Health Risk Assessment of Volatile Organic Compounds in a High Risk Group Surrounding Map Ta Phut Industrial Estate, Rayong Province

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Objective: *The health risks of a high-risk group, surrounding Map Ta Phut industrial estate, Rayong, which may be exposed to VOCs through inhalation of contaminated air and dermal contact of contaminated water were assessed.*
Material and Method: *The health risk was assessed for 19 subjects categorized as children, adult and elderly from Ban plong and Nong fab communities following the US Environmental Protection Agency (EPA) method. The VOC concentrations in ambient air and ground water were monitored by Pollution Control Department (PCD), Ministry of Natural Resources and Environment to represent average VOC exposure of subjects.*
Results: *The lifetime cancer risk of VOCs exposure from inhalation and dermal contact with ground water were $1.32x10^{-7}$-$5.21x10^{-6}$ for elderly, $1.18x10^{-7}$-$6.20x10^{-6}$ for adult and $8.93x10^{-7}$-$5.93x10^{-6}$ for children. For non-cancer risk, the hazard index was 0.44 for elderly, 0.38-0.42 for adult and 0.55 for children.*
Conclusion: *The lifetime cancer risk of the high-risk group living near Map Ta Phut industrial estate was in acceptable range for elderly, adult and children. For non-cancer risk, it is also acceptable.*

Keywords: *Ambient air, Groundwater, Health risk assessment, Volatile organic compounds*

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Volatile Organic Compounds (VOCs) are used in many production processes such as paint, dry cleaning solvent, petrochemical and oil refinery industries[1]. VOCs could be released from many sources such as petroleum refinery, fuel oil boiler, paint solvent, dry cleaning, biological processes and storage tanks[2]. The survey results of Thailand Environment Institute in 1999 from industries in Map Ta Phut industrial estate showed that the VOCs here mostly released from fuel combustion, incinerator, industries and storage tanks[3].

Map Ta Phut industrial estate is located in Map Ta Phut municipality, Rayong. It has 68 production industries such as gas separation, oil refinery, petrochemical, steel, plastic, fertilizer, power plants[4]. In 1997, students in the communities nearby the industrial estate complained about nuisance odor. They developed dizziness, sinusitis, sore throat and fatigue[5]. The monitoring of VOCs in ambient air in the community near Map Ta Phut Industrial estate found that the three average annual VOC concentrations, 1,3-butadiene, 1,2-Dichloroethane and benzene were above the Thai annual standard[6]. Due to air quality problems, health problems, ground water well contamination, VOC emissions affecting people's health, the government declared Map Ta Phut a pollution control area in 2009[7]. In the death report from Bureau of Policy and Strategy, Ministry of Public Health, the highest cause of death in Rayong was tumor at 54.83 cases per 100,000 population during January to September 2009. None of the studies identified the cause of tumor problems.

The present study aimed to assess health risk of the high-risk group living near the Map Ta Phut industrial estate. The subjects included children, working people and elderly who lived and worked nearby their homes and still used ground water for their everyday life.

Material and Method

The present study was a cross sectional study to assess health risk of the high risk group exposed to

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VOCs in contaminated air and ground water. The present study was reviewed and approved by the Ethics Committee on Human Rights Related to Human Experimentation, Mahidol University, under No. MUPH 2009-079.

Location of the study

Ban plong and Nong fab communities, Map Ta Phut district, Rayong, were selected because these two areas had high VOC concentrations in ambient air and some people here still used water from groundwater wells. Ban plong is located at 2 kilometer northeast of Map Ta Phut industrial estate. There were two groundwater wells and one air monitoring station of Pollution Control Department (PCD), Ministry of Natural Resources and Environment. Nong Fab is located 1 kilometer southwest of the industrial estate (Fig. 1). Nong Fab has one groundwater well and one air monitoring station of PCD. Rayong is close to the gulf of Thailand; the relative humidity is rather high about 77%. The average temperature is approximately 28°C.

Studied subjects

Subjects were recruited into the study following the inclusion criteria: males or females living and working in the community at least one year, using water from the ground water well for showering, washing and cleaning and participating in the present study with written informed consent. Nineteen subjects participated in this research: seven subjects from Ban plong community and twelve from Nong fab community.

