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Analysis of Industrial Source Contribution to Ambient Air Concentration Using AERMOD Dispersion Model

Laddawan Khamyingkert and Sarawut Thepanondh

Department of Sanitary Engineering, Faculty of Public Health, Mahidol University, and Center of Excellence on Environmental Health and Toxicology (EHT), Bangkok, Thailand

Abstract

Contribution of each type of industrial group to ambient concentration of SO_2 and NO_2 in Maptaphut industrial area, Thailand was evaluated in the study. AERMOD dispersion model was used to simulate for the maximum 1-hr and annual average concentration within modelling domain in the year 2013. Industrial emission sources were grouped into 5 types namely 1) Gas separation plant, 2) Metal, 3) Petrochemical industry, 4) Power plant and 5) Refinery, respectively. Totally, 422 stack sources were used as input data in this analysis. Results revealed that the maximum 1-hr average ground level concentrations of SO_2 and NO_2 were dominated by contributions from power plant group. Maximum annual average concentrations of these pollutants were mainly from Petrochemical industry group emissions. Therefore, controlling of SO_2 emission from Power plant group and NO_x emission from Petrochemical industry group should be given priority for appropriate controlling and management of these air pollutants in this industrial area.

Keywords: AERMOD; Maptaphut industry; nitrogen dioxide; sulfur dioxide

1. Introduction

The quality status of air is of crucial importance not only to healthy human life but also for wildlife, vegetation, water, and soil (Ayres, 1998; Schwela, 2000; Krzyzanowski, 2011). Bad air quality is generally a result of increasing levels of gaseous pollutants, which are mainly considered toxic for humans and other living organisms due to their extensive natural or anthropogenic activities (Harrison, 2001; Krzyzanowski, 2011). The most common primary anthropogenic pollutants produced by human activities are: (1) sulfur oxides (SO_x), especially sulfur dioxide (SO_2) which is produced mainly in power stations (Mokhtar *et al.,* 2014); (2) nitrogen oxides (NO_x), especially nitrogen dioxide (NO_2) which is released primarily via high temperature combustion; (3) carbon monoxide (CO) which is the major product of incomplete fuel combustion; (4) carbon dioxide (CO_2) which is released from combustion, cement production, and respiration; and (5) ammonia (NH_3) which is released primarily via agricultural processes (Department of the Environment and Heritage, 2005). The expansion and establishment of several industrial plants, including petrochemical plants and oil refineries, burned natural gas flames and power generation stations (Al-Saad *et al.,* 2010) are major emission sources particularly in the industries area.

The National Economic and Social Development Board (NESDB) of Thailand reported that Rayong is a province with a relatively high gross domestic product per capita among all 77 provinces in the county (NESDB, 2013). It is due mainly to the presence and growth of a large industrial sector. For the Maptaphut which is geographically located in Rayong at around 12.725833 ^{o}N (lat.), 101.172222 ^{o}E (long.), and is adjacent to the Gulf of Thailand, it is also home to the largest industrial complex of Thailand. It currently includes up to five industrial estates (IEs): Maptaphut, East Hemaraj, Asia, Padaeng, and RIL, comprising roughly 2,460 factories and a seaport with ten berths (Fig. 1) (Chusai *et al.,* 2012.).

Environmental systems integrated with air pollutant monitoring and atmospheric dispersion models can be used to obtain a good representation of concentration patterns in an area (Mazzeo and Venegas, 2008). As for this purpose, AERMOD has been widely used for evaluation of impact of emission sources to the level of air pollutants. Seangkiatiyuth *et al.* (2011) studied application of the AERMOD modelling system for environmental impact assessment of NO_2 emissions from cement factory complex in Thailand. Simulated values of NO_2 concentrations were compared with those obtained from measurements. It was found that, the quantile-quantile plot of concentrations in dry season was mostly fitted to the middle line. Predicted concentrations were not exceed the Thai ambient air quality standard for NO_2. Results from AERMOD simulation indicated that NO_2 emissions from the cement complex had no significant impact on nearby communities.

