EXPOSURE TO VOLATILE ORGANIC COMPOUNDS AND HEALTH RISKS AMONG RESIDENTS IN AN AREA AFFECTED BY A PETROCHEMICAL COMPLEX IN RAYONG, THAILAND

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Abstract. In Thailand, there is a growing concern regarding the possible effects of air pollution on the health of residents living near a petrochemical complex in Map Ta Phut Industrial Estate (MTPIE), Rayong Province, Thailand. We studied exposure to selected volatile organic compounds (VOCs) in Map Ta Phut and the association between residing near the petrochemical complex and respiratory ailments. We carried out a population-based cross-sectional study, utilizing health data regarding respiratory problems among adults collected as part of a Health Effects of Air Pollution study of residents living in Map Ta Phut Municipality, Thailand, using a standardized questionnaire. The distance from the subject's residence to the center of the MTPIE was mapped using a geographical information system (GIS). A total of 15,441 adults aged ≥ 13 years who lived in Map Ta Phut Municipality for at least 1 year were included in the study. Multiple logistic regression models were used to examine the relationship between the distance between the subject's residence and the MTPIE and the presence of the respiratory problems during the previous 12 months. A 5 km distance was chosen as the maximum study radius. Volatile organic compounds were observed higher concentrations at sites downwind from the MTPIE, and closer to the MTPIE. Study subjects who lived closer to the MTPIE reported an odor more frequently than subjects who lived farther from the MTPIE. Living closer to the MTPIE was associated with more acute respiratory problems, but not more chronic respiratory problems than living farther from the MTPIE. Adults aged ≥ 40 years were more likely to have respiratory symptoms and eye irritation than those aged < 40 years. Females were more likely to have dyspnea, wheezing and upper respiratory symptoms than males. Living near the MTPIE for more than 5 years was associated with an increased risk of wheezing and upper respiratory symptoms.

Keyword: VOCs, exposure, health effects, residential proximity, Map Ta Phut, Thailand

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INTRODUCTION

The impact of the petrochemical industry on the environment is a major concern, particularly, the effects of toxic

chemicals released into the air, soil, and water. These chemicals can be hazardous to human health. Volatile organic compounds (VOCs) are an important class of air pollutants because they are ubiquitous and associated with increased long-term health problems (Walther and Crinion, 2000). Many VOCs, such as benzene, are suspected or known to be carcinogenic or neurotoxic in humans (IARC, 1982).

Exposure to VOCs can cause acute and chronic toxicity in humans. Common short-term health effects of VOC exposure includes eye, nose, throat, and skin irritation. Headaches, nausea, dizziness, fatigue and shortness of breath may occur (USEPA, 2007). Many VOCs produce negative health effects if humans are exposed to high concentrations. Long-term exposure to low concentrations VOCs at or above regulatory standards may result in liver and kidney damage, resulting in elevation of liver enzyme levels and changes in lipid metabolism (Wallace, 1991).

Map Ta Phut Industrial Estate (MTPIE), located in Rayong Province, is the largest petrochemical industrial complex in Thailand and is thought to be a major source of VOCs and other toxic chemicals released into the atmosphere. The MTPIE houses 60 petrochemical plants with a long term goal becoming a petrochemical hub for Southeast Asia. Over the past 20 years, the MTPIE has expanded beyond the original plan. Ambient air monitoring conducted by the Pollution Control Department (PCD) in 2007 indicated benzene, 1,3-butadiene and 1,2-dichoroethane exceeded the safety levels set by the World Health Organization. Since the establishment of the MTPIE accidental spillage of chemicals has occurred with profound acute health effects on the surrounding communities. Diseases of the respiratory system, nervous system, reproductive system, muscular system, mental disorders, and cancers have become much more frequent than the rest of the country in the surrounding communities (DIW, 2001). Urinary trans,trans-muconic acid (ttMA) measured by the Department of Diseases Control (DDC) among 2,177 residents from 25 communities surrounding the MTPIE during June-August 2007 found 329 residents had elevated levels of ttMA (DDC, 2008)

Further investigations into the hazardous effects on health caused by the MTPIE are needed. Therefore, the Public Health Faculty of Thammasat University, funded by the Thailand Research Fund, conducted a study of the Health Effects of Air Pollution (HEAP) among residents living in Map Ta Phut Municipality to determine the health problems related to VOCs and other air toxins among residents living near the MTPIE. This study is part of a large population based epidemiology study examining the health effects caused by the MTPIE in the surrounding communities.