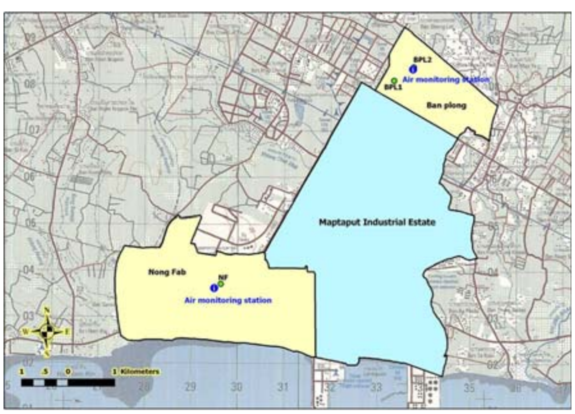

Fig. 1 The study area showing groundwater wells, ambient air monitoring stations in Ban plong and Nong fab, NF = Groundwater well in Nongfab, BPL1 = Groundwater well in Banplong No. 1 and BPL2 = Groundwater well in Banplong No. 2 community and Map Ta Phut industrial estate.

Those subjects could not afford to install piping for tap water in their areas. The rest of population has already used tap water for their everyday life. Most people in the communities had been working for the industries and they were not recruited into the study.

Data collection

All subjects were interviewed with questionnaire consisting of general characteristics, quantity and frequency of ground water used for their everyday life, and duration of stay in the community. The concentrations of VOCs in both ambient air and groundwater were obtained from the PCD. The VOCs in ambient air were measured monthly from September 2006 to June 2010 and the VOCs contaminated in ground water were collected 3 times per year from 2008 to 2009.

The 34 VOC concentrations in the ambient air were listed in Table 1. In addition, 15 VOCs contaminated in ground water were listed in Table 2.

Health risk assessment calculation

The health risk assessment was calculated following the US Environmental Protection Agency (US EPA)[8]. The cancer slope factors, reference doses, reference concentrations of those VOCs were taken from the US EPA[9]. Surface area (SA) of individual subjects was calculated using Du Bois model[10]. Out of 34 VOCs measured in ambient air, the number of cancer causing agent was 22 VOCs, namely: 1,1,2,2-tetrachloroethane, 1,1,2-trichloroethane, 1,1-dichloroethane, 1,2,4-trichlorobenzene, 1,2-dibromoethane, 1,2-dichloroethane, 1,2-dichloropropane, 1,4-dichlorobenzene, acrylonitrile, benzene, benzyl chloride, carbon tetrachloride, chlorobenzene, chloroform, chloromethane, cis-1,3-dichloropropene, ethyl benzene, hexachloro-1,3-butadiene, tetrachloroethylene, trans-1,3-dichloropropene, trichloroethylene and vinyl chloride monomer.

In addition, 8 out of 15 VOCs contaminants in groundwater may cause cancer to humans, which were 1,1,2-trichloroethane, 1,2-dichloroethane, benzene, carbon tetrachloride, ethyl benzene, tetrachloroethylene, trichloroethylene and vinyl chloride.

Cancer risk calculation

Cancer slope factor of each chemical was used for calculation of cancer risk; total risk was determined from summation of individual cancer risk both via inhalation and dermal contact. For health risk assessment, the lifetime cancer risk was estimated by using the equation below:

Cancer risk = Daily intake (mg/kg-day) x Cancer Slope Factors $(mg/kg\text{-}day)^{-1}$

For health risk assessment, individual body weight and exposure duration of each subject was used. The example of health risk assessment calculation for benzene exposure via inhalation and dermal contact regarding one subject was as follows:

Chronic daily intake: Inhalation

Benzene concentration in ambient air = 3.5×10^{-3} mg/m^3
Body Weight of subject = 78 kg
Average Time (AT) = 70 years (cancer risk) x 365days/years
Inhalation rate for adult (IR, m^3/day) = 20 m^3/day
Exposure duration of subject (ED, years) = 12 years
Exposure frequency (EF, day/year) = 365 days/year

$$\text{Intake (mg/kg-day)} = \frac{CA \times IR \times EF \times ED}{BW \times AT}$$

$$\text{Intake (Inhalation)} = \frac{3.5 \times 10^{-3}\ mg/m^3 \times 20\ m^3/day \times 365\ day/yr \times 12\ yr}{78\ kg \times 70\ yr \times 365\ day/yr}$$

