Health Risk Assessment of Industrial Emissions in Map Ta Phut, Thailand using AERMOD Modeling and GIS

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Abstract
A health risk assessment of air emissions from Map Ta Phut industrial complex in Thailand was carried out. Two gaseous pollutants, NO_2 and SO_2, were assessed for non-carcinogenic health risk using the Hazard Quotient (HQ) and Hazard Index (HI). Both short-term and long-term health effects were evaluated. Air dispersion modeling (AERMOD) was used to predict the ground level concentration within 5 km radius of the emission sources. The risk areas were identified by HI and the impact sites were illustrated by Geographic Information System (GIS). Resulting from the GIS based map, the impact areas were different between wet and dry seasons. In the long term annual average, both NO_2 and SO_2 significantly have health impact in the studied areas, HI > 1.

1. Introduction

The Map Ta Phut Industrial Estate (MTPIE) at the eastern seaboard region of Thailand is the largest industrial complex in Thailand, located at 12°30′N and 101°35′E, in the Map Ta Phut Municipality, Rayong Province. It was established in 1989 and initially consisted of four major categories of industry, namely gas separation plants, petrochemical plants, fertilizer plants and soda ash plants. The industrial area covers more than 10 square kilometers with 52 large-scale industrial plants, out of which, 32 factories are petroleum-related industry (http://www.mtpie.com). The Map Ta Phut Municipality, total area of 165.575 km^2, was comprised of 38 communities around the MTPIE and has a registered population of 53,901 (http://www.mtp.go.th). There were several reports on air pollution exposure and health effects in Map Ta Phut (Tanyanont and Vichit-Vadakan, 2012, Chantanakul et al., 2013 and Thepanondh and Toruksa, 2011). The epidemiological studies showed statistical associations between levels of air pollution and respiratory disorders of residents in the petrochemical complex areas. Living near the MTPIE was associated with an increased risk of wheezing and upper respiratory symptoms (Tanyanont and Vichit-Vadakan, 2012 and Chantanakul et al., 2013). The health impact of air pollution from industrial emissions has been of increasing concern, particularly among the residents living near sources. The industrial combustion has been known to emit various pollutants such as SOx, NOx, CO_2, dioxins, acid vapor and heavy metals (Davis et al., 1998). In this work, we focused on two primary pollutants, NO_2 and SO_2, because of their potential health effects (WHO, 2006). NOx was emitted from combustion processes in which both mobile and point sources were major emission sources (Davis et al., 1998). Most atmospheric NO_2 is initially emitted as NO, which is rapidly oxidized to NO_2. Regular exposure to NO_2 might cause an increased incidence of acute respiratory illness in children and other sensitive groups (WHO, 2006). The current WHO guideline value of 40 $\mu g/m^3$ (annual mean) and 400 $\mu g/m^3$ (1 hr mean) were set to protect the public from the health effects of gaseous NO_2. The short term exposure to SO_2 can effect lung function and the respiratory system including reduction in the mean forced expiratory volume over one second (FEV1), increases in specific airway resistance, and symptoms such as wheezing or shortness of breath. The WHO guideline value for SO_2 daily average was 125$\mu g/m^3$and an annual mean was 50 $\mu g/m^3$ (WHO, 2006). In this study, AERMOD was used as a tool to predict ground level concentrations of NO_2 and SO_2 for Health Risk Assessment (HRA) in an industrial complex. This aimed to identify the hazard risk areas among receptor sites near industrial sources. Both short-term and long-term health effects were expressed as Hazard Quotient (HQ) and Hazard Index (HI).The risk areas were identified by different HI and the impact sites were illustrated by Geographic Information System (GIS) based maps.