In Maptaphut area, AERMOD had been utilized by several studies. Chusai *et al.* (2012) used AERMOD to evaluate dispersion of NO_2 and SO_2 and relative roles of emission sources over this area. It was found that predicted data of both pollutants were under-estimated when compared with those observed data. Results also indicated that petrochemical industry played the major contribution in annual average area-wide concentrations of NO_2 and SO_2 in this area. A study of AERMOD tiering approach for NO_2 prediction in this industrial area was conducted by Tunlathorntham and Thepanondh (2015). Three methods were tested for their performance in modelling NO_2 concentrations (Tier1: total conversion of NOx to NO_2; Tier II: NO_2/NOx ratio of 0.60 and Tier III: ambient O_3 concentrations were used for calculation using the plume volume molar ratio method (PVMRM)). The results indicated that Tier 1 provided less bias with those measured data as compared with other tiers. It also performed very well in predicting the extreme end of NO_2 concentrations. This study recommended that Tier 1 was appropriate method for prediction of the annual average as well as in determining the maximum ground level concentration of NO_2 in the Maptaphut industrial area. Comparison of performances of AERMOD and CALPUFF dispersion models in predicting SO_2 and NO_2 concentrations was conducted by Jittra and Thepanondh (2015). Modelled results were compared with measured data and evaluation of model performance was carried out using statistical analysis. Results indicated that AERMOD could provide more accurate results than CALPUFF for NO_2 and SO_2 predictions. As for extreme end of concentration, results from the robust highest concentration analysis indicated that predicted data agreed well with those measured data when using AERMOD simulation.

This study is aimed to evaluate ground level concentrations of sulfur dioxide (SO_2) and nitrogen dioxide (NO_x) emitted from factories in Maptaphut industrial area. Contributions of each type of factory to the maximum ground level concentration are analyzed. This finding will be useful in prioritization of appropriate mitigation measures in controlling emission amount of each type of factory as well as demonstrate application of air dispersion model. It can then serve as a tool for management of air pollution problem.