Intake (Inhalation) $= 1.52 \times 10^{-4}$ mg/kg-day

Chronic daily intake: Dermal contact intake during showering

Benzene concentration in groundwater = 5×10^{-4} mg/L
Body weight of subject (BW) = 78 kg
Average time (AT) = 70 yr x 365 days/yr
Surface area (SA) = 18,786.93 cm^2
Exposure duration (ED, years) = 12 years
Exposure time (ET, hr/day) (showering) = 1 hr/day
Exposure frequency (EF, day/year) = 365 days/yr
Permeability constant (PC, cm/hr) = 0.11
Conversion factors (CF, L/cm^3) = 0.001

$$\text{Intake (Dermal contact)} = \frac{CW \times EF \times ED \times ET \times SA \times PC \times (L/1{,}000\ cm^3)}{BW \times AT}$$

Intake (Dermal contact)

$$= \frac{0.0005\ mg/L \times 365\ days/yr \times 12\ yr \times 1\ hr/day \times 18{,}786.93\ cm^2 \times 0.11\ cm/hr \times 0.001\ L/cm^3}{78\ kg \times 70\ yr \times 365\ days/yr}$$

Intake from dermal contact = 2.27×10^{-6} mg/kg-day

Therefore, chronic daily intake of benzene through inhalation and dermal absorption were 1.52×10^{-4} and 2.27×10^{-6} mg/kg-day, respectively. After that, the lifetime cancer risk was calculated by the following equation:

Cancer risk = Intake (mg/kg-day) x CSF of benzene
Cancer $risk_{inhalation}$ = 1.52×10^{-4} mg/kg-day x 7.80×10^{-9} $(mg/kg\text{-}day)^{-1}$
Cancer $risk_{inhalation}$ = 1.19×10^{-12}
Cancer $risk_{dermal\ absorption}$ = 2.27×10^{-6} mg/kg-day x 0.055 $(mg/kg\text{-}day)^{-1}$
Cancer $risk_{dermal\ absorption}$ = 1.25×10^{-7}
Lifetime cancer risk for benzene = SCancer risk of (Inhalation + Dermal contact)
= $1.19 \times 10^{-12} + 1.25 \times 10^{-7}$
Lifetime cancer risk for benzene = 1.25×10^{-7}

The lifetime cancer risk for inhalation exposure was calculated for 22 cancer-causing agents and dermal absorption was calculated for 8 cancer-causing agents. The total lifetime cancer risk was calculated by summing up the cancer risk for both inhalation and dermal absorption.

Non-cancer risk calculation

For non-cancer risk, hazard quotient was used. The impact of non-cancer health effect was determined as the hazard index (HI) which was the sum of all hazard quotients, as follows:

$$\text{Hazard quotient (HQ)} = \frac{\text{Daily intake}}{RfD}$$

Hazard index (HI) = HQ1 + HQ2 + … + HQi

The chronic daily intake of benzene through inhalation and dermal contact was calculated in the same way as cancer risk except that AT was equal to ED x 365 days/year, while ED was the exposure duration of each subject. The inhalation and dermal contact intake of benzene was 8.90×10^{-4} and 1.32×10^{-5} mg/kg/day, respectively. After that, the hazard quotient was calculated as follows:

$$\text{Hazard quotient} = \frac{\text{Intake}}{RfC}$$

$$\text{Hazard quotient}_{inhalation} = \frac{8.90 \times 10^{-4}\ mg/kg\text{-}day}{0.03\ mg/kg\text{-}day}$$

Hazard $quotient_{inhalation}$ = 2.97×10^{-2}

$$\text{Hazard quotient}_{dermal\ absorption} = \frac{\text{Intake}}{RfD} = \frac{1.32 \times 10^{-5}\ mg/kg\text{-}day}{0.004\ mg/kg\text{-}day}$$

Hazard $quotient_{dermal\ absorption}$ = 3.30×10^{-3}
Hazard index = ΣHazard quotient of (inhalation + dermal contact)
Hazard index = $2.97 \times 10^{-2} + 3.30 \times 10^{-3}$
Hazard index = 3.30×10^{-2}

The hazard $quotient_{inhalation}$ was calculated for 34 chemicals and the hazard $quotient_{dermal\ absorption}$ was calculated for 15 chemicals. The Hazard index was calculated by summing up the hazard quotient for all chemicals.