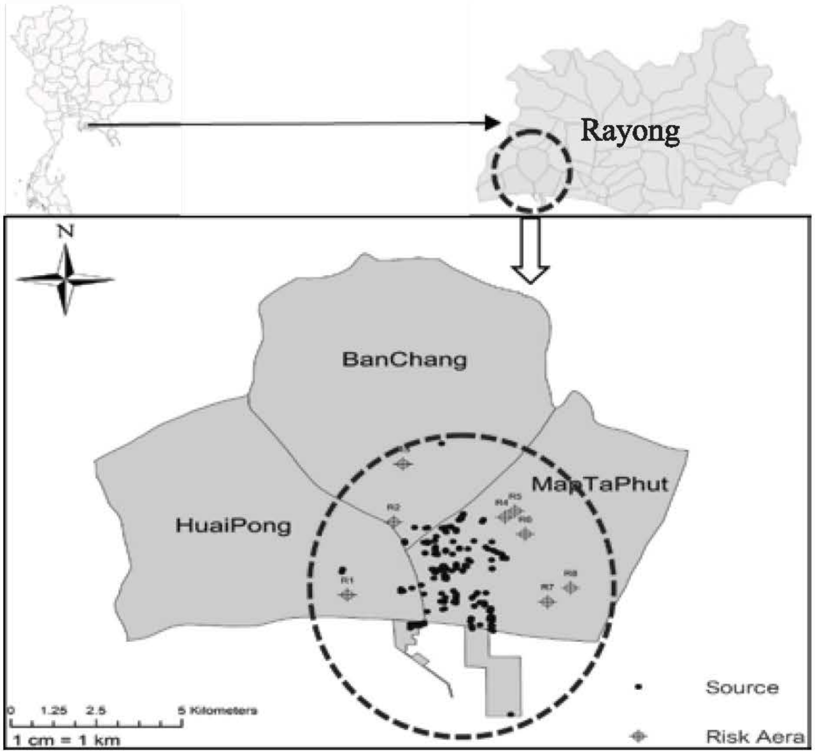


Figure1: The impacted areas: Banchang, HuaiPong and Map Ta Phut including eight communities R1-R8, ○ and 243 stack emission sources ●

2. Methodology

2.1 Study Sites

The study was conducted in three districts of Rayong province: Banchang, Huaipong and Map Ta Phut. The areas covered 243 stacks MTPIE emission sources and eight impact communities (R1-R8) within 5 km around the industrial complex. R1-R8 risk areas are school, temple, hospital and government offices, namely, R1 Wat Nong Fap School, R2 Map Chalut temple, R3 Field crops research center, R4 Muang Mai Maptaphut, R5 Chumchon Islam, R6 Health Promotion hospital, R7 Ban Takuan Public health center and R8Takuan temple. The details of studied sites were shown in Figure 1.

2.2 Air Dispersion Modeling

The American Meteorological Society - Environmental Protection Agency Regulatory Model (AERMOD) modeling system used in this study was run with a commercial interface, AERMOD View (Version 8.8.9) (Lakes Environmental Software). The steps involved in AERMOD modeling are shown in Figure 2. The required meteorological data for AERMOD including wind direction, wind speed, ceiling height, total cloud cover, direct normal radiation and relative humidity were also purchased from Lakes Environmental Software. The input data, emission inventory from 243 stacks in MTPIE, were provided by the Office of Natural Resources, Environmental Policy and Planning (ONEP), under the Ministry of Natural Resources and Environment of Thailand.

$$C(x,y,z) = \frac{Q}{u} P_y\{y;x\} P_z\{z;x\}$$

Equation 1

AERMOD is based on the steady state Gaussian dispersion equation. If the ground is taken to be the reference height (*z=0*), with the *x* axis of the co-ordinate system aligned along the wind direction at the source, empirical evidence indicates that the time averaged (typically one hour) concentration field can be described in terms of the Gaussian distribution. In this study, the pollutants ground level concentrations were generated from AERMOD by equation 1. Where: Q is the source emission rate, u is the effective wind speed, P_y and P_z are the probability density function (pdf) for the lateral and vertical concentration distributions, respectively.