We investigated whether residence proximity to MTPIE was associated with chronic respiratory or irritant health problems. We hypothesized that residents living closer to the MTPIE would have a higher risk of respiratory problems.

MATERIALS AND METHODS

Study site description

Map Ta Phut Municipality located in the Rayong Province, 200 km southeast of Bangkok, was the study site. Twenty years ago, Map Ta Phut Municipality was a small rural farming and fishing community. In 1978, the population of Map Ta Phut Municipality, an area of 14.1 km^2, was 8,434. In 2000, Map Ta Phut

Municipality had expanded to an area of 149 km^2. In 2001, Map Ta Phut Municipality again expanded to an area of 165 km^2. Presently, Map Ta Phut Municipality comprised of 25 communities around the MTPIE and has a registered population of 36,000 with an estimated non-registered population of over 100,000 outnumbering local residents (Greenpeace Southeast Asia, 2005).

There are three seasons in Map Ta Phut Municipality: hot season, rainy season, and cool season. Average temperatures range is 24-37°C. The highest mean rainfall is 267 mm during the month of September. The relative humidity ranges 60-95% (Pimpisut *et al*, 2005). The Map Ta Phut Municipality is affected by wind from the sea, which comes from the southwest and blows to the northeast at a medium speed of 6 ms^{-1}. The wind direction is from the south during February-May (hot season), and from the southwest during June-September (rainy season), and reverses direction from the northeast during October-January (cool season) (Pimpisut *et al*, 2005).The MTPIE is located to the south of most of the surrounding communities.

Study design and population

This study used the HEAP data set, collected during 2007-2008 by the Public Health Faculty of Thammasat University (Vichit-Vadakan *et al*, unpublished report). Information of 15,441 residents aged >13 years lived in Map Ta Phut Municipality for at least 1 year and ambient VOCs measured by the Pollution Control Department were used in our study.

The HEAP study was a population-based cross-sectional study of ambient airborne toxic chemicals originating from industrial sources as contributors to adverse health effects among populations living nearby (Vichit-Vadakan *et al*, 2009, unpublished report). The study focused primarily on five principle air pollutants: VOCs, particulate matter (PM_{10}) nitrogen dioxide (NO_2), sulfur dioxide (SO_2) and ozone (O_3). Estimated ambient air concentrations based on air dispersion models and residential proximity to the MTPIE were used as exposure indicators. The HEAP study was approved by the Thammasat University Ethical Review Board. The study population included permanent residents of Map Ta Phut who lived a 10 km radius of the MTPIE, numbering approximately 25,000 individuals. A total of 24,980 residents consented to participate in the HEAP (Vichit-Vadakan *et al*, 2009, unpublished report).

A questionnaire regarding general demographics and health status was filled out by each participant with a trained interviewer. The questionnaire asked about background information of the residents, including age, sex, occupational exposure (industrial worker), residential characteristics and the home environment, including indoor smoking. Information regarding potential sources of exposure to VOCs, such as use of pesticides, fertilizers, bug or insect spray and air fresheners, fueling gasoline, recent painting, and living within 500 m of potential sources of VOCs (gasoline station, busy road, automotive garage, dry cleaning facility, or furniture making shop), were also obtained. The questionnaire asked about acute and chronic respiratory problems, central nervous system (CNS) symptoms, and perception of chemical odors.

Respiratory problems and demographics

The chronic respiratory problems were defined as follows: 1) chronic cough as a "night cough for at least 3 months during the past year"; 2) chronic phlegm

