

## ASSIMILATIVE CAPACITY OF AIR POLLUTANTS IN AN AREA OF THE LARGEST PETROCHEMICAL COMPLEX IN THAILAND

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**ABSTRACT:** Assimilative capacities of sulfur dioxide (SO<sub>2</sub>) and oxides of nitrogen (NO<sub>x</sub>) in the largest petrochemical industrial complex in Thailand were evaluated in this study. AERMOD dispersion model was simulated to compute for ground level concentrations and spatial distributions of SO<sub>2</sub> and nitrogen dioxide (NO<sub>2</sub>) within a radius of 5 km from Maptaphut industrial area. Emission input consisted of 419 stacks which total amount of 2,071.82 and 2,163.66 g/s of SO<sub>2</sub> and NO<sub>x</sub> were used as baseline emissions. Maximum hourly average and annual concentrations predicted at 8 ambient air quality monitoring stations in the study domain were used to evaluate an assimilative capacity of these pollutants. Emissions of SO<sub>2</sub> and NO<sub>x</sub> were adjusted to the limit that predicted concentrations will not exceed their ambient air quality standards. Results indicated that in order to achieve both hourly and annual standards, NO<sub>x</sub> emissions must be reduced by at least 40% from its baseline value. As for SO<sub>2</sub>, emissions can be increased up to about 130% from current level. Results of this study indicated that an existing regulation in controlling individual emission source by using emission standard is insufficient. Analysis of air pollution as area-based approach by taking into consideration entire emission sources can support for better planning and management of pollution.

*Keywords:* AERMOD, Emission rate, Maptaphut, Assimilative capacity, NO<sub>x</sub>, SO<sub>2</sub>

### 1. INTRODUCTION

Maptaphut industrial area (MA) in Rayong province, Eastern region of Thailand. It was established in 1988 as part of the Thai's government policy to develop the eastern seaboard [1]. MA was established by the Eastern Sea Board development project as the specific area for petrochemical industries for the industrial development of the country. Main industries found in the Maptaphut industrial area are petrochemical industry, metal processing, oil refining, gas separation, electricity generation, and seaport [2]. The development and operation of the MA has occasionally brought out local environmental problems (e.g., air, wastewater, groundwater contamination, hazardous wastes), among which air pollution appears seriously perceived [3]. Importance is air pollutant the such, including nitrogen dioxide (NO<sub>2</sub>), sulfur dioxide (SO<sub>2</sub>), carbon monoxide (CO), particulate matter, volatile organic compounds (VOC), and others.

In order to support air quality management in the MA, the Thai's government declared the MA as a pollution controlled zone in 2009 [4]. This designation requires the Industrial Estate Authority of Thailand and entrepreneurs to seek for proper measures to limit and control emissions to the environment [5]. NO<sub>2</sub> and SO<sub>2</sub> are generally two main air pollutants well known to have adverse effects on human health, particularly on the respiratory system. Frequent complaints of chemical odor were also reported in the vicinity of this industrial complex [6]. NO<sub>2</sub> and SO<sub>2</sub> are air

pollutants required by the government for consideration when assessing the impacts of an industrial facility in order to acquire a permit for operation in the MA. Furthermore, they are also required parameters to be assessed when planning for future expansion of industrial activities of the MA [7].

The government has encouraged the studying on the air emissions assimilative capacity using air dispersion model in this area [7]. Efforts have been made to assess status of air quality using both direct measurement and predicted data from air quality model [8]. Evaluation of assimilative capacity of air pollution in this area can assist in area-based management of pollution problems together with individual emission source control through the implementation of emission standards.

This study evaluated assimilative capacities of sulfur dioxide (SO<sub>2</sub>) and oxides of nitrogen (NO<sub>x</sub>). AERMOD dispersion model was simulated to compute for ground level concentrations and spatial distributions of these pollutants within study area. Emission input consisted of stacks which total amounts of emission rate were used as baseline emissions. The maximum hourly average and annual ground level concentrations were predicted and were compared with the Thai's ambient air quality standards for SO<sub>2</sub> and NO<sub>2</sub>. Predicted data at 8 ambient air quality monitoring stations in the study domain were used to evaluate an assimilative capacity of these pollutants. Emissions of SO<sub>2</sub> and NO<sub>x</sub> were adjusted to the limit that predicted concentrations will not exceed

their ambient air quality standards.

