Applications of Atmospheric Dispersion Model for Air Quality Assessment of NO_x and SO_2 from Waste Incinerator

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Abstract

Oxides of nitrogen (NO_x) and sulfur dioxide (SO_2) are included in the criteria air pollutants and plays the role in the formation of acid rain. Waste incinerator are a major sources of NO_x and SO_2, particularly on local basic of air pollutions. This study was designed to assess the impact of NO_x and SO_2 emissions that are emitted from the waste incinerator at Walailak University to the ambient concentrations using an atmospheric dispersion model, AERMOD for the two simulated years of 2010 and 2012. Stack emissions of NO_x and SO_2 were taken from stack monitoring data of the waste incinerator. Meteorological data were mainly taken from Thai Metrological Department for the study area while terrain data were taken from ASTER GDEM database. Results indicated that maximum NO_x concentration were 3.30, 0.30 and 0.13 $\mu g/m^3$, respectively for 1-hour, 24-hour and annual average while those for SO_2 were 18.68, 1.72 and 0.72 $\mu g/m^3$, respectively. Simulated concentrations of NO_x and SO_2 were well below the values specified in the National Ambient Air Quality Standards of Thailand and World Health Organization Guidelines.

Keywords: Oxides of Nitrogen / Sulfur Dioxide / Atmospheric Dispersion Model / AERMOD

1.Introduction

Oxides of nitrogen (NO_x) and sulfur dioxide (SO_2) are produced during the oxidation processes [Seinfeld, J.H. and Pandis, S.N. 2006; Bai, Y., Thompson, G.E. and Martinez-Ramirez, S. 2006]. NO_x is defined as the combination of nitric oxide (NO) and nitrogen dioxide (NO_2) that are mainly emitted during the combustion, especially with excess volume of air and high temperature. SO_2 in the ambient air is mostly produced by the combustion of sulfur content in fuels [Seinfeld, J.H. and Pandis, S.N. 2006]. NO_x and SO_2 are generally included in the criteria pollutants of ambient air quality standards of national and international guidelines.[PCD.2014;USEPA.2014,WHO. 2006]. With their highly reactivity, NO_x and SO_2 are known to have adverse impacts on health (i.e. irritation on eyes, nose and throat, and respiratory problems) and on the environment (i.e. vegetation damages due to acid rains and visibility impairment) [WHO,2006,Afzali,A., Rashid M., Noorhafizah K. and Ammar M.R. 2014].

Waste generated by laboratories and the Healthcare Centers such as latex gloves, gauze, cotton balls, tissue paper etc. at Walailak University were measured to be around 200 kg/week. Compositions of waste can be classified into three main types: cotton balls and similar materials (65.5%), gloves and plastics (32.0%) and sharp materials (0.5%) [Khamwichit, W., Chareonsuk, T. and Khamwichit, A. 2010]. These types of waste were characterized as hazardous substances and require specific disposal methods [Khamwichit, W., Chareonsuk, T. and Khamwichit, A. 2010]. A number of methods could be employed to handle these unwanted materials, i.e. neutralization, encapsulation and thermal process. Incineration serves as a suitable solution. The incinerator at the university has been operated since 2010 with regular monitoring for stack emissions.

However, air pollutant concentrations surrounding the local communities were not regularly and thoroughly monitored. Concentrations of ambient air pollutants are predominantly dependent on meteorological parameters, i.e. ambient temperatures, wind speed and direction and height of mixing layer etc. [Seangkiatiyuth, K., Surapipith, V., Tantrakarnapa, K. and Lothongkum, A.W. 2011; Abdul-Wahab, S.A., Chan, K., Elkamel, A. and Ahmadi, L. 2014; Liamsanguan C. and Gheewala SH. 2007]. Hence, a mathematical model is therefore of interest and a cost-effective tool to assess the levels of pollutions [Sonawane, N.V., Patil, R.S. and Sethi, V. 2012, Haichao, W., Wenling, J., Lahdelma, R., Pinghua, Z. and Shuhui, Z. 2013, Thompson J. and Anthony H. 2005., Afzali, A., Rashid M., Noorhafizah K. and mmar M.R. 2014].This study is aimed at assessing the levels of NO_x and SO_2 concentrations and its dispersion behaviors surrounding the incinerator (10 km x 10 km) using the atmospheric dispersion model, AERMOD, in the two simulated years: 2010 and 2012.