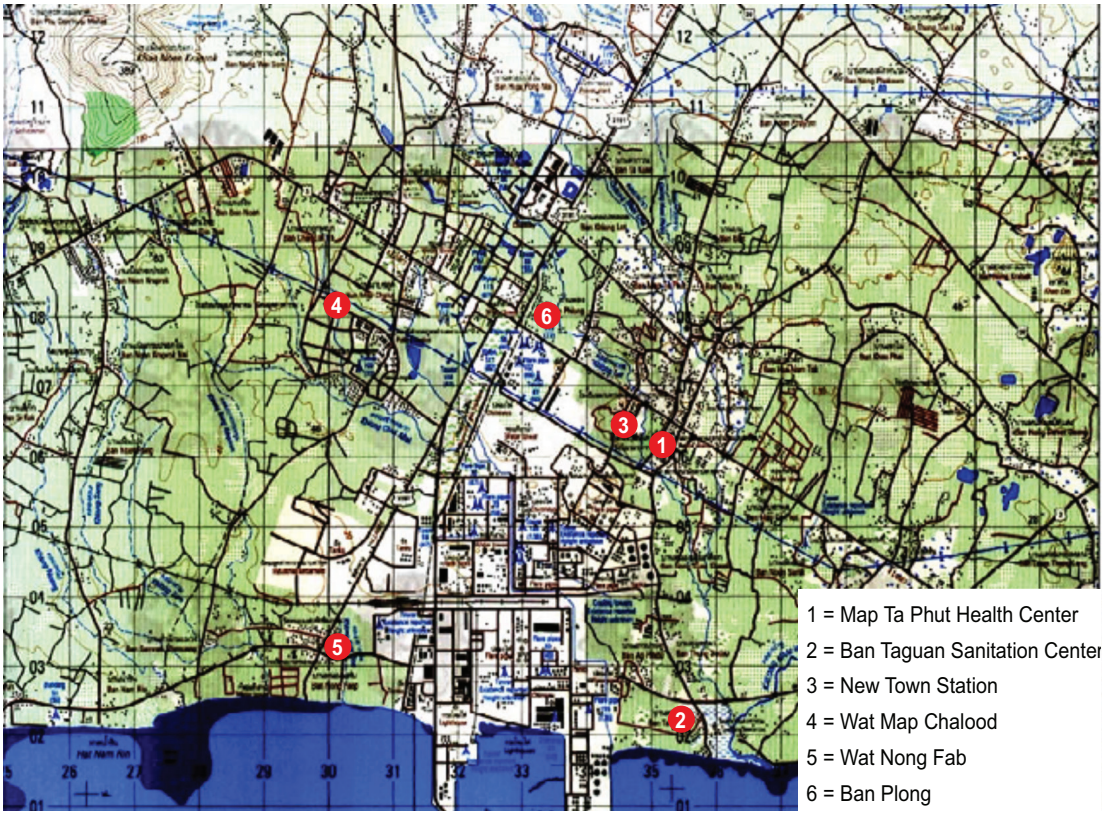

Fig 1–Location of sites for air quality monitoring in Map Ta Phut Municipality.

as a "phlegm for at least 3 month during the past year"; 3) chronic bronchitis as a "cough and/or phlegm on most days for 3 months or more out of the past year"; and 4) dyspnea as a "feeling of shortness of breath when walking at one's own pace on level ground". Acute respiratory symptoms included eye, throat and nose irritation, sore nose, sore throat, and chemical odor perception.

Ambient air VOCs

The VOCs concentrations were obtained from six ambient monitoring stations located around MTPIE (Map Ta Phut Health Center station (MHC), Wat Map Chalood station (MCL), Wat Nong Fab School station (WNF), Map Ta Phut New Town station (MNT), Ban Plong Community station (BPC), and Ban Taguan Sanitation Center station (BTG)). The Pollution Control Department (PCD) monitors 44 VOCs, NO_X SO_2, CO, and PM_{10} at these six sites in Map Ta Phut Municipality for 24 hours each month. Fig 1 shows the locations of the monitoring stations. Sampling was performed in accordance with United States Environmental Protection Agency (USEPA). Compendium Method TO-15 using 44-VOCs-mixed standard. The sampling schedule was random covering both weekdays and weekends. The PCD had adopted the USEPA quality assurance and quality control procedures for both sampling and analysis. The accuracy and validation of the data is maintained by

the use of National Institute of Standards and Technology (NIST) traceable calibration standards, the results are compared to other independent toxin monitoring methodologies.

Residential distance from the MTPIE

The proximity of residences to the MTPIE was used as a surrogate measure of VOC exposure. The addresses of all residences located within 10 km of the MTPIE were obtained. Geocoding of these addresses were first performed using geographic information system (GIS) software. Latitude and longitude coordinates were assigned to each residence in batch mode, and then the distance of each residence from the center of the MTPIE was calculated. Concentric rings of two radii around the MTPIE were drawn to classify the study population into two exposure groups. A 5 km cut-off point was chosen since our original results (Vichit-Vadakan *et al*, 2009, unpublished report) indicated the TVOC concentration estimated by air modeling within 5 km of the MTPIE was significantly higher than those further away (32.6+2.8 μg/m^3 *vs* 31.7+1.4 μg/m^3, $p < 0.05$) .