## 2. METHODOLOGY

### 2.1 Study Area

The study domain was designed to encompass the entire Maptaphut industrial area (MA). It is geographically located at around 12.7° N (latitude), 101.1° E (longitude) in Rayong province Thailand. Modeling domain covered an area of  $10 \times 10 \text{ km}^2$  with a horizontal grid spacing of 500 m. This modeling domain currently includes five industrial estates namely Map Ta Phut, East Hemaraj, Asia, Padaeng and RIL industrial estates [9]. Spatial distribution of these industrial estates in the study area was as shown in Fig.1.

In this study, a comprehensive Cartesian receptor grid extending to 5 km from the center of the emission source was used in the AERMOD modeling to assess the maximum ground-level pollutant concentrations. The Cartesian receptors grid ( $14.5 \text{ km} \times 14.5 \text{ km}$  domain) has a uniform spacing of 500 m. Eight discrete receptors were set in the modelling domain. The receptors were labelled as Health Promotion Hospital Maptaphut

(HMTP), Field Crops Research Center (FCRC), Ban Ta Kuan Public Health Center (BTKH), Wat Nong Fap School (WNFS), Muang Mai Maptaphut (MMTP), Map Chalut Temple (MCLT), Ta Kuan Temple (TKTP) and Chum Chon Islam (CCIL) as shown in Fig.1. The receptors were randomly selected to represent sensitive receptors such as residential area, schools, health care centers etc.

### 2.2 AERMOD model

AERMOD (American Meteorological Society/Environmental Protection Agency Regulatory Model) is a steady-state Gaussian plume model. AERMOD is a freely available software package provided by the United States Environmental Protection Agency (US.EPA) [11]. It is a refined dispersion model for simple and complex terrain for receptors within 50 km of a modelled source. The AERMOD modelling system used in this study was run with a commercial interface, AERMOD View (Version 8.7). This model was intensively validated for its ability in predicting ground level concentration of  $\text{SO}_2$  and  $\text{NO}_2$  in this study area [12], [13].