2. Methodology

2.1 The Study Site

The waste incinerator is located at 599,722E, 954,678N in Walailak University (see also Figure 1 for location). It was designed to process infectious and chemical waste at 100 kg/hour. There were 2 combustion chambers equipped with wet scrubbers and an adsorption unit for flue gas treatment before emission into the atmosphere [Khamwichit,W.,Chareonsuk, T. and Khamwichit, A. 2010].

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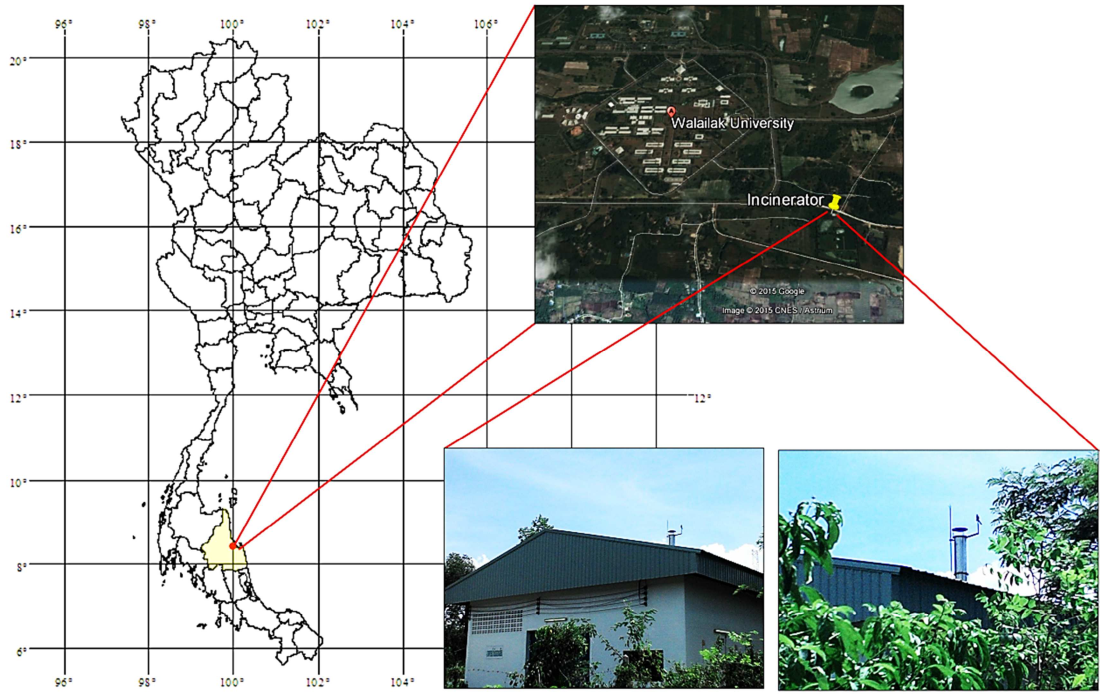

Figure 1: Study Area

2.2 Data Collection

There were three main types of input data for the modeling run: (1) emissions of NO_x and SO_2; (2) hourly meteorological input data; and (3) terrain data.

2.2.1 Emission rate and stack information

Emission rates of pollutants and stack parameters (see Table 1) were obtained from the Building and Facility Division and the Chemical and Process Engineering Laboratory at Walailak University. These data, particularly stack emissions of NO_x and SO_2 have been measured regularly by the Chemical and Process Engineering Laboratory. For the worst case scenario of air quality analysis, the study assumed continuous operation of the incinerator following the principal assumptions of AERMOD model. Note that actual operation of the incinerator is now around once a week since the quantity of waste generated (200 kg/week) is still much lower than the designed capacity (100 kg/hour).