Results

Studied subjects

They can be categorized into three groups, 6 children, 10 adults and 3 elderly. Their age ranges were 4-11 years old for children, 16-48 years old for adult and 64-80 years old for elderly. Their occupations were 21.1% vendors, 31.6% temporary employees, 10.5% agriculturists, 36.8% studying (Students) and 15.8% staying at home (Elderly).

VOCs in ambient air

Most annual VOC concentrations collected in Ban plong and Nong fab station were lower than the ambient annual standard except for 1, 2-dichloroethane, 1, 3-butadiene and benzene (Table 1). The average benzene concentration at Ban plong was nearly two times higher than that at Nong fab. The average vinyl chloride concentration at Ban plong was four times higher than that at Nong fab.

VOCs contaminated in ground water

Groundwater was collected for three wells, namely Banplong 1, Banplong 2 and Nong fab; subjects used ground water for showering, washing and cleaning

Table 1. Average VOC concentrations during 2006-2010 at Ban plong and Nong fab station and Thai annual standard

No.	VOCs	Average VOCs concentrations (µg/m^3)		Thai annual standard (µg/m^3) (µg/m^3)
		Ban plong	Nong fab	
1	1,1,1-Trichloroethane	0.2591	0.3132	-
2	1,1,2,2-Tetrachloroethane	0.0252	0.2467	-
3	1,1,2-Trichloroethane	0.2189	0.5500	-
4	1,1-Dichloroethane	0.0885	0.0399	-
5	1,1-Dichloroethylene	0.0300	0.0300	-
6	1,2,4-Trichlorobenzene	0.4341	0.9471	-
7	1,2,4-Trimethylbenzene	2.3624	0.7635	-
8	1,2-Dibromoethane	0.0400	0.5083	-
9	1,2-Dichlorobenzene	0.4011	0.1128	-
10	1,2-Dichloroethane	0.8512**	0.7171**	0.40
11	1,2-Dichloropropane	0.2446	0.3198	4
12	1,3,5-Trimethylbenzene	0.6045	0.3782	-
13	1,3-Butadiene	0.4325**	0.3957**	0.33
14	1,4-Dichlorobenzene	0.1363	0.1510	-
15	Acrylonitrile	0.3767	0.4650	-
16	Benzene	3.4725**	1.8636**	1.70
17	Benzylchloride	0.0600	0.5366	-
18	Bromomethane	0.1819	0.2958	-
19	Carbontetrachloride	0.5376	0.5517	-
20	Chlorobenzene	0.2282	0.3236	-
21	Chloroform	0.2827	0.3724	0.43
22	Chloromethane	1.0125	1.2050	-
23	cis-1,3-Dichloropropene	0.0200	0.3888	-
24	Ethylbenzene	1.9542	0.9368	-
25	Hexachloro-1,3-butadiene	0.2000	0.1900	-
26	m-Xylene	2.7296	1.1465	-
27	o-Xylene	1.5439	0.6362	-
28	p-Xylene	1.5522	1.3345	-
29	Styrene	0.4164	0.4686	-
30	Tetrachloroethylene	0.2641	0.3519	200
31	Toluene	18.4532	6.4259	-
32	trans-1,3-Dichloropropene	0.1300	0.8667	-
33	Trichloroethylene	0.3354	0.2585	23
34	Vinylchloride	1.8293	0.4415	10

* one year Volatile Organic Compounds (VOCs) in ambient air of Notification of National Environmental Board No. 30, BE 2550 (2007) under the Enhancement and Conservation of National Environmental Quality Act BE 2535 (1992), published in the Royal Government Gazette No. 124 Part 143 dated September 14, BE 2550 (2007)
** The average VOCs above the Thai annual standard

in their daily life. Fifteen VOCs were measured and most of them were not detectable. The VOCs detected were benzene, ethyl benzene, toluene, styrene and trans-1, 2-dichloroethylene as shown in Table 2. The concentrations of VOCs in ground water in these two communities were very low.