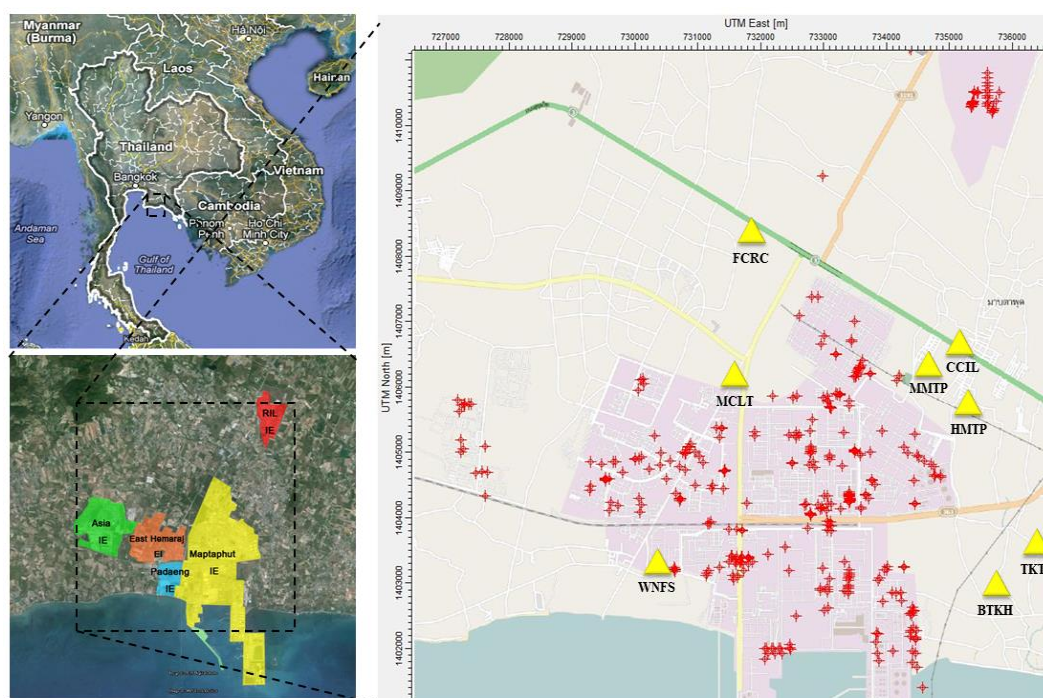


Fig.1 Study domain in a radius of 5 km from Maptaphut industrial area (yellow dots represent the position of receptors; red dots represent the position of point sources)

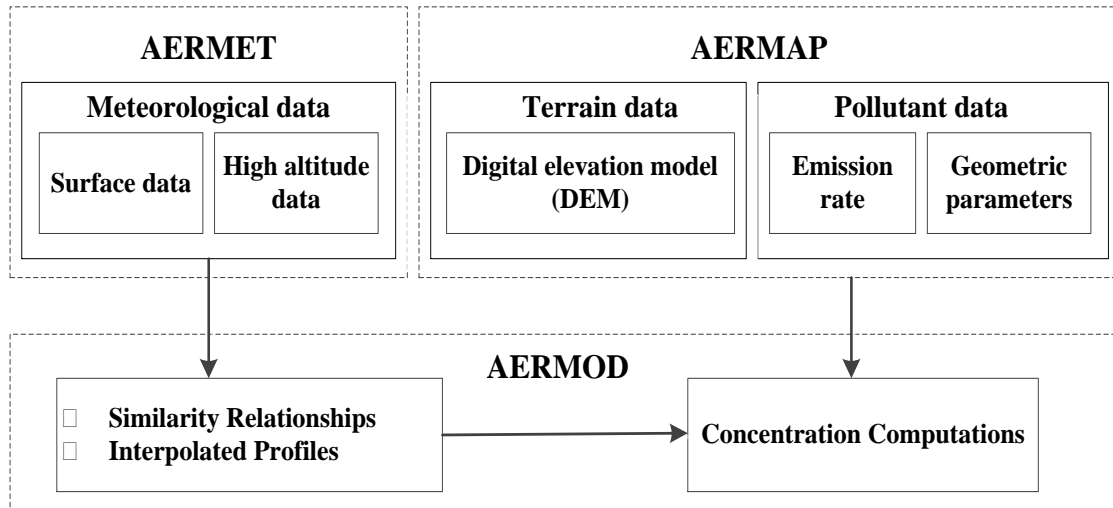


Fig.2 Input data of AERMOD

Input data of AERMOD consisted of meteorological, topographical and emission data [14]. Components of the input data are illustrated in Fig.2.

The meteorological parameters data input were prepared over one year (1<sup>st</sup> January 2013 to 31<sup>th</sup> December 2013). Data used in this study were generated by Mesoscale Meteorological Model (MM5) in TD-6201 format file. Data were then pre-processed using AERMET processor. The required meteorology data for AERMOD are surface data (hourly values) which describe conditions at the level closed to ground level. Surface data consisted of wind direction (degrees from true north), wind speed (m/s), dry bulb (ambient air) temperature (°C), dew point temperature (°C), total and opaque cloud cover (tenths), cloud ceiling height (m), station pressure (millibar), hourly precipitation amount (hundredths of inches) and relative humidity (%). The wind rose diagram in the year 2012 was as shown in Fig.3. Upper air data (daily values) which describe conditions at higher altitude in the atmosphere also be used in the model. Boundary layer parameters used by AERMOD, which are required as input to the AERMET processor, include albedo, Bowen ratio, and surface roughness [15].

The gridded data needed by AERMAP was selected from Digital Elevation Model (DEM) data and the terrain data was collected during the Shuttle Radar Topography Mission (SRTM3). The terrain data were pre-processed with AERMAP prior to modelling in AERMOD.