2.2.2 Meteorological data

The meteorological data were mainly taken from the meteorological station in Nakhon Si Thammarat Province (study area), while the absent values were filled with the data at the meteorological stations in Surat Thani and Trang Provinces, respectively. These two provinces are the nearest locations with similar meteorology. Meteorological data in 2 years of 2010 and 2012 were used. Note that 2010 was the year the operation of the incinerator started up, while 2012 was the study year to be used for result comparison and confirmation of the pollution prone area. Specifically, two types of meteorological data are required to run the model: surface and profile (upper air) data. Surface data consisted of hourly dry bulb temperature, wind speed and direction, cloud ceiling height and cloud cover. For upper air data, twice daily sounding upper air data were taken from the National Oceanic and Atmospheric Administration (NOAA) for the meteorological station in Nakhon Si Thammarat.

2.2.3 Terrain data

Terrain data as digital elevation data (DEM) file were obtained from the global data archive at ASTER GDEM. (data available at: http://gdem.ersdac.jspacesystems.or.jp/search.jsp) for the area of Nakhon Si Thammarat. The DEM provides with 30 m. in resolution to generation the elevation and hill height for stacks and receptors in the modeling system.

2.3 AERMOD Modeling Processes

AERMOD,an atmospheric dispersion model, is developed by the American Meteorological Society (AMS) and the US Environmental Protection Agency [USEPA.2004, USEPA.2009]. The model is designed based on Gaussian equation to simulate pollutant dispersions from various polluting sources including point, area and volume sources. It is designed for short-range dispersion ($\leq$ 50 km). However, to use the AERMOD, conservation of mass from sources was assumed, that means no chemical reaction takes place in the model simulation [USEPA.2004, USEPA.2009]. In this study, atmospheric removal mechanisms due to wet and dry depositions of NO_x and SO_2 were not considered. The simulated pollutant concentrations were mainly due to loading rates of emissions and dispersion mechanisms. AERMOD (USEPA Version 09292) was used. The model domain was set up at 10 km x 10 km (Cartesian 50 x 50 grids of 200 m resolution). AERMOD comprised of two main preprocessors: AERMET and AERMAP.

2.3.1 AERMET

AERMET is a meteorological preprocessor for AERMOD. AERMET is developed to covert the meteorological data to the suitable format for AERMOD [USEPA.2004, USEPA.2009]. Outputs from AERMET module consisted of surface meteoroidal data and upper air data.

2.3.2 AERMAP

AERMAP is a terrain preprocessor for AERMOD. AERMAP is developed to utilize Digital Elevation Data (DEM) to generate the appropriate file to be used within the control file of AERMOD. This file contains scaling factors of elevation and hill height for all indicated sources and receptors in the modeling domain [USEPA.2004, USEPA.2009].

3. Results and Discussion

3.1 Oxides of Nitrogen (NO_x)

The simulated NO_x concentrations in comparison with the National Ambient Air Quality Standards (NAAQS) of Thailand and the World Health Organization (WHO) guidelines are shown in Table 2.

The maximum simulated concentrations of NO_x were 3.30, 0.30 and 0.13 µg/m^3,respectively for 1 hour, 24 hour and annual averages over the domain of 5 km radius surrounding the incinerator. The area with maximum concentrations of NO_x contributed by the stack emission in this study were mainly within 500 m radius around the source. Simulated concentrations all cases did not exceed the NAAOS and WHO guidelines.

Table 1: Stack and emission information

Parameters		Stack
Stack Location (UTM)		599722E, 954678N
Stack Demension	Height (m)	9.42
	Diameter (m)	0.40
	Temperature k)	384.6
	Velocity (m/s)	0.6
Loding Rate (g/s) [a]	NO_x	0.006
	SO_2	0.034

Remark: Information was obtained from the Building and Facility Division and the Chemical and Process Engineering Laboratory at Walailak University
[a] Maximum emission rates in 2010 were used for worst case analysis.

