Simulation and monitoring of sulfur dioxide and nitrogen oxide in the Jakarta metropolitan area.

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Abstract: From July 2000 to December 2001, SO_2, NO_2 and NO_x concentrations at 20 sampling points in the Jakarta metropolitan area were measured using passive samplers. High concentrations of SO_2 were found near the power plant in the northern part of the city and high levels of NO_x in the central area due to heavy traffic volume. Simulation results also indicated that SO_2 concentrations would be high near the power plant in the northern part of Jakarta and that NO_x concentrations would be high along roads and in the central city. We found a good correlation between the simulation and observations within factor 2, because most simulated concentrations exited between two times and a half time of observed concentrations. Factories contributed approximately 68% of SO_2 emissions, and 49% of NO_x emissions were released by motor vehicles.

Keywords: Passive sampler, monitoring, simulation, sulfur dioxide, nitrogen oxide

Introduction

Jakarta, the capital city of the Republic of Indonesia, was previously known as Batavia. Jakarta belongs to the island of Java, located south of the equator, at longitude 106.48 W and latitude of 6.17 S. Jakarta has a fast growing population and is the eleventh largest city in the world. In 1950, there were approximately 1.4 million

residents, and by 1995, the population increased to 11.5 million. By 2015, Jakarta is expected to be the fifth largest city in the world. (Cahyandito, 2001). One impact of population growth and economic development has been the increase of air pollution problems. Jakarta City ranks as one of the most polluted cities in the world (WHO, 1999). Transportation sources are estimated to emit 80% of total nitrogen oxides (NO_x) and factories emit 70% of total sulfur oxides (SO_x) in Jakarta (Ostro, 1994). As in any large industrialized city, there is a growing demand for automobiles. According to the Land Transport Organization, there are currently more than 3 million vehicles in Jakarta (1999), and their number is expected to increase every year. This increasing number and density of vehicles requires an increased consumption of oil and other energy sources. The proliferation of vehicles is one of the major factors contributing to a decline in air quality.

Although the concentrations of air pollutants such as sulfur dioxide (SO_2), NO_x and total suspended particulate matter (TSP) in Jakarta have been monitored under several projects(Cohen,1997; EMC, 1994; JICA and EIMA, 1995; KPPL, 1997), for certain monitoring projects, the analysis of the data were lack and a report was not published. Although the published report indicates that TSP concentrations exceed the World Health Organization (WHO) standard, and that concentrations of NOx and carbon monoxide (CO) are also comparatively high (Achmadi, 1996), each of the monitoring projects considered a limited number of monitoring points, and there has not been a project that has monitored the entire Jakarta region continuously over a fixed term or that has analyzed the results.

In this study, SO_2 and NO_x concentrations were collected at 20 sampling locations throughout the Jakarta metropolitan area, and monitoring was conducted throughout the year. The main objective of expanding the number of sampling points was to obtain a more detailed depiction of SO_2 and NO_x concentrations in order to clarify the present air quality conditions in Jakarta City. SO_2 and NO_x emission levels were also estimated from historic statistical data for fuel consumption, population and motor vehicles, and annual average concentrations were calculated using a mathematical model.
We compared the calculated results with the observed monitoring results in order to verify the validity of our source estimation in Jakarta.

Measurement of air pollution

1. Sampling points

The concentrations of SO_2, NO_2 and NO_x were measured at 20 sampling points in the Jakarta City area, which were selected with the following criteria; the distance from main road is over 20m, the height from ground level is over 2m. The location of the sampling points are shown in Figure 1, and the representative geographical area and name of the sampling locations are shown in Table 1.