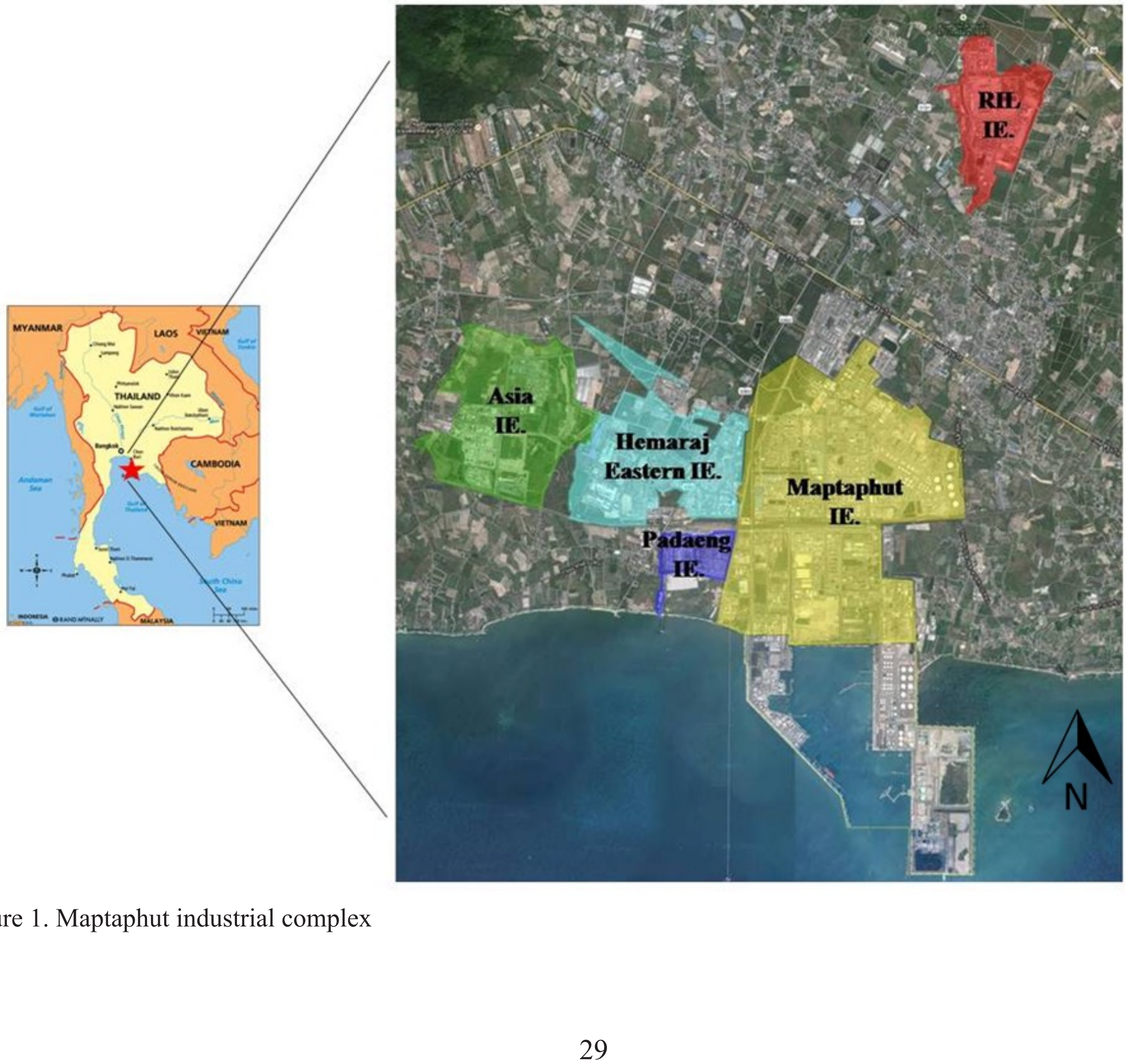

Figure 1. Maptaphut industrial complex

2. Materials and Methods

2.1. AERMOD model

AERMOD is a regulatory dispersion model of U.S. Environmental Protection Agency. It has been widely used for environmental impact assessment purpose (Silverman *et al.,* 2007; Suadee, 2008; Huertas *et al.,* 2012). AERMOD system consists of three main processors: AERMAP as the terrain processor, AERMET as the meteorological processor, and AERMOD as the main dispersion model processor (Chusai *et al.,* 2012; Mokhtar *et al.,* 2014). The AERMOD system is considered accurate for dispersion modelling at distances not exceeding 50 km from the emission sourc (Seangkiatiyuth *et al.,* 2011; Krzyzanowski, 2011).The AERMOD system is publicly available and updated occasionally (Chusai *et al.,* 2012). In this study, dispersion of SO_2 and NO_2 were modelled to evaluate their maximum ground level concentrations in the study area. AERMOD View version 8.7.0 (Lakes environmental) was used for this purpose.

2.2. Modelling configuration

The surface and profile meteorological data, used in this study were derived from MM5-preprocessed meteorological data. Potential temperature profiles were based on elevation above mean sea level (for primary meteorological) which was 36 meters. Data periods read from meteorological data files were started from the 1st hour in 1st January to the 24th hours in 31st December 2013. The gridded data needed by AERMET were selected from Digital Elevation Model (DEM) data and the terrain data were collected during the Shuttle Radar Topography Mission (SRTM3/ SRTM1). Numbers of grid points were 2500 grids with grid spacing of 500 meter. In this study, a comprehensive Cartesian receptor grid extending to 10 km from the centre of the emission source was used in the AERMOD model. In this study, full conversion of NOx to NO_2 (100% conversion) was used as assumption for NO_2 prediction taking into consideration the result from previous study by Tunlathorntham and Thepanondh (2015).