Spatial distributions of NO_x concentrations for maximum 1 hour, and 24 hour and annual annual average in 2010 and 2012 are indicated in Figure 2 - Figure 4. The dispersion patterns and concentrations of NO_x in 2010 and 2012 were rather similar for all simulation cases.

Table 2: Summary of maximum NO_x concentration

Description	NO_x (µg/m^3)		
	1 Hour Average	24 Hour Average	Annual Average
Max. concentration [a]			
- 2010	3.30	0.29	0.13
- 2012	2.44	0.30	0.11
Location of max. concentration			
- 2010	(599,522N, 954,678E)	(599,722N, 954,878E)	(599,522N, 954,678E)
- 2012	(599,522N, 954,678E)	(599,722N, 954,878E)	(599,722N, 954,878E)
NAAQS of Thailand [b]	320	n.s.	57
WHO guidelines [b]	200	n.s.	40

Remark: [a] Excluding background concentrations; [b] Specified as NO_2; n.s. is not specified.

For 1 hour average NO_x simulation (Figure 2), maximum concentrations were found to be 3.30 and 2.44 µg/m^3, respectively in 2010 and 2012. Hourly simulated NO_x concentrations were accounted for around 1% of NAAQS value (320 µg/m^3). For 24 hour average NO_x simulation (Figure 3), maximum concentrations were found to be 0.29 and 0.30 µg/m^3, respectively in 2010 and 2012. For annual average NO_x simulation (Figure 4), maximum concentrations were found to be 3.30 and 2.44 µg/m^3, respectively in 2010 and 2012. Hourly simulated NO_x concentrations

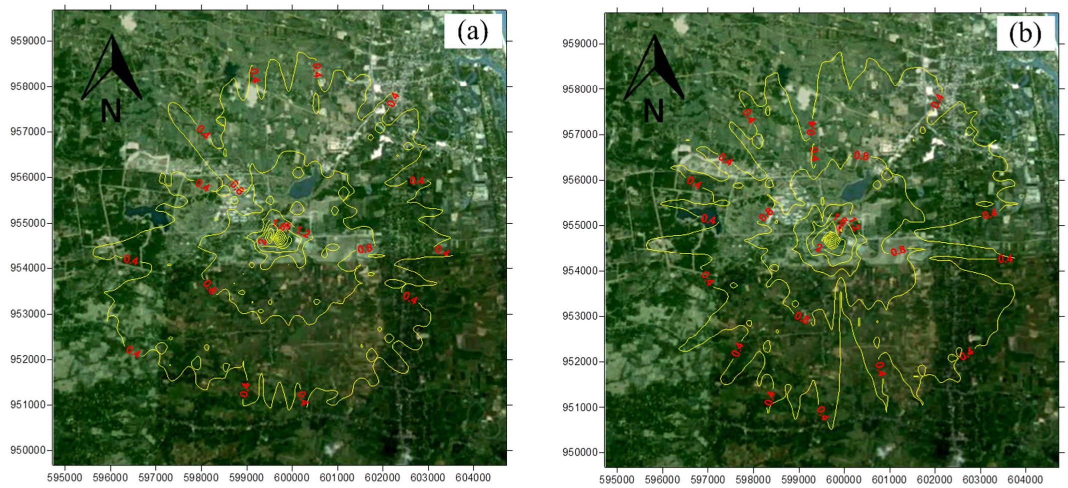

Figure 2: Maximum 1-hour average NO_x concentrations (µg/m^3) in (a) 2010 and (b) 2012