Data analysis

To describe over all 44 VOCs measured in Map Ta Phut Municipality during September 2006 - August 2007, means and standard deviations of concentrations, minimums and maximums for each VOC were computed. For each monitor, the measured concentrations of a compound were averaged so one value represented all the readings taken during the year. When VOCs concentrations fell below the detection limits of the monitor(s), a value of one-half the analytical detection limit was used to represent the concentration. The VOCs were classified into chemical families according to their chemical structure. The distributions of demographic characteristics of adults by residential proximity to the MTPIE were tested using chi-square tests for categorical variables, such as sex, smoking (yes/no), present smoking indoors (yes/no) and occupational exposure (yes/no) using a *t*-test for continuous variables such as age. The prevalence of respiratory health problems by residential distance to the MTPIE was analyzed by a chi-square test to assess the association of each variable. Logistic regression model was then fitted for each health outcome, and adjusted odds ratios and corresponding 95% confidence intervals were calculated. Potential confounding variables were obtained from the questionnaire: age, sex, smoking, presence of smoking indoors, length of time living at that residence, other environmental exposure within 500 m of the residence, such as garage, nearby dry cleaning facilities, nearby furniture maker shops, and nearby gasoline stations, nearby main roads, and prevailing wind direction. All statistical analyses were performed with SPSS for Windows Versions 15 (SPSS, Chicago, IL).

RESULTS

VOC concentrations in Map Ta Phut Municipality

The 44 VOCs identified were classified into chemical families: 11 aromatics or alkyl benzene, 4 freons, 5 halogenated hydrocarbons, 2 alkenes and 1 other. The sum of the VOC measured in the air sample is referred to as total VOC (TVOC). Aromatics constituted the largest group of VOCs found in Map Ta Phut Municipality, accounting for 67% (19.99 μg/m^3) of the VOCs found; while freon and halogenated hydrocarbons accounted for 16% (4.91 μg/m^3) and 15% (4.44 μg/m^3), respectively. The contribution of the

alkenes was approximately 2% (0.51µg/m^3). Thirty-four of the 44 VOCs detected in Map Ta Phut Municipality had annual average concentrations well below 1.0 µg/m^3 at all sites. Of the individual compounds, members of aromatic and freon families were the predominant VOC species at all six sampling sites. Toluene had the highest concentration of all the quantified compounds (10.21µg/m^3) and had a maximum average 24-hour concentration of 37.10 µg/m^3 in the MHC, followed by freon-12 (2.87 µg/m^3, range 2.68-3.08) and benzene (2.80 µg/m^3, range 1.63 - 4.04) (data not shown). The average concentrations of the other quantified aromatic compounds ranged from 0.21 µg/m^3 to 1.8 µg/m^3, while concentrations of the halogenated hydrocarbons, except chloromethane, were below 1 µg/m^3.

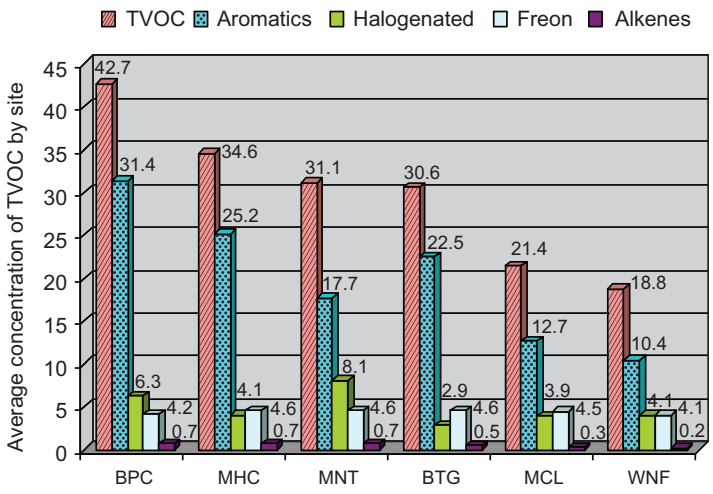

Fig 2–Average of concentration of VOCS (µg/m^3).