2.3. Emission data

Emission data were obtained from Office of Natural Resources and Environmental Policy and Planning (ONEP) database. These data were reported by each factory for the process of environmental impact assessment and were used as emission limit for each individual emission sources during its operation period. This study classified industry into five groups: 1) Gas separation plant (GSP), 2) Metal, 3) Petrochemical industry (Petrochem), 4) Power plant and 5) Refinery. Totally, there were 422 point sources, located in these five industrial estates. Characteristics of stack emission source were as summarized in Table 1.

3. Results and Discussion

Performance of the model was evaluated by comparing predicted with observed data within the study domain. Statistical analysis was employed to determine performance of the model in predicting overall concentrations and extreme high-end concentrations. Details were reported in Tunlathorntham and Thepanondh (2015) and Jittra and Thepanondh (2015). The configurations of model in these studies were set as the same with our study. Generally, it was found that AERMOD provided good agreement between the modelled and the observed NO_2 and SO_2 concentrations as well as showed ability in predicting extreme high-end concentration.

Table 1. Characteristics of stack emission sources

Stack emission group	Number of stack	Stack height Mean+S.D. (m)	Stack diameter Mean+S.D. (m)	Stack exit temperature Mean+S.D. (K)	Stack exit velocity Mean+S.D. (m/s)	SO_2 Mean+S.D. (g/s)	NO_x Mean+S.D. (g/s)
GSP	13	59.31+47.80	2.69+0.78	460.68+27.37	24.48+12.12	1.14+0.83	4.83+1.73
Metal	28	32.84+17.23	1.59+1.46	559.75+253.68	11.40+6.45	1.92+4.77	0.74+0.96
Petrochem	310	33.51+16.15	1.28+0.88	451.57+183.36	11.74+8.92	1.13+4.04	1.81+7.73
Power plant	45	48.78+33.00	3.91+1.65	408.31+33.96	20.45+6.15	29.88+153.67	34.26+100.12
Refinery	26	51.25+27.81	2.01+0.93	504.16+102.01	11.99+4.80	12.39+37.67	4.21+6.86

S.D. = Standard deviation

Table 2. Contribution of each emission source group to annual average concentration of SO_2

Group	Total emission (g/s)	Concentration (μg/m^3)	Percentage
GSP	14.83	0.26	0.40%
Metal	53.62	0.68	1.05%
Petrochem	337.48	57.91	89.64%
Power plant	1344.48	3.21	4.97%
Refinery	309.68	2.54	3.94%
Total	2,060.09	64.60	100%
Thai's standard (annual average)		100 μg/m^3	

Results from this study indicated that the highest annual average concentration of SO_2 from model simulation was predicted as 64.60 μg/m^3. About 90% of predicted concentration was contributed by emission of Petrochemical industry group. Power plant, Refinery and Metal group corresponded to about 4.97%, 3.99% and 1.05%, respectively (Table 2.). Thematic pollution map of SO_2 simulation was as illustrated in Fig. 2.

As for NO_2, the highest annual average concentration was predicted by the AERMOD model as 65.84 μg/m^3 (Fig. 3). This predicted value exceeds the Thai ambient air quality standard for NO_2 concentration. Modelled results predicated that this concentration was mainly contributed by emission of Petrochemical (about 67.23%) and Power plant (about 28.23%) industrial group, respectively. Summary of emission source contributions to annual concentration of NO_2 were presented in Table 3.

It should be noted that spatial distributions of annual concentration of SO_2 and NO_2 were also relevant to wind characteristics in the study area. During the dry season (November - March), this area is governed by the northeastern wind. However in the wet season (April - October), the southwestern wind plays as the dominant wind direction. The wind rose diagram of the year 2013 was as illustrated in Fig.4. Therefore, it was found from model simulation that mostly of air pollutants were transported to the north and northeast directions from emission sources.