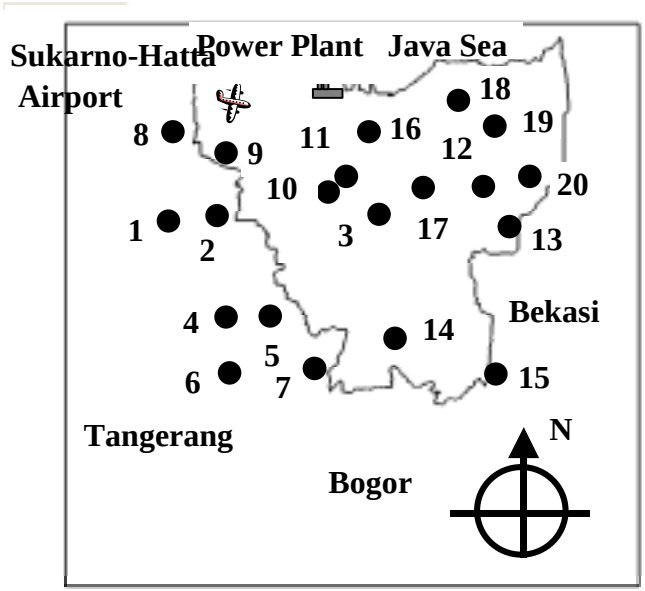

Figure 1. Locations of sampling points in Jakarta City.

Table 1. Representative area and name of sampling points.

Area	Point	Number
South Jakarta	Kunciran	1
	Cileduk	2
	KPPL	3
	Pamulang	4
	Ciputat	5
	EMC	6
	Cinere	7
West Jakarta	Batu Ceper	8
	Semanan Indah	9
	Kebon Jeruk	10
	Slipi	11
East Jakarta	Pulogadung	12
	Duren Sawit	13
	Cijantung	14
	Cipayung	15
Central Jakarta	Sawah Besar	16
	Matraman	17
North Jakarta	Tanjung Priuk	18
	Sukapura	19
	Cakung	20

2. Sampling procedures

2.1. Structure of passive sampler

The advantage using a passive sampler is easy to operate, without energy power, and low cost (Hangartner, 2001). The principle of passive sampler is based on the molecular diffusion. Air pollutant gases in the air are transferred by the flowing wind and will react and collected on filter, which is coated with an absorbent species. Many researches (Bush, 1998; Glasius, 1999) about the comparison of passive sampler and active sampler reported that passive sampler was the useful method to measure air pollution concentration. A passive sampler used (Ogawa passive sampler, PS 115) has two collection elements equipped with filters for the collection of gaseous substances. One filter is used for the collection of SO_2 and NO_2, and the other for the collection of NO_x. A photograph and a structural diagram of the passive sampler used in this study are shown in Figure 2a and Figure 2b, respectively.

Figure 2a. Photo of passive sampler

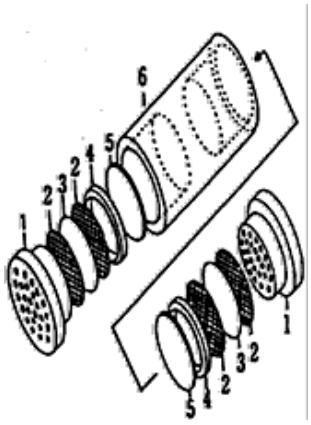

Figure 2b. Structure of passive sampler

2.2. Field sampling

The collection of measurements was started in July 2000 and continued until

December 2001. The passive samplers were used to provide measurements as described in section 2.1. The passive samplers were prepared and installed by EMC (Environmental Management Center) staff at 20 sampling points, as shown in Figure 1. The filters were exposed to the air for two weeks, then collected, put into vials and packed in an aluminum bag to protect the impact of air and solar radiation. Each month, 160 collected filters (20 sampling points x 2 filters x 4 weeks) were sent to Japan. The concentrations of SO_2, NO_2 and NO_x were analyzed at Osaka University.

3. Method of chemical analysis

SO_3^- was extracted from the filters into pure water by shaking for 30 minutes, then oxidized to SO_4^{2-} by Pt and H_2O_2, and then sample conductivity was measured by ion chromatography. NO_2 and NO_x were measured by adding a color development reagent (N (1-naphtyl) ethylenediamine hydrochloride (NEDA) + Sulfanilamide solution). The colored solution was transferred to a photocell tube of a spectrophotometer to measure the absorbance. For reference, an unexposed blank filter and standard solution were processed in the same manner.