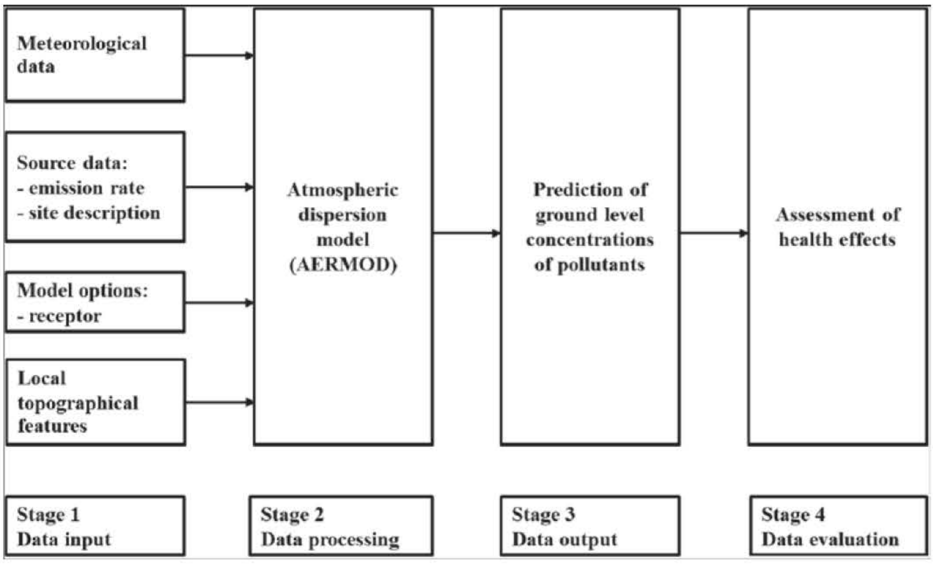


Figure 2: Flow in AERMOD modeling system

2.3 Geographic Information Systems

The Geographic Information System (GIS) has been used as a tool for hazard area identification. In this study, air pollution distribution and risk areas were mapped to compare short term and long term exposure risk areas. To measure distances, a geodesic calculator was used to convert Bath-Geo WGS84 projection coordinates (longitude/latitude) into the Universal Transverse Mercator (UTM) Zone 47(47N). Spatial data of stack's co-ordinates, predicted air pollution values from AERMOD, Exposure Concentration and HI were prepared in spread sheet before upload in the GIS map using ARCGIS 10.2. The ordinary kriging running mode was selected for self-maps illustration.

2.4 Health Risk Assessment (HRA)

Inhalation Exposure Concentration (EC_{inh}) was quantified as described in equation 2.

$$EC_{inh} = C \times ET \times EF \times ED / AT$$

Equation 2

Where: C: concentration of each pollutants, NO_2 and SO_2 ($\mu g/m^3$), were predicted from AERMOD; ET: exposure time (24 hours/day); EF: exposure frequency (350 day/year); ED: exposure duration (30 years); AT: average time (for non-carcinogens, AT = ED in years × 365 days × 24 hours/day; for carcinogens, AT= 70 years × 365 days × 24 hours/day). For non-carcinogenic health risk due to inhalation, risk characterization was performed by quantifying the hazard using the Hazard Quotient (HQ) equation (3) which was defined following the USEPA method (US EPA, 2009);

