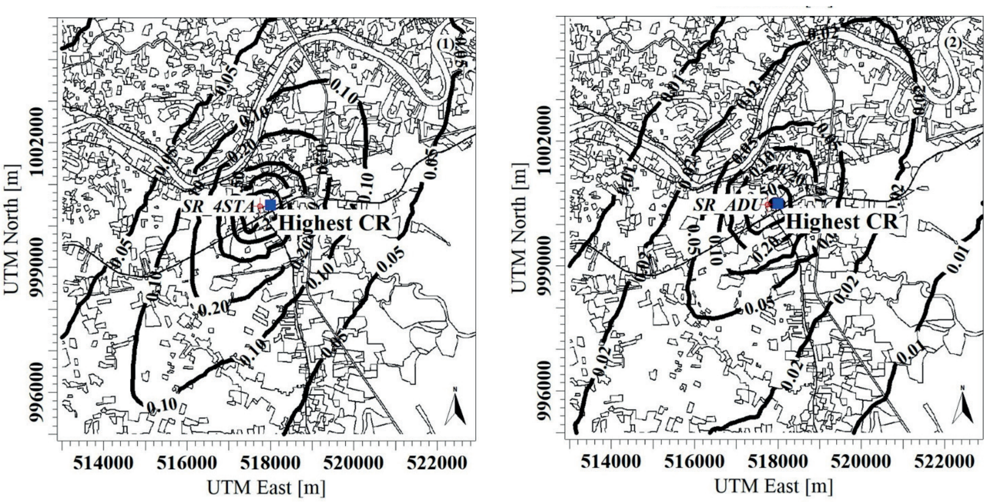


Figure 4. Lung cancer risk distribution of the multi-chemical emissions from the SR MSWIs: (1) from exposure at birth and (2) From adulthood (E-06).

4. Conclusion and Recommendation

From the human HRA, the CR results have been shown not to be acceptable (E-06) in all lung cancer risk scenarios and partial scenarios of skin cancer. The reason for this negative finding could be that only the worst-case scenarios were studied because of waste input, topography meteorology and site characteristics of both locations. The monitoring measure should be considered to observe the pollutant concentration for all COPCs. In addition, the CR values are a bit higher than the reference because the levels of Cr and Cd slightly high, so that, in view of the results obtained, a monitoring measure should be considered for the purpose of observing the pollutant concentrations. The health authorities should be surveillance in the vulnerable group including infants, and their mother, toddlers and pre-schools, and elderlies.

This study could be adopted for use as an HRA in Thailand for the development of projects designed to eliminate overflowing waste from MSWIs. Furthermore, the results from this study could provide a great deal of important information for decision makers, enabling them to develop policies to control the impacts of MSWIs. It is important to note that the larger-size MSWIs were found to have cancer risks that exceeded acceptable levels, while the smaller sizes had a less adversarial effect. Also, as based on the modeling input information, the coastal area of SR can be affected by GLC because of moisture, temperature and wind, so that the location of the MSWIs should be considered carefully in order to reduce the GLC to the extent possible.

On the basis of this study, projects can be started to develop future guidelines for the reduction of COPC concentration deposits along all routes, especially inhalation routes, the feeding of breast milk from mothers to infants and focusing on proper hygienic practices gleaned from the other pathways. For the purpose of future study, the fly and bottom ash should be calculated to estimate risk, because heavy metals in the ash can be deposited into the soil.

Limitation of this study could be the unit risk that used to calculate the cancer risk, basically used for adult, however this study assumed the same of unit risk for infant, toddler and pre-school, and child to estimate the risk in these stages. As the results, people living near the MSWIs may be at a higher risk of cancer due to other chemical exposures and other target organs not including in this study. In the further study, the non-carcinogenic COPCs could be applied in order to assess as long-term health effect for non-carcinogens.

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