4. Measurement results

Figures 3a, 4a, and 5a show the distribution of the annual average concentration of SO_2, NO_2 and NO_x from July 2000 to December 2001, respectively. Figures 3b, 4b, and 5b show the annual average concentration and the standard deviation of SO_2, NO_2 and NO_x, respectively. Measurements at all sites were not collected in August 2000 because of a traffic accident. As the concentrations at sampling points 7 and 15 were the high value, we investigated these sampling fields. We confirmed that exhaust gases from motor vehicles affected these fields, because the sampling points were selected near roads. Therefore the measurement results collected at sampling points 7 and 15 were not adopted. SO_2 concentrations at sampling points 9 and 16 exceeded atmospheric standard of Indonesia (21 ppb). The highest concentrations of SO_2 were found at north Jakarta (18,19,20). NO_x concentration at sampling point 11 was over 40 ppb and was the close value to atmospheric standard of Indonesia (48 ppb). The ratio NO/NO_2 was over the value of 1.0 at most sampling points. This result means that NO concentration is high and suggests that motor vehicles are the major contributor of NO_x concentration.

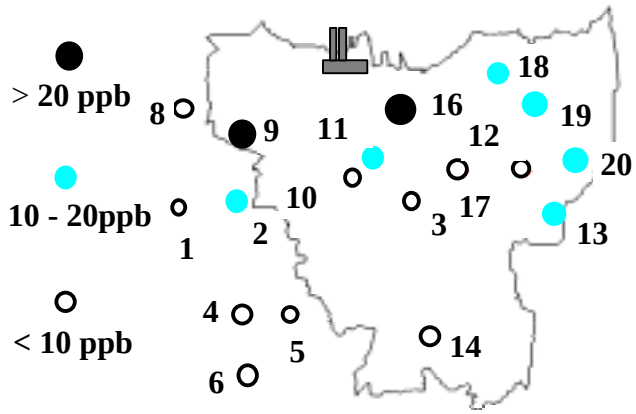

Figure 3a. Distribution of annual average concentration of SO_2 from July 2000 to December 2001.

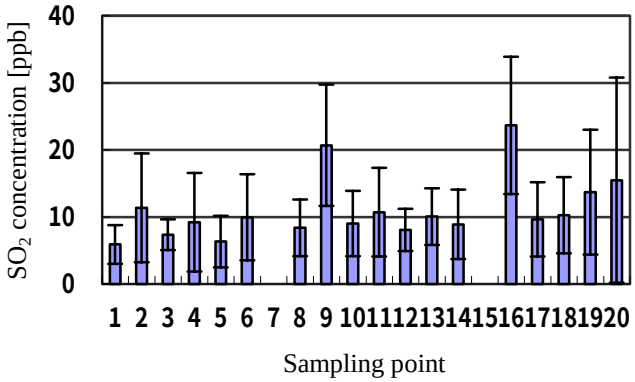

Figure 3b. Annual average concentration and standard deviation of SO_2

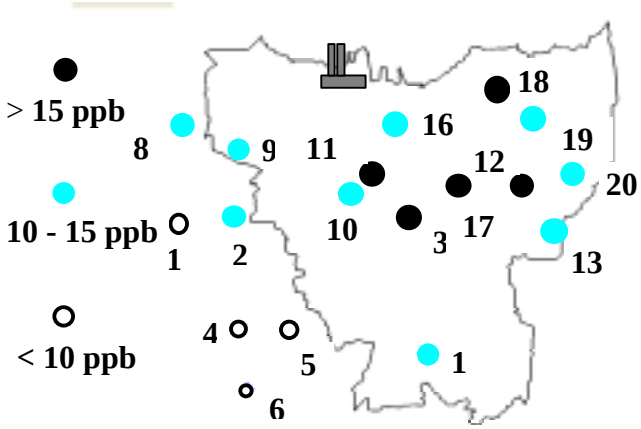

Figure 4a. Distribution of annual average concentration of NO_2 from July 2000 to December 2001.