VOC concentrations at each site

Fig 2 shows the average concentration of the TVOC and each family of compounds at the six sites. The highest TVOC concentration was seen at BPC (42.7 µg/m^3), followed by MHC (34.5 µg/m^3), MNT (31.1 µg/m^3) and BTG (30.5 µg/m^3). The lowest TVOC was seen at MCL (21.4 µg/m^3) and WNF (18.8 µg/m^3). The aromatics constituted the largest group of VOCs at all the sites, accounting for over 50% of the total (Fig 2). Aromatic compounds at WNF, BMTPIE and MHC accounted for 70% of the total VOCs.

Of the individual compounds, toluene, benzene, and freon-12 were the most abundant compounds found in Map Ta Phut Municipality. Toluene, benzene and xylenes were found higher at monitoring sites located north of the MTPIE than at the other sites. During the study period, benzene, 1,3-butadiene and 1,2-dichloroethane exceeded WHO air quality standard for benzene (1.7 µg/m^3), 1,3-butadiene (0.33 µg/m^3) and 1,2-dichroloethane (0.04 µg/m^3) at monitoring sites north of the MTPIE, and a site close to the MTPIE (data not shown).

Association between selected respiratory symptoms and residence proximity to the MTPIE

Table 1 shows the demographic characteristics of subjects by residence proximity to the MTPIE. The characteristics of residents living within 5 km of the MTPIE significantly differed from those living greater than 5 km from the MTPIE, except for age. Table 2 shows the prevalence of selected respiratory symptoms by distance of residence from the MTPIE. All acute respiratory symptoms and perception of a chemical odor were significantly more frequent among residents living < 5 km from the MTPIE than among residents living

Table 1
Demographic characteristics of adults by residential proximity to the MTPIE.

Characteristics	Residential distance to the MTPIE	
	≤ 5 km	> 5 km
No. recruited	8,175	7,266
Age (yrs), mean (SD)	36.5 (14.5)	36.9 (15.04)
Sex (female %)	57.0[a]	58.55
Current smoker (%)	23.8[a]	19.85
Presence of indoor smoking (%)	41.5[a]	39.23
Length of residence at current address > 5 years (%)	65.2[a]	71.70
Occupational exposure (%)	38.2[a]	42.17

[a] p-value <0.05

Table 2
Prevalence of adverse respiratory outcomes, unadjusted and adjusted odds ratio (OR) with 95% confident interval (95% CI) for residents living within 5 km of the MTPIE.

Respiratory outcomes	Prevalence (%)			Unadjusted			Adjusted[b]		
	Total	< 5 km	> 5 km	OR	95% CI		OR	95% CI	
Chronic respiratory symptom									
Chronic cough	1.5	1.7	1.3	1.30	0.98	1.67	1.35	1.00	1.82
Chronic phlegm	2.5	2.6	2.3	1.20	0.94	1.43	1.26	1.00	1.59
Dyspnea	24.7	25.2	24.2	1.10	0.88	1.46	0.99	0.91	1.08
Wheezing	3.4	3.3	3.5	1.10	0.98	1.14	0.94	0.77	1.15
Chronic bronchitis	1.6	1.7	1.5	0.90	0.79	1.13	1.23	0.93	1.64
Respiratory symptom									
Lower respiratory	26.4	26.7	26.1	1.04	0.97	1.12	0.98	0.90	1.06
Upper respiratory	21.5	20.6	22.6	0.89[a]	0.82	0.96	0.97	0.89	1.06
Acute respiratory symptom									
Eye irritation	16.9	19.5	14.0	1.49[a]	1.36	1.62	1.59[a]	1.45	1.76
Nose irritation	2.9	3.3	2.4	1.38[a]	1.14	1.68	1.48[a]	1.19	1.84
Sore nose	2.4	2.8	1.9	1.52[a]	1.22	1.88	1.62[a]	1.27	2.05
Throat irritation	2.1	2.5	1.6	1.61[a]	1.28	2.03	1.65[a]	1.28	2.13
Sore throat	2.0	2.4	1.5	1.58[a]	1.25	2.01	1.65[a]	1.27	2.15
Chemical odor perception	16.2	21.7	9.9	2.52[a]	2.29	2.77	2.59[a]	2.33	2.87

[a] p<0.05
[b] OR adjusted for the effects of age, gender, current smoking, presence of indoor smoking, occupational exposure, length of residence, and potential sources of exposure, such as burning, filling a tank with gasoline, recent painting, having an attached garage, nearby dry cleaning facility, gasoline station, furniture making shop or living near a main road.