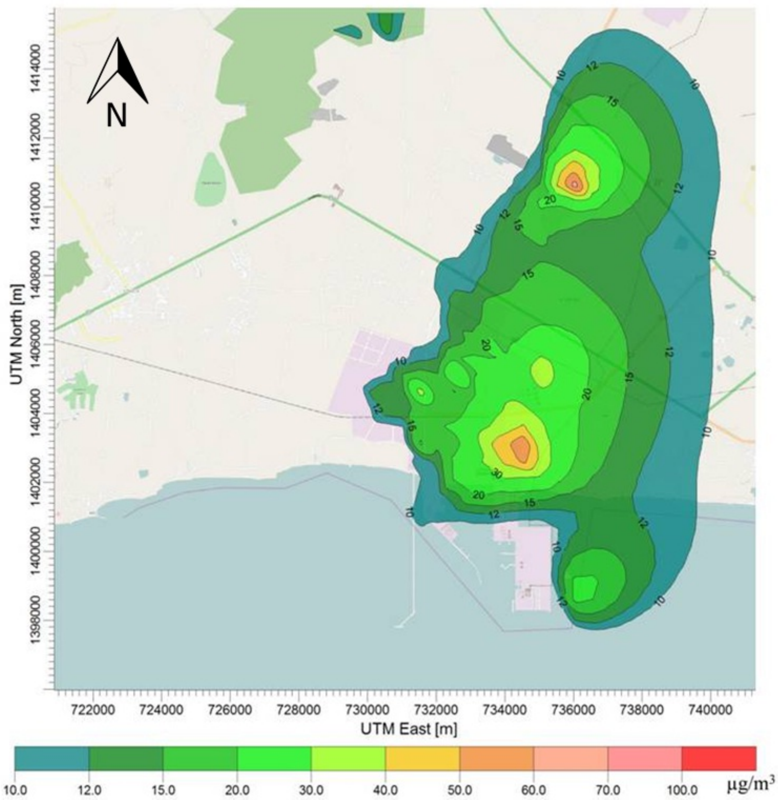

Figure 2. Concentrations contour map from annual simulation of SO_2

Table 3. Contribution of each emission source group to annual average concentration of NO_2

Group	Total emission (g/s)	Concentration (μg/m^3)	Percentage
GSP	62.72	0.35	0.53%
Metal	20.73	0.67	1.02%
Petrochem	491.34	44.26	67.23%
Power plant	1541.71	18.59	28.23%
Refinery	109.49	1.97	2.99%
Total	2225.99	65.84	100%
Thai's standard (annual average)		57 μg/m^3	

Contribution of petrochemical industry group to annual concentrations of SO_2 and NO_2 were larger than the power plant group even though their emissions were almost four times lower than emissions of power plant factories. This could be explained by the fact that the heights of stacks of the power plant group are much taller than petrochemical factories. These characteristics enhanced the dilution abilities of emissions from power plant and reducing concentrations of air pollutants at the ground surface level. Transportation of plume emitted from the power plant group probably might not reach the ground level within the modelling domain because it may travel to the longer distant than the study area prior reaching the ground.

Therefore, high levels of these pollutants might be observed in an area far from the power plant factories. In order to evaluate influence of power plant group to the ground level concentrations, AERMOD was also simulated to acquire the maximum 1-hr average concentration of SO_2 and NO_2 in the study domain. Model results indicated that the highest concentration were about 2,362 and 4,399 μg/m^3 for SO_2 and NO_2, respectively. These predicted values exceed the Thai ambient air quality standards. It should be noted that the location having highest maximum ground level concentration of both pollutants was located in the same area as presented in Fig. 5 and Fig. 6. This finding came from the influence of elevation of terrain in the