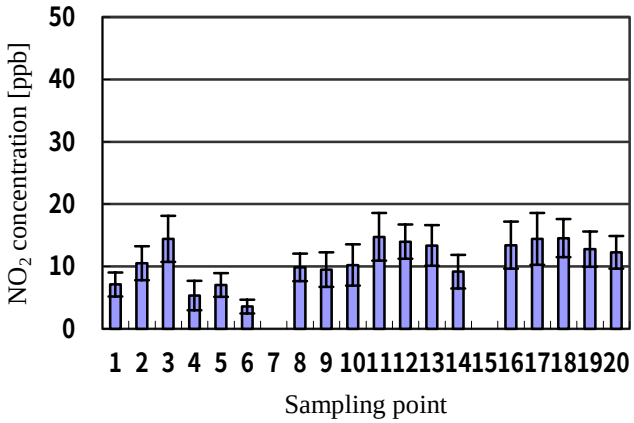

Figure 4b. Annual average concentration and standard deviation of NO_2

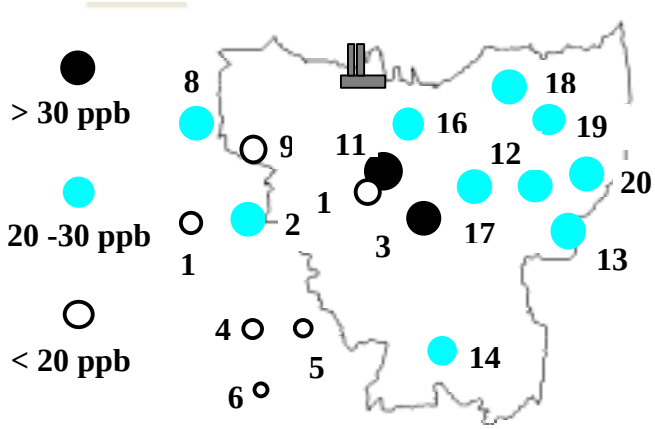

Figure 5a. Distribution of annual average concentration of NO_x from July 2000 to December 2001.

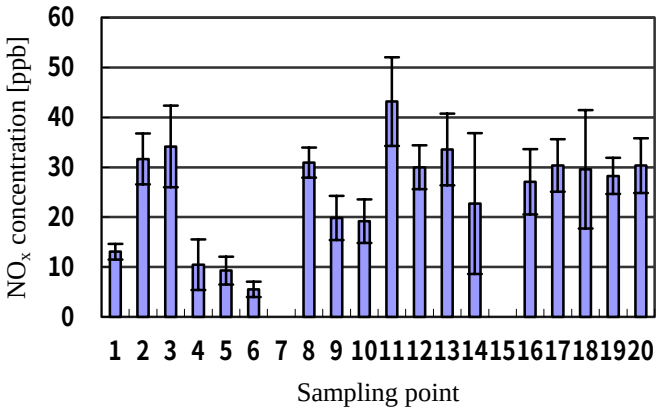

Figure 5b. Annual average concentration and standard deviation of NO_x

Emission loads of SO_2 and NO_x

1. Emission load from factories

In 1995 and 1996, JICA (Japan International Cooperation Agency) and EMC conducted measurement for the concentrations of SO_2, NO_x and TSP, temperature of exhaust gas, diameter of stack and stack height at 36 factories; power plant, glass, and cement. The emission loads from these major factories occupy about 75% of whole emission loads from all factories. These data were used as the emission loads from surveyed facilities. However, we re-estimated the power plant SO_2 emission load to be 24,300 t/yr, based on fuel consumption, sulfur content, and amount of power generation regarding operating conditions obtained during an interview in April 2000 (private communication). The emission load from un-surveyed factories was estimated by

$$E_{uns} = \sum E_{suv} \times F_{uns} / F_{suv} \qquad (1)$$

where E_{uns} and F_{uns} are the emission load and fuel consumption of un-surveyed factories, respectively. E_{sur} and F_{sur} are the emission load and fuel consumption of surveyed factories, respectively.