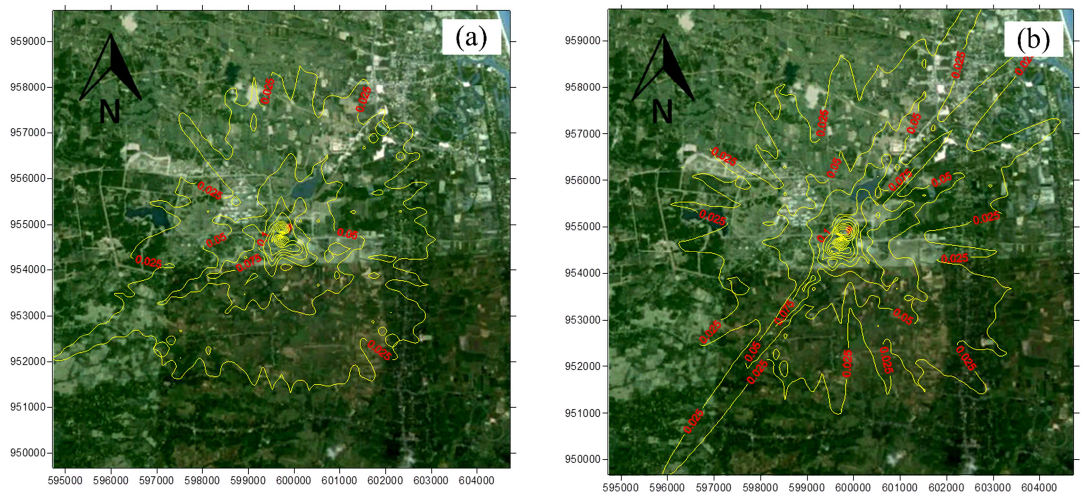

Figure 3: Maximum 24-hour average NO_x concentrations (µg/m^3) in (a) 2010 and (b) 2012

were accounted for around 1% of NAAQS value (320 µg/m^3). For 24 hour average NO_x simulation (Figure 3), maximum concentrations were found to be 0.29 and 0.30 µg/m^3, respectively in 2010 and 2012. For annual average NO_x simulation (Figure 4), maximum concentrations were found to be 0.13 and 0.11 µg/m^3, respectively in 2010 and 2012 that were accounted for around 0.2% of

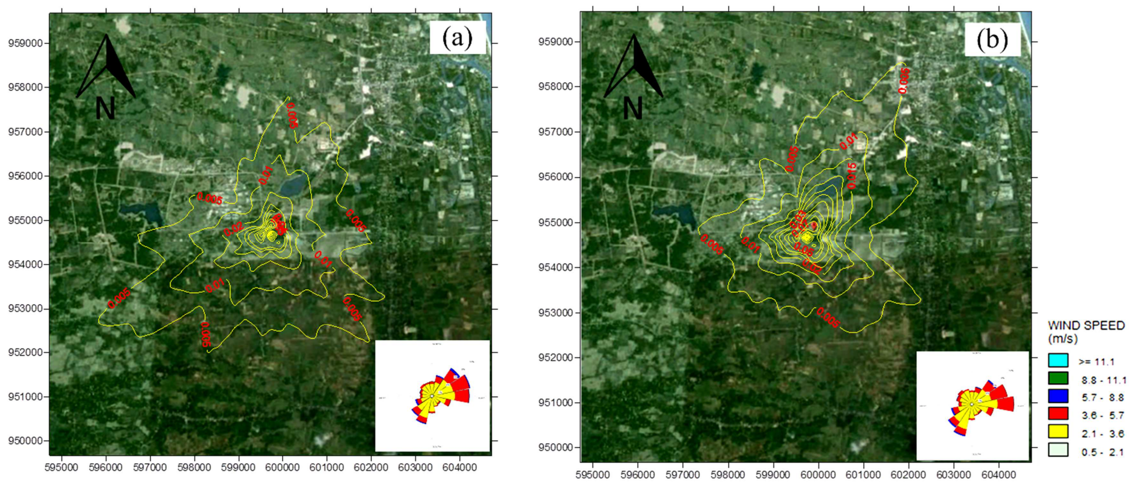

Figure 4: Annual average NO_x concentrations (µg/m^3) in (a) 2010 and (b) 2012

NAAQS value (57 µg/m^3).In Figure 4, annual wind pattern was also attached. Wind direction was predominated by Northeast and Southwest with the average wind speeds of approximately 2.1 - 5.7 m/s. It was consistent with the annual average NO_x simulation. The pollutant plumes lay on Northeast and Southwest directions. High simulated concentrations of NO_x for 1 hour and 24 hour average were found mostly during October and February, particularly November.