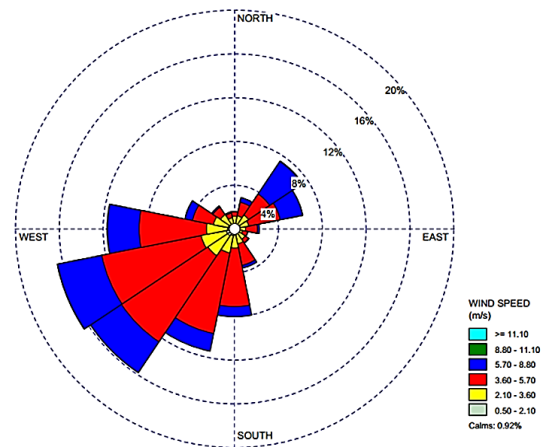


Fig.3 Wind Rose in 2012 of Maptaphut industrial area.

### 2.3 Emission Sources Data

Stack emission data (Table 1 and Table 2) were obtained from the database for MA, which was compiled and reported by the Office of Natural Resource and Environment Policy and Planning [16]. These data consisted of stack height, diameter, exit temperature (Kelvin), exit velocity (m/s) and emission rate (g/s). These emission data comprised of 419 stacks covering entire stacks in the study area.

Table 1 Physical parameters of stacks

Stack emission group	Number of stacks	Height Mean±SD (m)	Diameter Mean±SD (m)	Exit Temperature Mean±SD (K)	Exit Velocity Mean±SD (m/s)
Petrochemical industry (PETROCHEM)	307	33.30 ± 16.02	1.28 ± 0.88	450.44 ± 150.94	11.76 ± 8.13
Power plant (PP)	45	48.78 ± 33.00	3.91 ± 1.65	408.31 ± 33.97	20.45 ± 6.15
Oil refinery (Refinery)	26	21.60 ± 27.81	0.75 ± 0.92	74.21 ± 102.01	4.11 ± 4.80
Metal industry (Metal)	28	32.83 ± 17.23	1.59 ± 1.46	553.32 ± 233.06	11.4 ± 6.45
Gas Separate Plant (GSP)	13	59.31 ± 47.80	2.69 ± 0.77	460.68 ± 27.37	24.48 ± 12.12

Table 2 Emission rates of SO<sub>2</sub> and NO<sub>x</sub>

Stack emission group	SO <sub>2</sub> <sup>a</sup> (g/s)		NO <sub>x</sub> <sup>a</sup> (g/s)	
	Mean±SD	Total	Mean±SD	Total
Petrochemical industry (PETROCHEM)	1.14 ± 4.06	349.24	1.38 ± 2.25	428.98
Power plant (PP)	29.88 ± 153.67	1344.48	34.26 ± 100.12	1541.74
Oil refinery (REFINERY)	19.64 ± 37.67	309.77	4.09 ± 6.86	109.49
Metal industry (METAL)	1.91 ± 4.77	53.5	0.74 ± 0.96	20.73
Gas Separate Plant (GSP)	1.14 ± 0.83	14.83	4.82 ± 1.73	62.72
Total	-	2071.82	-	2163.66

notes : <sup>a</sup> maximum measured/estimated emission rates

## 2.4 Assimilative Capacity Estimation

Determination of assimilative capacities of sulfur dioxide (SO<sub>2</sub>) and oxides of nitrogen (NO<sub>x</sub>) were carried out by simulation of AERMOD dispersion model. Ground level concentrations and spatial distributions of these pollutants were analyzed as outputs of the simulation. Maximum hourly average and annual concentrations predicted at 8 ambient air quality monitoring stations in the study domain were used to evaluate an assimilative capacity of these pollutants. Emissions of SO<sub>2</sub> and NO<sub>x</sub> were adjusted to the limit that predicted concentrations will not exceed their ambient air quality standards.