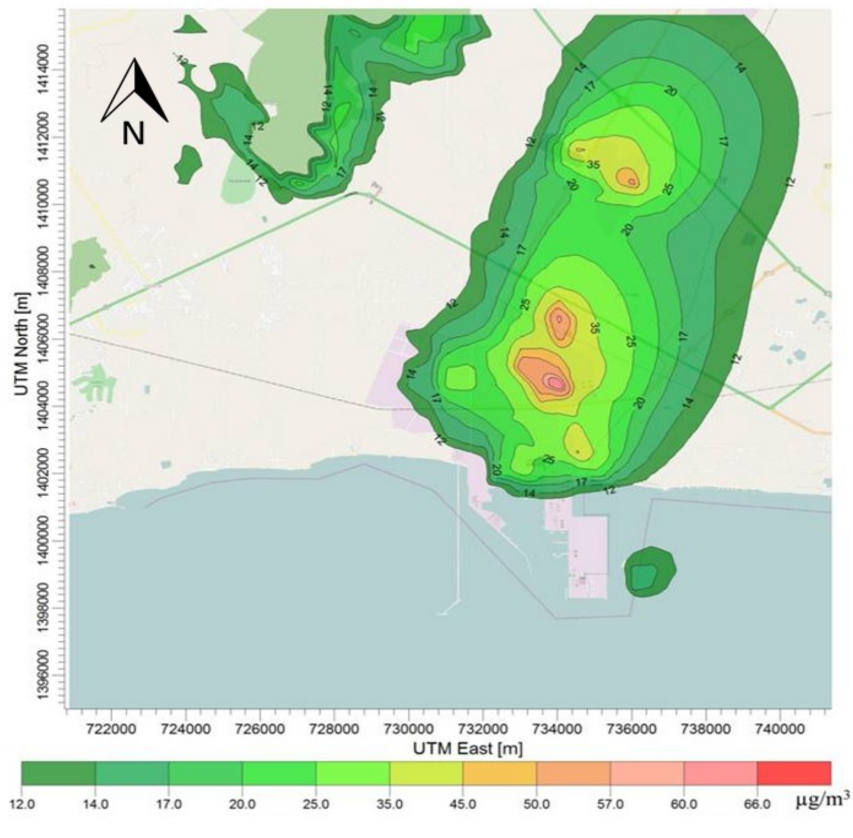

Figure 3. Concentrations contour map from annual simulation of NO_2

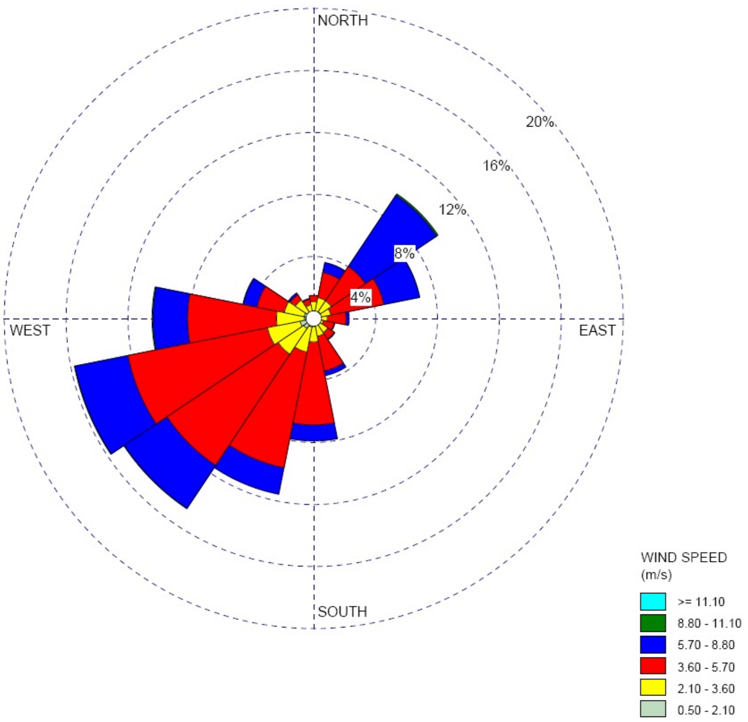

Figure 4. Wind rose diagram of the year 2013

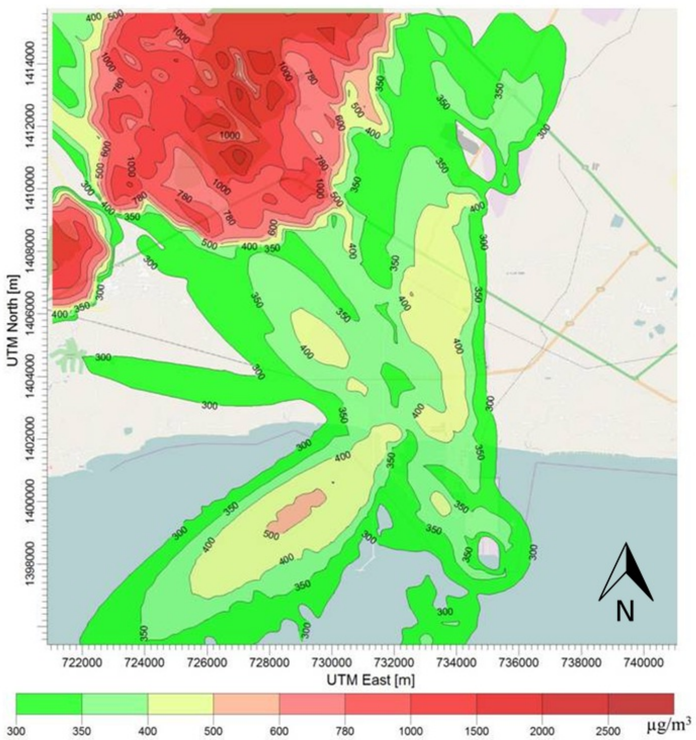

Figure 5. Concentrations contour map from hour simulations of SO_2

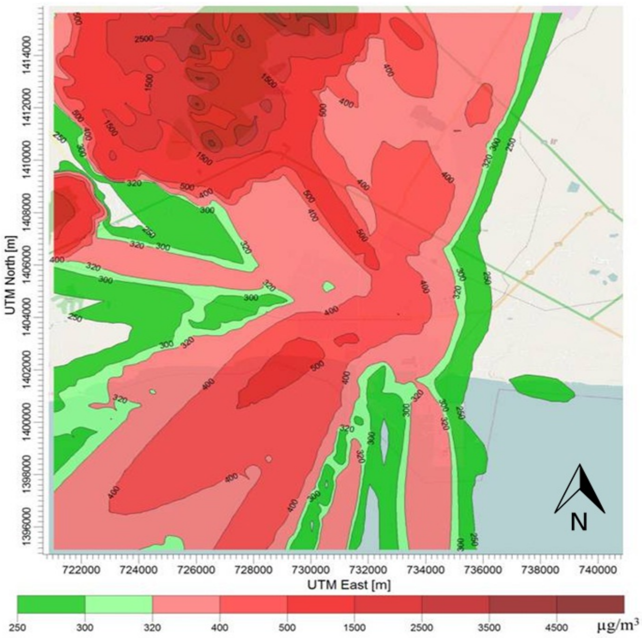

Figure 6. Concentrations contour map from hour simulations of NO_2

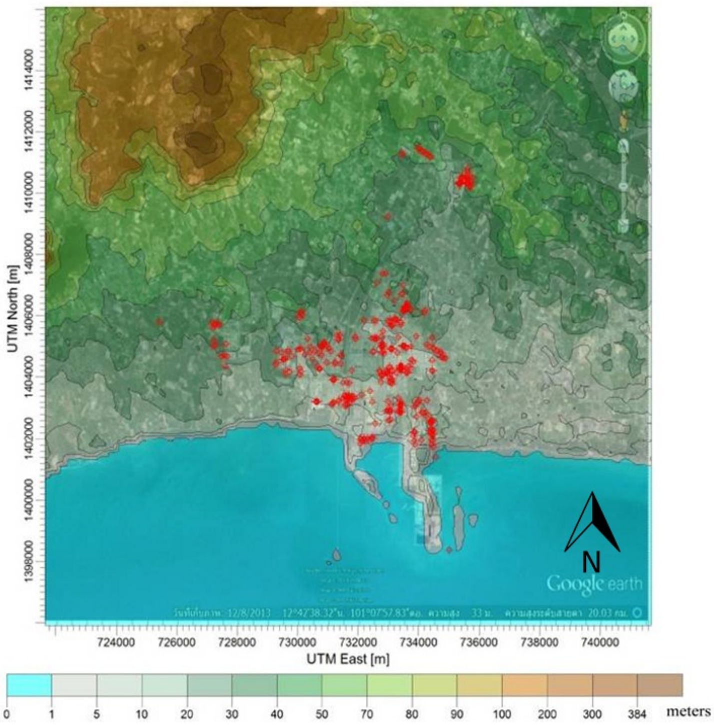

Figure 7. Terrain characteristic of the study domain (red dot represent location of stack)

study domain. High concentrations of SO_2 and NO_2 were predicted in the mountain areas north western of the industrial complex as show in Fig. 7. Most of the maximum ground level concentration of SO_2 and NO_2 (1-hr average) emitted was from Power plant group. Contribution of each emission source group to the highest 1-hr concentration was summarized in Table 4.

Results from this analysis revealed that in order to manage SO_2 and NO_2 pollution in the industrial area controlling of emission from Power plant industrial group should be given the first