Health risk assessment

The results of cancer risk estimation of subjects in Ban plong and Nong fab communities from inhalation exposure of VOCs in ambient air are presented in Table 3. The elderly had highest estimated cancer risk from inhalation of VOCs at 3.12×10^{-6}. The chemicals presenting high risks were 1,2,4-trichlorobenzene, benzyl chloride and chlorobenzene. Children at Nong fab had the lowest cancer risk at 5.00×10^{-18}. The average cancer risks from dermal contact with ground water are presented in Table 4. The risks presented for children,

Table 2. Average VOC concentrations in groundwater and groundwater quality standard

No.	VOCs	Average VOCs concentrations (μg/L)			Thai standard* (μg/L)
		Banplong 1	Banplong 2	Nong Fab	
1	1,1,1-Trichloroethane	<0.5	<0.5	<0.5	<200
2	1,1,2-Trichloroethane	<0.5	<0.5	<0.5	<5
3	1,1-Dichloroethylene	<0.5	<0.5	<0.5	<7
4	1,2-Dichloroethane	<0.5	<0.5	<0.5	<5
5	Benzene	<0.5	0.64	0.583	<5
6	Carbon tetrachloride	<0.5	<0.5	<0.5	<5
7	cis-1,2-Dichloroethylene	<0.5	<0.5	<0.5	<70
8	Ethyl benzene	1.333	0.66	<0.5	<700
9	Styrene	<0.5	0.96	0.583	<100
10	Tetrachloroethylene	<0.5	<0.5	<0.5	<5
11	Toluene	1.3	<0.5	<0.5	<1,000
12	Xylenes	<0.5	<0.5	<0.5	<10,000
13	trans-1,2-Dichloroethylene	<0.5	<0.5	0.667	<100
14	Trichloroethylene	<0.5	<0.5	<0.5	<5
15	Vinylchloride	<0.3	<0.3	<0.3	<2

* groundwater quality standards from Notification of the National Environmental Board No. 20, BE 2543 (2000), issued under the Enhancement & Conservation of National Environment Quality Act BE 2535 (1992), published in the Royal Government Gazette, Vol. 117 Special part 95 D, dated September 15, BE 2543 (2000)

adult and elderly were generally low. The chemicals presented higher risks were tetrachloroethylene, benzene, vinyl chloride and carbon tetrachloride.

The lifetime cancer risk of the high risk subjects from VOCs exposure via inhalation and dermal contact are presented in Table 5. The cancer risks from inhalation of VOCs were much higher than that from dermal contact. The cancer risk of adult at Nong fab (3.87×10^{-6}) was higher than that at Bang plong (9.28×10^{-7}).

The hazard index from inhaling VOCs in ambient air and contacting with groundwater during showering ranged from 0.38 to 0.55 (Table 6). Therefore, the non-cancer hazards of VOCs for chronic adverse effect from VOC exposure via dermal contact and inhalation in these two communities are acceptable.

Uncertainty

Concerning VOC concentrations in ground water below the detection limit, the present study used the detection limit of the method for calculation of the health risk, which may represent the worst-case scenario of this high-risk group. The VOC concentration in ambient air used the average VOC concentration of each chemical in the past five years to represent the VOC exposure of subjects. These parameters would add uncertainty into the analysis.

Discussion

This current study selected two communities, Ban plong and Nong fab on the northeast and southwest of the Map Ta Phut industrial estate. The Map Ta Phut industrial estate was close to the sea; the wind directions were influent by land and sea breeze during the day time and nighttime, respectively. The two communities were on the opposite sites of Map Ta Phut industrial estate. The subjects living and working in the community were recruited as a high-risk group; they had high potential exposure to VOCs in ambient air. They also used ground water from ground water wells in the community. The limited number of subjects was recruited because only 19 subjects were still using underground water wells in the two communities.