3.2 Sulfur Dioxide(SO_2)

The simulated SO_2 concentrations in comparison with the NAAQS and WHO guidelines are shown in Table 3. The maximum simulated concentrations of SO_2 were 18.68, 1.72 and 0.72 µg/m^3, respectively for maximum 1 hour, 24 hour and annual averages over the domain of 5 km. radius surrounding the incinerator. Similarly to NO_x, the area with maximum concentration of SO_2 contributed by the stack emission in this study, were mainly within 500 m radius around the source. Simulated concentrations for all cases also did not exceed the NAAQS and WHO guidelines.

Table 3: Summary of maximum SO_2 concentration

Description	SO_x (µg/m^3)		
	1 Hour Average	24 Hour Average	Annual Average
Max. concentration [a]			
- 2010	18.68	1.63	0.72
- 2012	13.85	1.72	0.62
Location of max. concentration			
- 2010	(599,522N, 954,678E)	(599,722N, 954,878E)	(599,522N, 954,678E)
- 2012	(599,522N, 954,678E)	(599,722N, 954,878E)	(599,922N, 954,878E)
NAAQS of Thailand	780	300	100
WHO guidelines	n.s.	20	n.s.

Remark: [a] Excluding background concentrations; n.s. is not specified.

Spatial distributions of SO_2 concentrations for maximum 1 hour, 24 hour and annual averages in 2010 and 2012 are indicated in Figure 5 - Figure 7. For 1 hour average SO_2 simulation (Figure 5), maximum concentrations were found to be 18.68 and 13.85 µg/m^3, respectively in 2010 and 2012. Hourly simulated SO_2 concentrations were accounted for around 2.4% of NAAQS value (780 µg/m^3). For 24 hour average SO_2 simulation (Figure 6), maximum concentrations were found to be 1.63 and 1.72 µg/m^3, respectively in 2010 and 2012. Daily simulated SO_2 concentrations were accounted for around 0.57% of NAAQS value (300 µg/m^3) and 8.6% of WHO value (20 µg/m^3), respectively. For annual average SO_2 simulation (Figure 7), maximum concentrations were found to be 0.72 and 0.62 µg/m^3, respectively in 2010 and 2012 that were accounted for around 0.7% of NAAQS value (100 µg/m^3). Wind pattern was consistent with the annual average SO_2 simulation. Similarly to NO_x, high simulated concentrations of NO_x for 1 hour and 24 hour averages were found mostly during October and February, particularly November.

In discussion, the simulated NO_x and SO_2 concentrations were well below the NAAQS and WHO air quality guidelines; however, monitoring campaigns would be set up to surveillance the actual concentrations of air pollutants at the local receptors, particularly at the locations of high simulated concentrations. Increasing rates of the chemical and infectious wastes from laboratory and healthcare sectors in the future due to the growing number of students and the establishment of new hospital, respectively would increase the local pollution burdens. Long term exposures to NO_x and SO_2 at low concentrations could be a cause of chronic bronchitic symptoms of asthmatic children [WHO. 2006]. Modeling performance evaluation with the monitoring data was recommended prior to apply the simulation results for further analysis of adverse health impacts. To obtain monitoring data, systematic measurement of ambient NO_x and SO_2 could be initially set up at least at the sensitive receptors downwind of the pollution source.