> 5 km from the MTPIE, except for upper respiratory symptoms were reported less often among residents who lived within 5 km of the MTPIE. Other symptoms had no significant association with proximity to the MTPIE.

Since the prevalence of respiratory symptoms may be associated with indoor characteristics and other potential environmental exposures, multiple logistic regression models were next applied to examine the association between the prevalence of selected respiratory symptoms and distance from the MTPIE (Table 2). The odd ratios were adjusted for age, gender, current smoking, presence of indoor smoking, occupational exposure, length of residence, and potential sources of exposures, such as burning, filling a tank with gasoline, recent painting, having an attached garage, having a nearby dry cleaning facility, gasoline station, furniture making factory or living near a main road. Having controlled for these potential confounding factors, upper respiratory, as well as chronic respiratory symptoms had no association with distances, but acute respiratory symptoms had a positive association with living within 5 km of the MTPIE. The increased risks for having these adverse respiratory outcomes among adults living within 5 km from the MTPIE compared to those living farther away were: 1.6 for eye irritation (95% CI 1.45- 1.76), 1.5 for nose irritation (95% CI 1.19- 1.84), 1.6 for throat irritation (95% CI 1.27-2.05), 1.7 for sore throat (95% CI 1.28-2.13), and 1.7 for sore nose (95% CI 1.27-2.15). Chronic cough and chronic phlegm were more common among residents living within 5 km of the MTPIE than those living farther away, although there were not significant (p=0.052 and p=0.061, respectively). Residents living < 5 km from the MTPIE reported smelling a bad odor outdoors 2.6-time more often than those living > 5 km from the MTPIE (95% CI 2.33- 2.87).

Logistic regression models revealed residents who lived in Map Ta Phut Municipality longer than 5 years had an increased risk of wheezing (OR 1.25; 95%CI 1.01-1.56) and upper respiratory symptoms (OR 1.24; 95%CI 1.12-1.36) (data not shown). The models also showed residents aged > 40 years had an increased risk for all chronic respiratory symptoms, including chronic cough (OR 1.03; 95%CI 1.02-1.04), chronic phlegm (OR 1.47; 95%CI 1.18-1.84), wheezing (OR 1.51; 95%CI 1.25-1.82), dyspnea (OR 1.51; 95%CI 1.39-1.63), chronic bronchitis (OR 2.19; 95%CI 1.67-2.86), lower respiratory tract symptoms (OR 1.54; 95%CI 1.42-1.67), and eye irritation (OR 1.64; 95%CI 1.25-1.57). Females had a significantly higher risk of having dyspnea (OR 1.30; 95%CI 1.03-1.65), wheezing (OR 1.30; 95%CI 1.03-1.65), lower respiratory symptoms (OR 1.85; 95%CI 1.68-2.04), upper respiratory symptoms (OR 1.20; 95%CI 1.09-1.33), eye irritation (OR 1.40; 95%CI 1.25-1.57), nose irritation (OR 1.44; 95%CI 1.13-1.85), and a sore nose (OR 1.56; 95%CI 1.18-2.06) compared to males in logistic models. Living downwind from the MTPIE had a negative association with dyspnea and lower respiratory symptoms, and no association with other respiratory problems. The model revealed smoking was positively associated with dyspnea, wheezing, lower and upper respiratory symptoms. The presence of smoking indoors was associated with an increased risk of having dyspnea and lower respiratory symptoms. The model also showed other sources of exposure were associated with respiratory symptoms. For example, living near a furniture making shop increased the risk of chronic

phlegm, upper and lower respiratory symptoms; use of pesticides increased the risk of chronic phlegm, chronic bronchitis, wheezing, and upper respiratory symptoms.