The average 34 VOC concentrations measured were generally lower than the Thai annual standard. The VOCs emission in Map Ta Phut industrial estate may come from a variety of sources, e.g. stack emissions, leakage from storage tanks, industrial and municipal wastes, which could not be controlled. It was observed that 1, 2-dichloroethane, 1, 3-butadiene and benzene were released from factories; 1, 2-dichloroethane was used in the synthesis of vinyl chloride monomer[12]. Benzyl chloride, acrylonitrile, 1, 2, 4-trimethylbenzene and 1, 3-butadiene were originated from industrial process[11,12]. The average

Table 3. Average cancer risk from inhalation of VOCs in ambient air in Nong Fab and Ban Plong communities

VOCs	Ban plong		Nong fab	
	Adult (n = 4)	Elderly (n = 3)	Children (n = 6)	Adult (n = 6)
1,1,2,2-Tetrachloroethane	1.56E-16	4.60E-16	1.12E-15	1.58E-15
1,1,2-Trichloroethane	3.50E-16	1.10E-15	6.89E-16	9.72E-16
1,1-Dichloroethane	1.52E-17	4.45E-17	5.00E-18	7.05E-18
1,2,4-Trichlorobenzene	1.67E-07	4.91E-07	2.67E-07	3.77E-07
1,2-Dibromoethane	2.57E-12	7.54E-12	2.39E-11	3.37E-11
1,2-Dichloroethane	2.37E-12	6.96E-12	1.46E-12	2.06E-12
1,2-Dichloropropane	8.61E-14	2.97E-13	8.42E-14	1.04E-13
1,4-Dichlorobenzene	5.27E-14	1.82E-13	4.37E-14	5.40E-14
Acrylonitrile	9.02E-13	3.11E-12	8.33E-13	1.03E-12
Benzene	9.54E-13	3.29E-12	3.83E-13	4.72E-13
Benzylchloride	3.59E-07	1.24E-06	2.40E-06	2.96E-06
Carbontetrachloride	2.84E-13	9.80E-13	2.20E-13	2.70E-13
Chlorobenzene	4.02E-07	1.39E-06	4.26E-07	5.26E-07
Chloroform	2.30E-13	7.90E-13	2.25E-13	2.78E-13
Chloromethane	6.42E-11	2.21E-10	5.71E-11	7.05E-11
cis-1,3-Dichloropropene	2.82E-15	9.72E-15	4.10E-14	5.05E-14
Ethyl benzene	1.72E-13	5.94E-13	6.12E-14	7.61E-14
Hexachloro-1,3-butadiene	1.55E-13	5.35E-13	1.10E-13	1.36E-13
Tetrachloroethylene	5.50E-14	1.89E-13	5.47E-14	6.74E-14
trans-1,3-Dichloropropene	1.83E-14	6.32E-14	9.13E-14	1.13E-13
Trichloroethylene	2.36E-14	8.15E-14	1.36E-14	1.68E-14
Vinylchloride	2.83E-13	9.80E-13	5.12E-14	6.31E-14
Estimated cancer risk	9.28E-07	3.12E-06	3.10E-06	3.87E-06
Range	1.52E-17 -4.02E-07	4.45E-17 -1.24E-06	5.00E-18 -2.40E-06	7.05E-18 -2.96E-06

Table 4. Average cancer risk from dermal contact of VOCs in ground water in Nong fab and Ban plong communities

VOCs	Ban plong		Nong fab	
	Adult (n = 4)	Elderly (n = 3)	Children (n = 6)	Adult (n = 6)
1,1,2-Trichloroethane	3.33E-09	4.89E-09	2.84E-09	2.52E-09
1,2-Dichloroethane	3.49E-09	5.13E-09	2.98E-09	2.63E-09
Benzene	5.96E-08	9.32E-08	5.50E-08	4.86E-08
Carbon tetrachloride	1.90E-08	2.79E-08	1.62E-08	1.43E-08
Ethylbenzene	1.13E-08	1.42E-08	4.20E-09	3.72E-09
Tetrachloroethylene	8.89E-08	1.30E-07	7.58E-08	6.70E-08
Trichloroethylene	1.43E-09	2.09E-09	1.22E-09	1.07E-09
Vinylchloride	2.21E-08	3.25E-08	1.89E-08	1.67E-08
Estimated cancer risk	2.09E-07	3.10E-07	1.77E-07	1.57E-07
Range	3.60E-08 -1.25E-07	3.57E-08 -2.53E-07	2.33E-08 -4.67E-07	2.13E-08 -4.96E-07