In this study, we compared the simulated values with the standard, without taking into account the background concentrations. Lack of monitoring stations as mentioned earlier in the area is one of the reasons for not considering background concentration. In addition, the study area is located in a rural area far from sources of air pollution, i.e. main roads and industries. Background concentrations of ambient air pollutants, NO_x and SO_2, could be expected to be rather low.

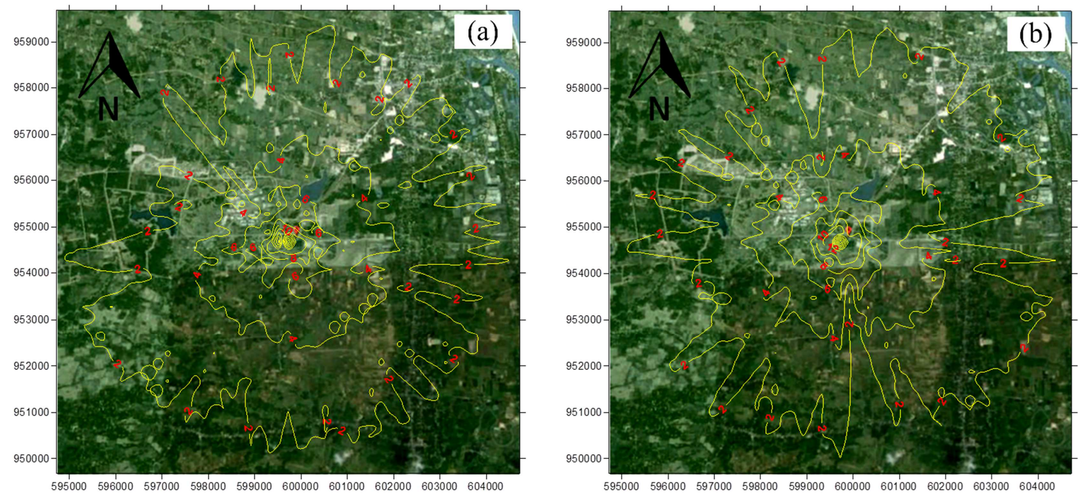

Figure 5: Maximum 1-hour average SO_2 concentrations (μg/m^3) in (a) 2010 and (b) 2012

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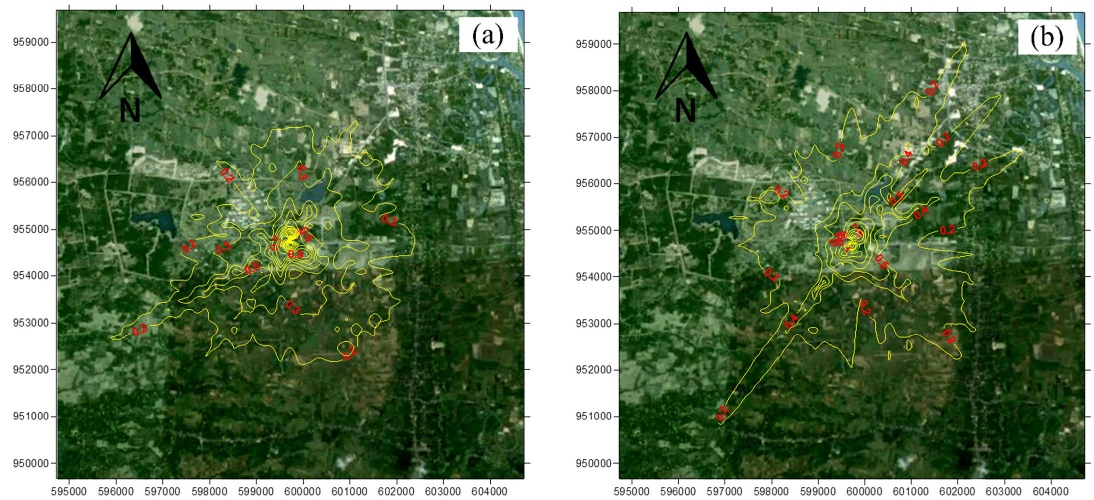