DISCUSSION

In the present study, the average concentration of TVOC was 29.9 μg/m^3 and the range was 18.8-42.7 μg/m^3 (the greatest concentration was north of the MTPIE and the lowest concentration was west of the MTPIE). Aromatics constituted the largest group of VOCs, accounting for 67% of the total amount of quantified VOCs (TVOC). When the concentration of each family of VOCs was compared at the six sites, all families of VOCs were at a higher concentration north of the MTPIE, except freon; wind direction could be the reason for this finding. Apart from the sea breeze during the day time, in Map Ta Phut Municipality the wind blows mostly from the southwest. It is possible the emissions are carried toward the community to the north of Map Ta Phut Municipality. High concentrations of TVOC and all families of VOCs were also observed to the west of the MTPIE (site BTG); this may be because this site is closest to (less than 1 km) a plastic manufacturing site that produces polycarbonate and ABS.

Toluene, benzene and xylenes were found in higher concentrations north of the MTPIE consistent with the findings reported by Pimpisut *et al* (2006), where toluene and benzene were found at higher concentrations downwind. Petrochemical industries and refineries were identified as the main BTEX sources in Map Ta Phut Municipality. Although the annual average concentrations of most of the compounds were found at lower concentrations around the MTPIE, benzene, 1,3-butadiene and 1,2-dichloroethane exceeded the WHO 24-hour air quality standard recommendations (Thepanondth *et al*, 2008) at sites north and closest to the MTPIE, suggesting residents living in these areas are at greater risk of exposure to the VOCs.

Studies of long-term exposure to air pollution suggest an increased risk of respiratory illness (Hertel *et al*, 2001). Previous studies conducted in Map Ta Phut Municipality suggest the health of these residents may be adversely impacted by exposure to such toxins. For example, an excess risk of respiratory diseases was found among residents near the MTPIE in a study conducted by Jadsri *et al*, (2006). The present study failed to find significant relationships between chronic respiratory symptoms and residential proximity to the MTPIE. However, chronic cough and chronic phlegm in the present study were more common among residents living within 5 km of the MTPIE, although not significant. The results do show an increased in rate of irritation associated with residential proximity to the MTPIE. A study conducted in northeastern England showed persons with asthma living closest to air pollution sources had an average of 12 asthma attacks during the previous 12 months (Bhopa *et al*, 1998). Ware *et al* (1993) found patients with physician-diagnosed asthma and chronic lower respiratory symptoms were more likely to have been exposed to VOCs of industrial origin. The results support our hypothesis that residents living closer to the MTPIE would have more respiratory problems. A bad odor was reported more often by residents living < 5 km from the MTPIE. This suggests residents living closer to the MTPIE are being exposed to greater concentrations of VOCs. However, there was no evidence of increased

risk associated with living downwind from the MTPIE. Dyspnea and lower respiratory symptoms were negatively associated with living downwind from the MTPIE. This may be due to possible bias resulting from unmeasured exposures related to living downwind from the MTPIE.

The results show those who lived longer than 5 years near the MTPIE had an increased risk for dyspnea and wheezing. Older adults (> 40 years) were more affected by chronic respiratory problems, lower respiratory symptoms, and eye irritation. We also found women had a higher risk of acute and chronic respiratory symptoms than men. An explanation for this finding may be women spent most their time at home, since most of them are housewives, while men were away during the day at their jobs, resulting in an increased exposure among women. These findings suggest those exposed for longer periods of time were more likely to develop respiratory diseases, and suggests older adults may be most susceptible to these effects (Balmes, 2002).

This study had a number of limitations. VOCs were not monitored in some areas. The information regarding respiratory symptoms was self-reported and subject to recall bias. Residents may have interpreted questions differently. Distance from the MTPIE was used as an indicator for environmental exposure. A major drawback of this approach is incorrect characterization of air pollution exposure, raising concerns for measurement error and incorrect risk estimates. This was a cross-sectional study, limited by the fact it was carried out at one point in time, giving no indication of sequence of events – whether exposure occurred before, during or after symptoms occurred, making impossible to infer causality.

In conclusion, industrial emissions are a main source of air pollution in Map Ta Phut Municipality. Low level of VOCs might not have a significant health impact, but interactions between VOCs species and other pollutants could cause adverse health outcomes. The results suggest a need for environmental policies to reduce industrial pollution and resident exposure. Some residents may be disproportionally exposed to higher levels of air pollution since respiratory symptoms were more common among residents living closer to the MTPIE. Future research in Map Ta Phut Municipality should consider evaluating how emissions are distributed and how they affect the community. Special attention should be given to communities located in the north and northeast of the MTPIE. Further investigations regarding health effects of lifelong exposure to air pollutants are recommended.

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