$$HQ = EC / RfC$$

Equation 3

$$HI = \sum HQ$$

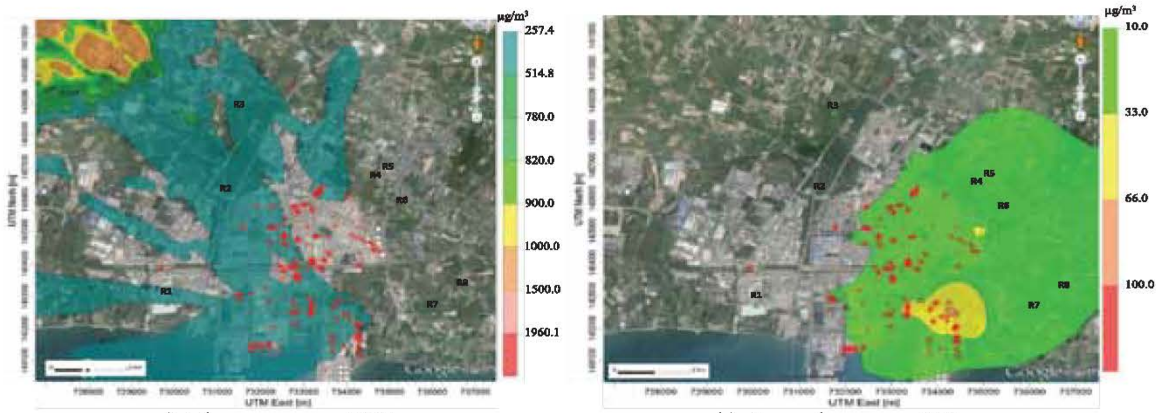
Equation 4

Where: EC = exposure air concentration ($\mu g/m^3$); RfC = reference concentration ($\mu g/m^3$) HQ of less than one ($HQ < 1$) indicates that pollutant concentration is below the reference concentration (RfC) value whereby the potential risk is within acceptable levels. In this case, no action required to reduce the pollutant's level. Therefore, $HQ < 1$ was considered safe. Nevertheless, it should be noted that $HQ > 1$ does not necessarily suggest a likelihood of adverse effects (US EPA, 2013a). According to EPA's Integrated Risk Information System, IRIS report, RfC of NO_2 and SO_2 are not available (http://www. epa.gov/iris/subst/0080.htm) so we used WHO guideline values (WHO, 2006) to calculate HQ by equation (3). To define the risk areas of NO_2 and SO_2, the hazard index (HI) was calculated from the sum of HQ as in equation (4). It was used to assess the overall potential for non-carcinogenic defects posed by more than one chemical. $HI < 1$ indicates that there is no significant risk of non-carcinogenic effects. Conversely, $HI > 1$ indicates the chance of non-carcinogenic effects occurring, with a probability of increasing health risk (US EPA, 2013b).

3. Results and Discussion

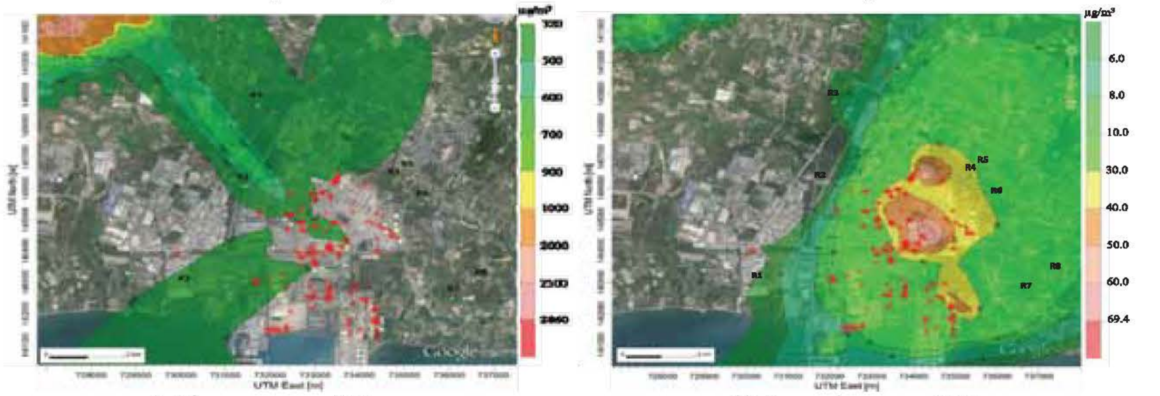
3.1 The Modeling Results

Predicted ground level concentrations from AERMOD were validated against measurement values in 2013 elsewhere (Jittra and Thepanondh, 2014). Both NO_2 and SO_2 predicted values were found with index of agreement of 0.99, compared with measured data. The maximum concentrations were found lower than the ambient air quality standard and WHO guideline values as summarized in Table 1. As for the short-term seasonal variation of HQ, the pollution concentrations in February were selected as the dry season exposure, and the concentrations in July represented the wet season exposure. The Map Ta Phut area was influenced by the sea wind, which sweeps from southwest to northeast with a wind speed typically below 6 m/s, Figure 5d. However, there is some changing with occasional wind from the north into the area from October to December and the wind direction comes from the south to the area in February-April. In the wet season, the wind blows from southwest into the area communities and MTPIE from June to September. Figure 3a, 3b showed SO_2 dispersion on 1-h and annual average and Figure 4a, 4b showed NO_2 dispersion on 1-h and annual average. For short term 1-hour average, SO_2 in Figure 3a and NO_2 in Figure 4a in area R1, R2 and R3 were found exceeding WHO guidelines. For annual average concentration, both SO_2 and NO_2 in all sites were lower than annual The World Health Organization guidelines.