VOC concentrations at Ban plong and Nong fab were not much different except that benzene and vinyl chloride were considerably higher at Ban plong. Long-term exposure to benzene can result in aplastic anemia or leukemia. The vinyl chloride can cause primary brain cancer, lung cancer, lymphoma, and cancers of the blood and blood-forming organs[13]. The rate of tumor and cancer cases in Rayong increased from 444.3 cases to

Table 5. Average lifetime cancer risk from VOCs exposure via inhalation and dermal contact with ground water

Lifetime cancer risk of VOCs exposure	Ban plong		Nong fab	
	Adult (n = 4)	Elderly (n = 3)	Children (n = 6)	Adults (n = 6)
Cancer $risk_{inhalation}$	9.28E-07	3.12E-06	3.10E-06	3.87E-06
Cancer $risk_{dermal\ contact}$	2.09E-07	3.10E-07	1.77E-07	1.57E-07
Total cancer risk	1.14E-06	3.43E-06	3.27E-06	4.02E-06
Range	1.18E-07 -1.70E-06	1.32E-07 -5.21E-06	8.93E-07 -5.93E-06	7.64E-07 -6.20E-06

Table 6. Non cancer risk from VOCs exposure via inhalation and dermal contact with ground water

Non cancer risk of VOCs exposure	Ban plong		Nong fab	
	Adult (n = 4)	Elderly (n = 3)	Children (n = 6)	Adults (n = 6)
Hazard quotient $_{inhalation}$	3.71E-01	4.30E-01	5.31E-01	4.07E-01
Hazard quotient $_{dermalcontact}$	1.36E-02	1.01E-02	1.51E-02	9.10E-03
Hazard index	3.84E-01	4.40E-01	5.46E-01	4.16E-01
Range	2.86E-01 -4.91E-01	3.44E-01 -5.17E-01	2.66E-01 -7.30E-01	5.04E-02 -6.16E-01

1,263.5 cases in 100,000 populations from 1997 to 2005; it increased almost three times in 8 years[14]. The results also showed that the age-standardized incidence rate (ASR) for leukemia in Muang district was highest at 6.25 cases in 100,000 population when compared with other districts[14]. It was difficult to develop evidence to prove that leukemia cases could be caused by benzene exposure. Since May 3, 2009, The National Environmental board announced that the Map Ta Phut and communities nearby and some other areas are in the air pollutants control area according to the law.

The 5-year average concentration of VOCs (2006-2010) was used to calculate health risk assessment of the high-risk group living near Map Ta Phut industrial estate. Regarding VOCs exposure in ambient air, six children in Nong fab had an average cancer risk of $3.27x10^{-6}$; four children out of 1,000,000 were likely to develop cancer in their lifetime. Three elderly subjects participated in the present study; the oldest was 80 years old. The average lifetime cancer risk for elderly was $3.43x10^{-6}$; four elderly from 1,000,000 populations were likely to develop cancer. However, the lifetime cancer risk found in the current study was acceptable according to US EPA guideline; the acceptable risk ranged 10^{-4}-10^{-6}[8]. The chemicals presented high risks were 1, 2, 4-trichlorobenzene, benzyl chloride and chlorobenzene. It is interesting to note that Nong fab community had lower level of VOCs than the Bang plong community did, but the average excess cancer risk for adults at Nong fab ($3.87x10^{-6}$) was higher than those at Ban plong ($9.28x10^{-7}$). It is because the duration of exposure of adult at Nong fab was two times higher than that of adult at Ban plong. The duration of exposure to VOCs or the duration of stay in the area is the main predictor of estimated risk. Although the estimated risk is acceptable, these chemicals can cause cancer. The exposure of these chemicals should be kept at a minimum. Therefore, the reduction of VOC concentrations in the communities is really important. When comparing the results of the present study with other studies, the cancer risk in the current study was lower than the study of Ohura et al (2009)[15]. They found that cancer risk of 8 VOCs was $5x10^{-5}$ and $8x10^{-5}$ in summer and winter in an industrial harbor city, respectively.

The cancer risks from dermal contact with VOCs in ground water in these two communities were very low. The exposure to these cancer-causing agents should be limited to the minimum. The study of Fan et al found that the cancer risk of the use of contaminated ground water were a hundred times higher than the general risk guidance value because they used groundwater contaminated VOCs at 1 μg/L[16]. The VOCs contaminated in groundwater of this current study were lower or non-detectable for most VOCs. This implies that some VOCs contaminants in environments may be released from various factories, traffic conditions, households. However, the health effect of VOCs exposure greatly depended on toxicity of chemical, concentration of exposure, exposure duration, exposure frequency, individual susceptibility and subject behavior.