The emission load and the fuel consumption were summarized in Table 2. The emission load from un-surveyed factories was distributed in proportion to population density of Jakarta City.

Table 2. Emission load from factories.

Fuel type	Consumption		SO_2 emission Load [t/yr]		NO_x emisson load [t/yr]	
	survey(1)	un-survey(2)	survey(1)	un-survey	survey(1)	un-survey
HSD [kl/yr]	295,886	72,446	1,429	350	1,347	330
IDO [kl/yr]	153,021	37,466	299	73	1,100	269
MFO [kl/yr]	498,109	121,957	5,740	1,405	18,154	4,445
NG $10^6[m^3/yr]$	4,060	994	256	63	0	0
Total			7,727	1,891	20,601	5,044

HSD: High Speed Diesel
IDO: Industrial Diesel Oil
MFO: Marine Fuel Oil
NG :Natural Gas
(1) JICA and EIMA, 1995; (2) JSO 1997

2. Emission load from motor vehicles

Traffic volumes were investigated by the Department of Transportation in Indonesia three times per day (8 a.m.-10 a.m., 0 p.m.-2 p.m., and 4 p.m.-6 p.m.) in many places, but not for all roads (DTI, 2000). The traffic volumes per day were estimated, assuming that the diurnal variation of the traffic volume in Jakarta City of

Indonesia was the same as in Osaka City of Japan. We think that this assumption doesn't induce the large error, as both Jakarta City and Osaka City are similar mega city. The traffic volumes for the roads without measurements were presumed to be comparable to the traffic volumes at nearby roads. NO_x emission load from motor vehicles was estimated by

$$E_{veh} = \sum f_{veh,i} \times T_i \times L_i \times 10^{-6} \quad (2)$$

where E_{veh} t/yr is the emission load from motor vehicles, i is the type of motor vehicle, $f_{veh,i}$ gkm^{-1}vehicle^{-1} is the emission factor, T_i vehicle/yr is the traffic volume and L_i km is the road length. Motor vehicles are classified into 9 types: motorcycle, passenger car, taxi, microbus, bus, van, small truck, truck with 2 axles, and truck with 3 axles. We used 1980 values (traffic speed of 40 km/h) from Japan as the emission factors. Institute for Transportation and Development Policy reported that 90% of motor vehicles sold in Indonesia was imported from Japan and 70% of these vehicles was used in the Jakarta Metropolitan area (see www.itdp.org /ST /ST6 /ST6JAK.doc). Therefore the value of the emission factors is reasonable. The emission factor for each type of motor vehicles is shown in Table 3.

SO_2 emission load from motor vehicles was estimated from sulfur content of gasoline fuel and diesel fuel. The fuel consumption and sulfur content are shown in Table 4. SO_2 emission load was distributed in proportion to traffic volume.

Table 3. NO_x emission load from vehicles.

Vehicle type	f_{veh} (1) [gkm^{-1}vehicle^{-1}]	$T \times L$ 10^6 [km]	Emission load [t/yr]
Passenger car	0.3	875	263
Taxi	0.3	12,076	3,623
Van	2.24	794	1,780
Microbus	1.06	690	732
Bus	3.09	431	1,331
Small truck	2.04	1,060	2,162
Truck with 2 axles	3.09	278	858
Truck with 3 axles	4.2	24	100
Motorcycle	0.09	13,408	1,207
Total			12,055

(1) NRI 1997

Table 4. SO_2 emission loads of vehicles.