priority. Intermittent control scheme can be applied to intensive controlling of emissions from Power plant group. For example, it can be used to reduce production capacity during unfavourable meteorological conditions. As for Petrochemical industrial group, controlling of NO_x emission should be more stringent in order to achieve long-term ambient standard of this air pollutant.

4. Conclusions

Industrial source contribution to ambient SO_2 and NO_2 concentrations in Maptaphut industrial area, Thailand was evaluated in this study by using AERMOD dispersion modelling. Emission source consisted of 422 stack sources with total emission loading of 2060.09 g/s and 2225.99 g/s for SO_2 and NO_x, respectively. AERMOD was simulated covering a period of one year (the year 2013). Maximum 1-hr as well as annual average concentrations of SO_2 and NO_2 were predicted. Modelled results indicated that the maximum 1-hr average ground level concentration of both pollutants were higher than the Thai's ambient air quality standards. This peak concentration could be explained as domination of emission from Power plant industrial group. Maximum annual average concentrations of SO_2 and NO_2 were mainly contributed by Petrochemical industrial group. This analysis revealed that efforts in controlling of SO_2 emissions from Power plant group and NO_x emissions from Petrochemical industrial group could be appropriate in management of air pollution problems in this industrial area.

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Table 4. Contribution of each emission source group to maximum 1-hr average concentrations of SO_2 and NO_2

Group	SO_2		NO_2	
	Concentration (μg/m^3)	Percentage	Concentration (μg/m^3)	Percentage
GSP	2.35E-3	0.00%	0.64	0.01%
Metal	-	-	0.12	0.00%
Petrochem	1E-5	0.00%	186.25	4.24%
Power plant	2360.62	99.92%	4210.84	95.73%
Refinery	1.83	0.08%	0.92	0.02%
Total	2362.46	100%	4398.77	100%
Thai's standard (hour average)	780 μg/m^3		320 μg/m^3	

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Correspondence to
Assistant Professor Dr. Sarawut Thepanondh
Department of Sanitary Engineering,
Faculty of Public Health,
Mahidol University,
Bangkok 10400,
Thailand
Email: sarawut.the@mahidol.ac.th