Figure 6: Maximum 24-hour average SO_2 concentrations (μg/m^3) in (a) 2010 and (b) 2012

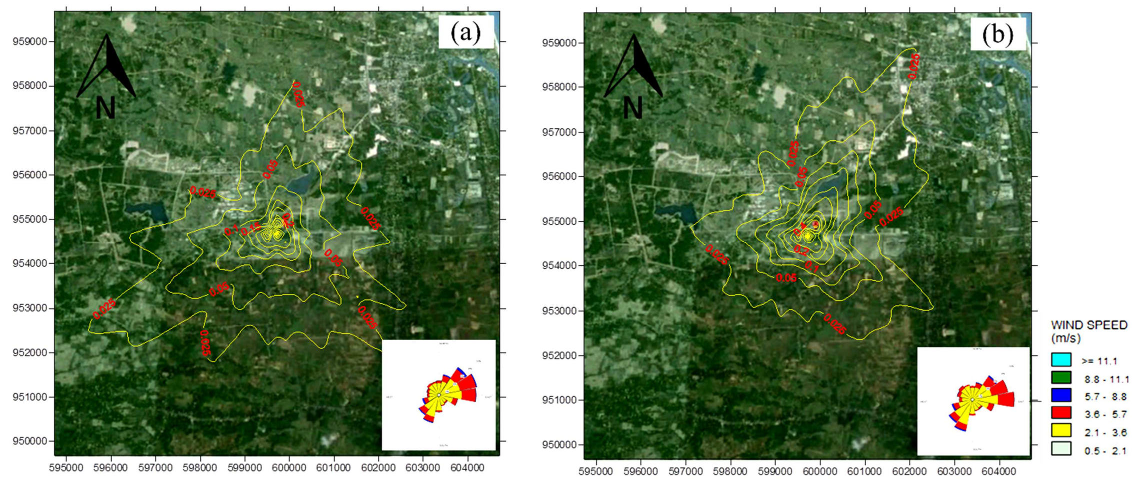

Figure 7: Annual average SO_2 concentrations (μg/m^3) in (a) 2010 and (b) 2012

We have also seen clearly that maximum hourly, daily and annual averages of simulated results in two different years (2010 and 2012) located mainly within 500 m from the incinerator with similar locations. For spatial analysis, although there is lack of data from the monitored area, modeling results showed that the air pollutants would remain prominent to the local source. For temporal analysis, high simulated concentrations of NO_x and SO_2 were mainly found during October and February due to the meteorological patterns. Particularly, November was found to be the month of greatest numbers of high concentrations. For short term mitigation, avoiding the operation in these months as much as possible could be expected to reduce the pollution burdens to the local receptors. As mentioned earlier, quantity of waste generated was still lower than the incinerator capacity. It is a promising solution to store the waste for a few months. For long term measures however, a redesign of the stack parameters, i.e. increasing stack height could be another suggestion, but this requires financial support. To design the proper stack height, modeling systems would need to be set up again to analyze the impacts of different stack heights on the local air quality.

4. Conclusions

The maximum simulated concentrations of NO_x were 3.30, 0.30 and 0.13 µg/m^3, respectively for maximum 1 hour, 24 hour and annual average while those for SO_2 concentrations were 18.68, 1.72 and 0.72 µg/m^3, respectively. Due to a lack of background ambient concentrations, simulated values were compared directly with the standards. Both simulated NO_x and SO_2 concentrations were well below the standard values of both Thai legislation and WHO guidelines. It is noteworthy that high concentrations of NO_x and SO_2 were mostly found during October - February, and particularly in November. Therefore, by avoiding use of the incinerator during these months, it can be expected to reduce pollution burdens to nearby local communities and receptors. For long term mitigation, the redesign of the stack parameters, i.e. increasing stack height would be expected to reduce air pollution to the local receptors.

5.Acknowledgements

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