## 3. RESULTS

Assimilative capacities of sulfur dioxide (SO<sub>2</sub>)

and oxides of nitrogen (NO<sub>x</sub>) in this study were determined as value of total emission of air pollutant which its predicted ground level concentration was not higher than the Thai's ambient air quality standard [17]. The values of 780 and 100 µg/m<sup>3</sup> which are designated ambient air quality standard of SO<sub>2</sub> were used to compare with predicted one hour and annual concentration, respectively. As for NO<sub>2</sub>, predicted 1 hr and annual concentrations were compared with the values of 320 and 57 µg/m<sup>3</sup> (ambient air quality standards for NO<sub>2</sub>), respectively. Simulated results in an existing condition and predicting assimilative capacities of these pollutants were summarized in Table 3.

Table 3 Predicted maximum hourly and annual average concentrations at receptor sites in the study domain

Receptor	SO <sub>2</sub>				NO <sub>2</sub>			
	Hourly std. $\leq 780$ ( $\mu\text{g}/\text{m}^3$ )		Annual std. $\leq 100$ ( $\mu\text{g}/\text{m}^3$ )		Hourly std. $\leq 320$ ( $\mu\text{g}/\text{m}^3$ )		Annual std. $\leq 57$ ( $\mu\text{g}/\text{m}^3$ )	
	current	130% increased	current	130% increased	current	40% reduced	current	40% reduced
HMTP	236	543	28	65	290	185	32	21
FCRC	338	777	9	21	364	240	13	8
BTKH	236	543	20	46	238	151	18	12
WNFS	330	760	8	18	488	300	11	6
MMTP	305	700	21	49	312	197	38	24
MCLT	339	779	9	22	392	250	17	11
TKTP	208	479	17	38	228	145	15	10
CCIL	261	600	20	47	287	181	34	22

## SO<sub>2</sub>

In an existing condition, there were about 2071.82 g/s of SO<sub>2</sub> emitted from entire study area. The maximum 1 hr and annual average concentration were predicted as about 339 and 28  $\mu\text{g}/\text{m}^3$  at MCLT and HMTP, respectively. These values were not exceed ambient air quality standard of SO<sub>2</sub>. Therefore, there are still rooms for increasing of emissions of SO<sub>2</sub> in this area. Predicted data at MCLT station was used to test the ability to increase SO<sub>2</sub> emission which the maximum hourly average concentrations will not exceed the ambient standard (Fig.4). It was found that in this case, emission rate of SO<sub>2</sub> could be increased up to about 4765.19 g/s or about 130 % from its existing condition. At this level, the maximum 1 hr average ground level concentration was predicted as 779.7  $\mu\text{g}/\text{m}^3$ . The maximum annual concentration at HMTP station was predicted as 65  $\mu\text{g}/\text{m}^3$ . These predicted concentrations were not exceeded their ambient air quality standards. Comparisons of pollution maps of SO<sub>2</sub> annual average concentration in an existing condition (total emission rate of 2071.82 g/s) with its predicted assimilative capacity (total emission rate of 4765.19 g/s) were as illustrated in Fig.5.

## NO<sub>x</sub>

Modeled results indicated that annual average concentrations of NO<sub>2</sub> at every receptor points were not exceed its annual standard in the existing emission rate. However, predicted maximum 1-hr average concentrations at FCRC, WNFS and MCLT stations were higher than 320  $\mu\text{g}/\text{m}^3$  which is set as ambient standard for 1-hr average of NO<sub>2</sub>. These predicted values were about 488, 392 and 364  $\mu\text{g}/\text{m}^3$  at WNFS, MCLT and FCRC, respectively. Therefore, in order to achieve attainment of air quality in this area, emissions of NO<sub>x</sub> must be decreased from its current level. Predicted data at WNFS station was used to test the ability to increase NO<sub>x</sub> emission which the maximum hourly average concentrations will not exceed the ambient standard (Fig.6). Results from model simulation indicated that at emission rate of about 1296.54 g/s, predicted 1-hr average ground level concentration of NO<sub>2</sub> at every receptor points will be compiled with its environmental standard. Predicted maximum 1-hr average can be achieved by about 44 % reduction from current emission rate of NO<sub>x</sub> from petrochemical and Power plant (formerly 1970.72 g/s as 1103.60 g/s). This value was corresponded to about 40 % reduction from current emission rate of NO<sub>x</sub> (2163.66 g/s). Comparisons of pollution maps of NO<sub>2</sub> annual average concentration in an existing condition with its predicted assimilative capacity (total emission rate of 1296.54 g/s) were as presented in Fig.7.