a) 1 hour average SO2 b) Annual average SO_2

Figure 3: Dispersion of SO_2 over MTPIE and 5 km vicinity areas



a) 1 hour average NO_2 b) Annual average NO_2

Figure 4: Dispersion of NO_2 over MTPIE and 5 km vicinity areas

Table 1: Predicted maximum ground level concentration compared with WHO guideline values and The National Ambient Air Quality limit

Pollutant	Short – term concentration (μg/m³)		Short – term concentration WHO Guideline (μg/m³)	Long – term concentration (μg/m³)	Long – term WHO Guideline (μg/m³)	Annual ambient air quality limit (μg/m³)
	Dry season	Wet season				
O_2	49.65	46.34	125	38.88	50	100
NO_2	22.85	54.66	400	31.89	40	57

3.2 Health Risk Assessment

3.2.1 Hazard Quotient (HQ)

The HQs of NO_2 and $SO_2$was calculated from equation 3. HQs of short-term (1-h) and long-term (annual) non-carcinogenic health risks were shown in Table 2. All sites have HQ < 1 which could mean no potential adverse health effects exist during short term dispersion. The HQs of long term annual concentrations were within standard level and HQs were less than one. However, high HQs in three sites R4, R5 and R6 were found in both short term and long term cases.

3.2.2. Hazard Index (HI)

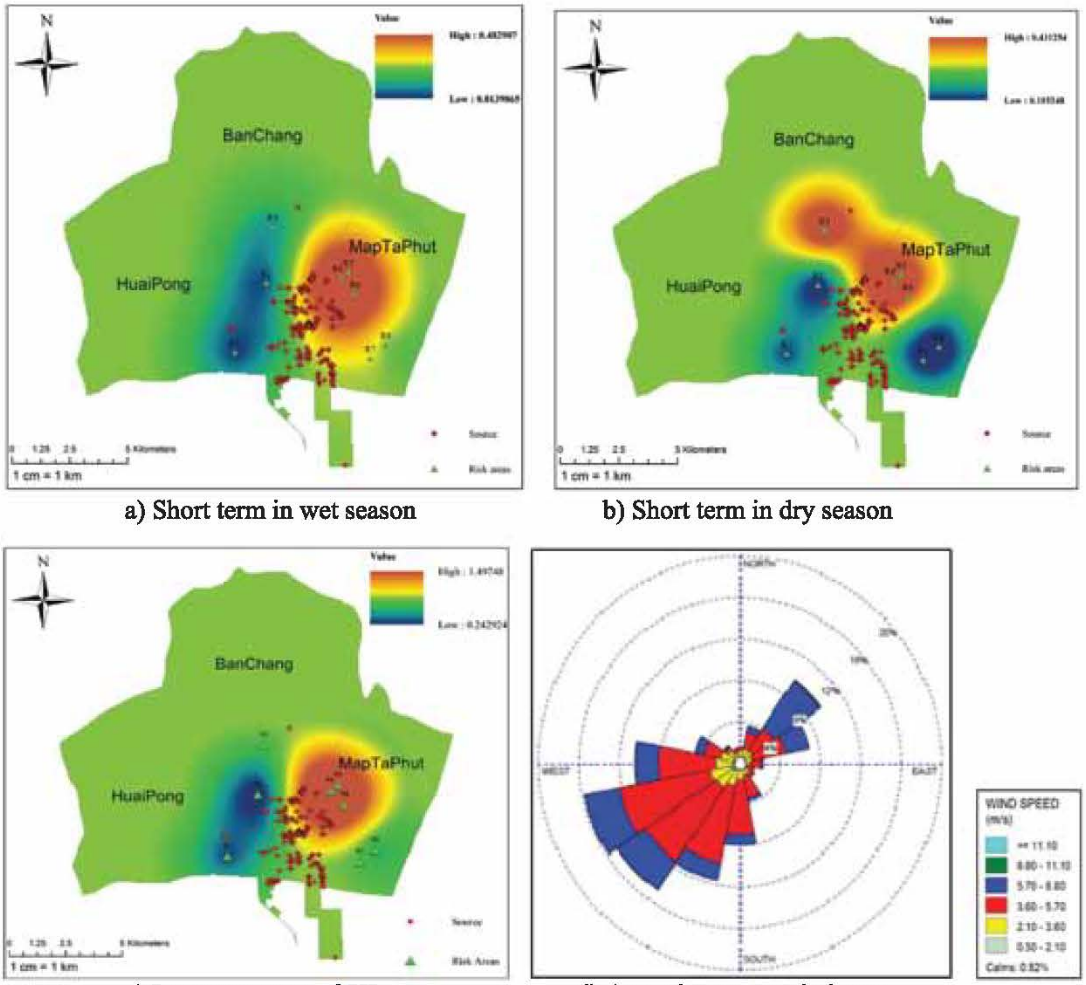
The Hazard Index (HI) of short term and long term exposures were calculated from equation 4. HI and related areas were summarized in Table 3. For the short term HI was lower than 1 at all sites however the long term exposure showed the high HI values 1.51, 1.27 and 1.25 at R4, R5 and R6 in the Map Ta Phut district, respectively. A potential adverse health effects exists during long-term dispersion of NO_2 and SO_2 in the near source areas. The risk areas were identified by different HI and the impact sites were illustrated by GIS-based maps in Figure 5. The impact sites were different between wet and dry seasons. This could be due to wind changing speed and direction.