The average, lifetime cancer risk from VOCs exposure through both inhalation and dermal contact with ground water during showering showed that the highest risk was adult at Nong fab; four out of 1,000,000 people were likely to develop cancer in their lifetime. The excess cancer risks for children and adults were similar in the two communities. The children have shorter durations of exposure than adults; but children have lower body weight than adults. It is important that children in the communities be taken good care of because children may have more adverse health effect than adults. However, the cancer risk found in the high-risk groups is in the acceptable range. This could imply that the health risk of other groups would be in the acceptable range.

Since the Map Ta Phut industrial area and other areas nearby were the pollution control area, the National Environment Board appointed committees to formulate the action plan on pollution mitigation and elimination in Rayong area. This would include reduction of air and water pollution and industrial wastes, improvement of air and water quality, provision of health care, rehabilitation, community participation in the monitoring of air quality and future's area development.

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Potential conflicts of interest

None.

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การประเมินความเสี่ยงสุขภาพของประชาชนที่อาศัยใกล้นิคมอุตสาหกรรมมาบตาพุดจากการรับสัมผัสสารอินทรีย์ระเหยง่ายในอากาศและน้ำใต้ดิน

พรรณวดี สิงห์แก้ว, พรพิมล กองทิพย์, วิทยา อยู่สุข, สุทธินันท์ ฉันท์ธนกุล

วัตถุประสงค์: *ประเมินความเสี่ยงสุขภาพของกลุ่มคนที่มีความเสี่ยงสูงอาศัยอยู่ใกล้นิคมอุตสาหกรรมมาบตาพุด จังหวัดระยองจากการได้รับสัมผัสสารอินทรีย์ระเหยง่ายในบรรยากาศและน้ำใต้ดินที่ปนเปื้อน*

วัสดุและวิธีการ: *ความเสี่ยงต่อสุขภาพของกลุ่มตัวอย่าง 19 ราย จัดเป็น เด็ก ผู้ใหญ่และผู้สูงอายุจากชุมชนบ้านพลงและหนองแฟบจะประเมินตามวิธีการของ US Environmental Protection Agency ความเข้มข้นของสารอินทรีย์ระเหยง่ายในบรรยากาศและน้ำใต้ดินตรวจวัดโดยกรมควบคุมมลพิษ กระทรวงทรัพยากรธรรมชาติและสิ่งแวดล้อม เพื่อใช้ปีนค่าเฉลี่ยการรับสัมผัสสารอินทรีย์ระเหยง่ายของกลุ่มตัวอย่าง*

ผลการศึกษา: *ความเสี่ยงของการเกิดมะเร็งตลอดชีวิตของประชาชนจากการรับสัมผัสสารอินทรีย์ระเหยง่ายจากการหายใจและการสัมผัสทางผิวหนังของน้ำใต้ดินมีค่า* $1.32x10^{-7}$*-*$5.21x10^{-6}$ *สำหรับผู้สูงอายุ* $1.18x10^{-7}$*-*$6.20x10^{-6}$ *สำหรับผู้ใหญ่และ* $8.93x10^{-7}$*-*$5.93x10^{-6}$ *สำหรับเด็ก สำหรับความเสี่ยงที่ไม่ใช่การเกิดมะเร็ง ค่าดัชนีอันตรายเป็น 0.44 สำหรับผู้สูงอายุ 0.38-0.42 สำหรับผู้ใหญ่และ 0.55 สำหรับเด็ก*

สรุป: *ความเสี่ยงเฉลี่ยของการเกิดมะเร็งตลอดชีวิตของกลุ่มคนที่มีความเสี่ยงสูงอาศัยอยู่ใกล้นิคมอุตสาหกรรมมาบตาพุดอยู่ในระดับที่ยอมรับได้ทั้งผู้สูงอายุ ผู้ใหญ่และเด็ก สำหรับความเสี่ยงที่ไม่ใช่การเกิดมะเร็งอยู่ในเกณฑ์ที่ยอมรับได้เช่นเดียวกัน*