Fuel type	Consumption[(1)] [kl/yr]	Sulfur content[(2)] [%]	Specific gravity [kg/l]	Emission load [t/yr]
Premium	1,441,925	0.015	0.735	318
Solar diese	1,431,259	0.396	0.849	9,624
Total				**9,942**

(1) JSO, 1997; (2) JICA and EIMA,1995

Table 5 NO_x emission load from households.

Fuel type	Consumption[(1)]	f_{hsd} [(2)]	Emission load [t/yr]
Kerosene	1441925[kl/yr]	2.1[kg/kl]	2,698
LPG	1431259[t/yr]	2.06[kg/t]	325
Total			**3,023**

(1) JSO, 1997; (2) JICA and EIMA, 1995

Table 6. SO_2 emission loads from households.

Fuel type	Consumption[(1)] [kl/yr]	Sulfur content[(2)] [%]	Specific gravity [kg/l]	Emission load [t/yr]
Kerosene	1,284,683	0.11	0.867	2,450

(1) JSO 1997; (2) JICA and EIMA, 1995

3. Emission load from households

Statistical data for fuel consumption, an emission factor for fuel combustion and sulfur content were used to estimate the emission load from households. NO_x emission load from households was estimated by

$$E_{hsd} = \sum f_{hsd} \times F_{hsd} \times 10^{-3} \qquad (3)$$

where E_{hsd} t/yr is the emission load of households, f_{hsd} is the emission factor for fuel combustion and F_{hsd} is the fuel consumption of households. The emission factor and the fuel consumption were summarized in Table 5.

SO_2 emission load from households was estimated from sulfur content of kerosene as shown in Table 6. Both NO_x and SO_2 emission load from households was distributed in proportion to the population density of Jakarta City.

4. Total emission load

The emission load rate for SO_2 and NO_x from each source is shown in Figures 6a and 6b, respectively. The SO_2 emission load from surveyed and un-surveyed factories was 68% of the total SO_2 emission load. The SO_2 emission load from the power plant

was more than 43% of the total. The NO_x emission load from motor vehicles was 49% of the total NO_x emission load. The World Bank (Shasawd 1997) reported that the NO_x emission load from motor vehicles was 80% and was 2.5 times larger than our estimated emission loads. Our estimated travel length was twice the travel length used by the World Bank. In contrast, the value used as the emission factor in the present study was about one-fifth the value of that used by the World Bank.

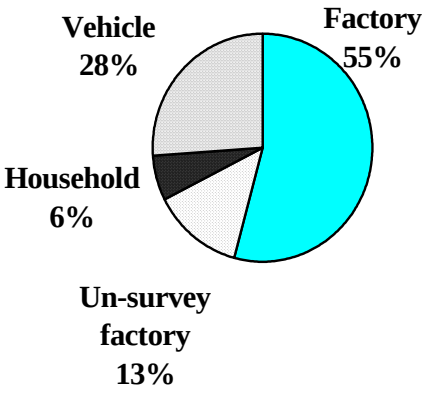

Figure 6a. Total SO_2 emission load (38,037 t/yr)

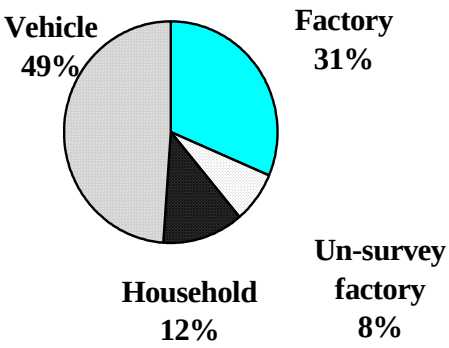

Figure 6b. Total NO_x emission load (24,969 t/yr)

Meteorological Data

Meteorological data from Sukarno-Hatta airport for the year 2000 were used in the simulation model. Wind direction was divided into 16 directions and calm conditions. Wind speed was divided into 7 ranks: 0-0.9(calm condition), 1-1.9, 2-2.9, 3-3.9, 4-5.9, 6-7.9, and 8m/s (EAJ, 1993). The stability of the atmosphere was divided into moderately unstable conditions (during the day) and stable condition (at night) by Pasquill-Gifford chart (EAJ, 1993). The frequency distribution of wind direction and wind speed are shown in Figures 7a and 7b, respectively. The wind direction from south to west (wind direction number: 8 -12) was dominant.