Table 2: HQs of short-term and long term exposure in Map Ta Phut (WHO guideline SO_2 125 μg/m^3, NO_2 400 μg/m^3)

Pollutants	Risk areas	Dry Season		Wet Season		Annual	
		EC (μg/m3)	HQ	EC (μg/m^3)	HQ	EC (μg/m^3)	HQ
SO_2	R1	15.53	0.12	1.25	0.01	10.01	0.2
	R2	14.13	0.11	2.67	0.02	7.08	0.14
	R3	43.77	0.35	7.73	0.06	21.99	0.44
	R4	47.6	0.38	44.43	0.36	37.28	0.75
	R5	41.38	0.33	35.73	0.29	31.06	0.62
	R6	34.48	0.28	39.06	0.31	29.47	0.59
	R7	13.28	0.11	15.81	0.13	12.3	0.25
	R8	12.09	0.1	13.5	0.11	10.71	0.21
NO_2	R1	9.53	0.02	1.18	0	5.19	0.13
	R2	7.02	0.02	2.15	0.01	3.9	0.1
	R3	8.35	0.02	1.94	0	5.24	0.13
	R4	21.92	0.05	52.41	0.13	30.58	0.76
	R5	18.42	0.05	45.79	0.11	26.09	0.65
	R6	16.87	0.04	48.83	0.12	26.34	0.66
	R7	8.62	0.02	26.39	0.07	13.73	0.34
	R8	6.91	0.02	21.86	0.05	11.28	0.28

Table 3: Hazard index of Pollutions in short-term and long-term

Risk areas	Short - term		Long - term
	Dry season	Wet season	
R1	0.15	0.01	0.33
R2	0.13	0.03	0.24
R3	0.37	0.07	0.57
R4	0.44	0.49	1.51
R5	0.38	0.40	1.27
R6	0.32	0.43	1.25
R7	0.13	0.19	0.59
R8	0.11	0.16	0.50



a) Short term in wet season b) Short term in dry season

c) Long term annual HI d) Annual average wind rose

Figure 5: Site Distribution of HI and wind rose: a. Short term in wet season, b. Short term in dry season, c. Long term annual HI d. Annual average wind rose

4. Conclusion

A health risk assessment was conducted in an industrial site complex, Rayong province, Thailand. The data were compiled from an extensive risk area and a number of stack emission sources. Air dispersion modeling is suitable to predict the ambient concentrations. Although the short term HQ and HI were found less than 1, the area near sources in Map Ta Phut district could be recommended for further monitoring. Potential health risk in three areas, namely R4 MuangMai Map Ta Phut, R5 Chumchon Islam and R6 Health promotion hospital in Map Ta Phut were found in the long term exposure to NO_2 and SO_2. The risk areas were identified by HI and the impact sites were illustrated by Geographic Information System. These types of approaches and further study for health impact mapping may offer a comprehensive strategy to the decision-making processes of the EMP (environmental management policy).

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