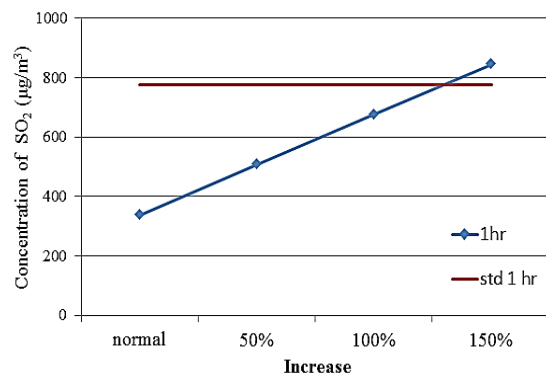


Fig.4 Maximum hourly concentrations from increasing of emissions of  $\text{SO}_2$  at MCLT

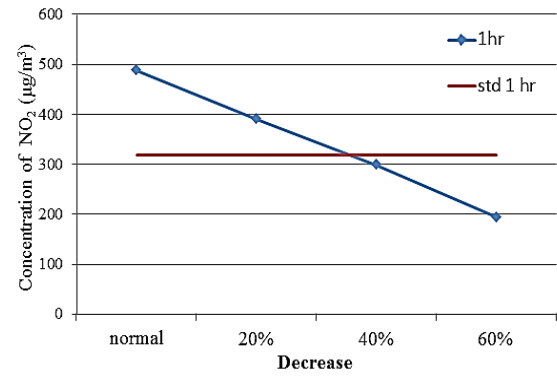


Fig.6 Maximum hourly concentrations from decreasing of emissions of  $\text{NO}_x$  at WNFS

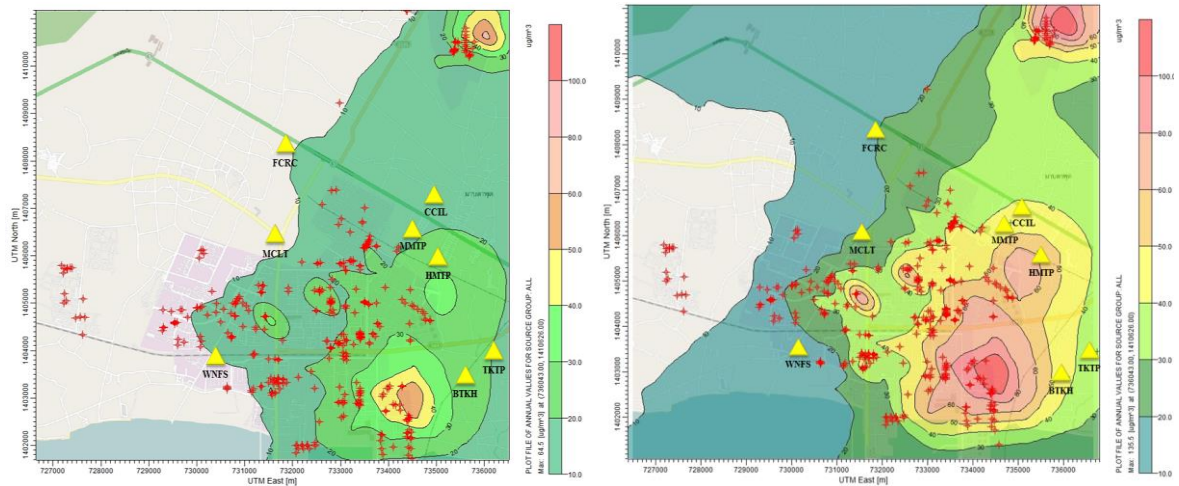


Fig.5 Annual average concentration of  $\text{SO}_2$  for normal emission rate and 130% emission rate increasing

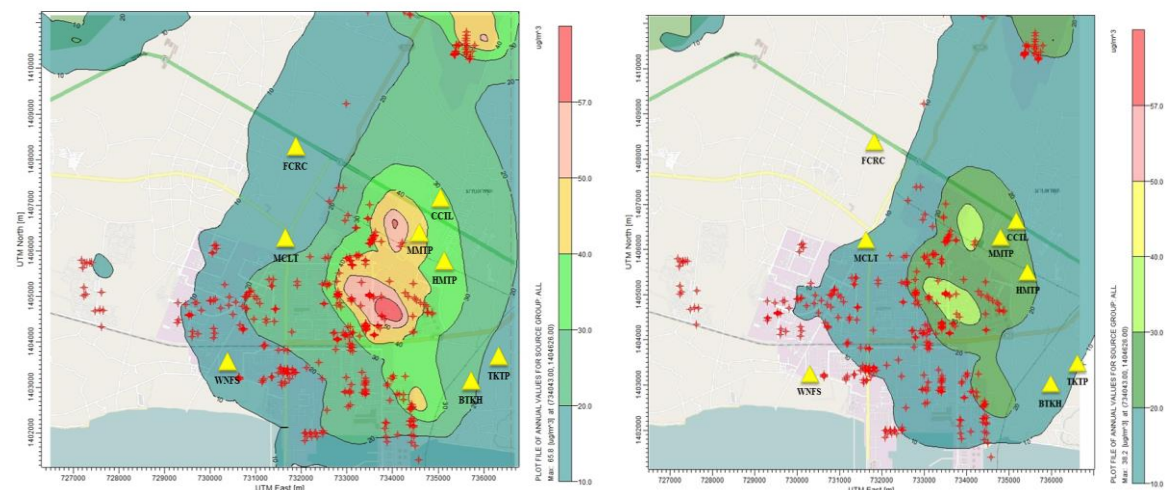


Fig.7 Annual average concentration of  $\text{NO}_x$  for normal emission rate and 40% emission rate decreasing from petrochemical & chemical industries and power plant

#### 4. DISCUSSION AND CONCLUSION

This study focused on analysis of assimilative capacities of sulfur dioxide (SO<sub>2</sub>) and oxides of nitrogen (NO<sub>x</sub>) in the largest petrochemical industrial complex in Thailand. AERMOD dispersion model was simulated to compute for ground level concentrations and spatial distributions of SO<sub>2</sub> and nitrogen dioxide (NO<sub>2</sub>). Results indicated that under current emission rate, predicted maximum NO<sub>2</sub> concentration (1-hr average) was higher than its ambient air quality standard. Therefore, emissions of NO<sub>x</sub> must be reduced from its existing level. Evaluation of carrying capacity indicated that emission rate of NO<sub>x</sub> in the entire area must be reduced to the level of about 1296.54 g/s in order to attain NO<sub>2</sub> ground level concentrations within the environmental quality standard. This amount corresponded to about 40% decreased from current total emission rate. A study on source contribution of NO<sub>2</sub> concentration in Maptaphut area indicated that mostly of NO<sub>2</sub> at WNSF were contributed by petrochemical industrial and Power plant group (about 91 %) [10], [18]. Therefore, efforts in reducing NO<sub>x</sub> emissions should be given to those petrochemical factories in this industrial complex. As for SO<sub>2</sub>, the values of maximum 1-hr and annual average concentrations at receptors predicted under current emission rate were below the Thai ambient standard for SO<sub>2</sub>. It was estimated that emission rate of SO<sub>2</sub> could be increased up to 4765.19 g/s in order to attain ground level concentration of SO<sub>2</sub> within its environmental standard. These emission amounts corresponded to about 130 % increasing from current SO<sub>2</sub> emissions in this study area. Results of this study revealed that an existing regulation in controlling individual emission source by using emission standard may insufficient. Analysis of air pollution as area-based approach by taking into consideration entire emission sources can support for better planning and management of pollution in the study area as well as can be used for further implementation in other industrial complex areas.

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