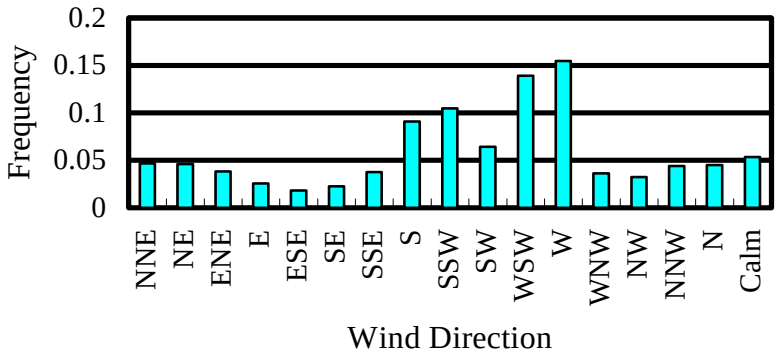

Figure 7a. Frequency distribution of wind direction.

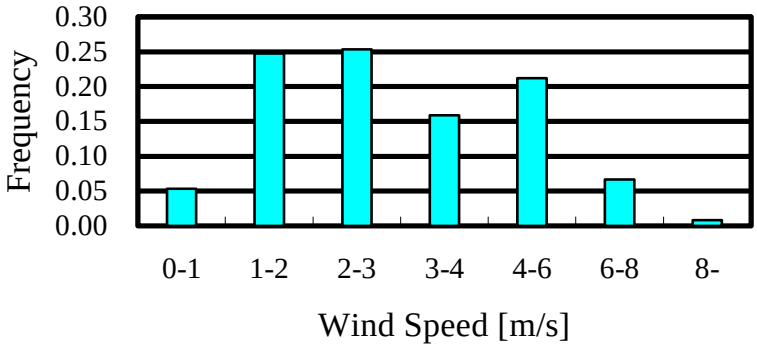

Figure 7b. Frequency distribution of wind speed.

Simulation Model

The annual average concentrations of SO_2 and NO_x were calculated using Plume model (Eq.(4)) for windy conditions (for wind speed higher than 1m/s) and using Puff model (Eq.(5)) for calm conditions (for wind speed lower than 1m/s).

$$c = \frac{Q_p}{\pi \sigma_y \sigma_z u} \exp\left(-\frac{y^2}{2\sigma_y^2}\right) \exp\left(-\frac{H_e^2}{2\sigma_z^2}\right) \tag{4}$$

$$c = \frac{2Q_p}{(2\pi)^{3/2}\gamma} \left(\frac{1}{R^2 + \left(\alpha/\gamma\right)^2 He^2} \right) \tag{5}$$

where Q_P is the emission rate, H_e is effective stack height, U is wind speed, σ_y and σ_z are plume width in y and z direction respectively, R is the distance from a source and α and γ are rate of increase of the horizontal plume width and the vertical plume width, respectively. The effective stack height for surveyed factories was calculated from CONCAWE formula for windy conditions and from Briggs' formula for calm conditions (EAJ 1993). The emission heights for motor vehicles, households and un-surveyed factories were assumed to be constant at 1.5, 5 and 30m, respectively.

The simulated region was 50 km x 50 km, and was divided into 100 x 100 meshes.

Simulation Results

The simulation results for SO_2 and NO_x are shown in Figures 8a and 8b, respectively. The emission load from the power plant, located at the north part of Jakarta City, made the most substantial contribution to SO_2 concentrations. NO_x concentrations

in the central part of Jakarta City were higher than in other regions because of the heavy traffic volume. It was found that the areas of high NO_x concentrations corresponded to the distribution of main roads.

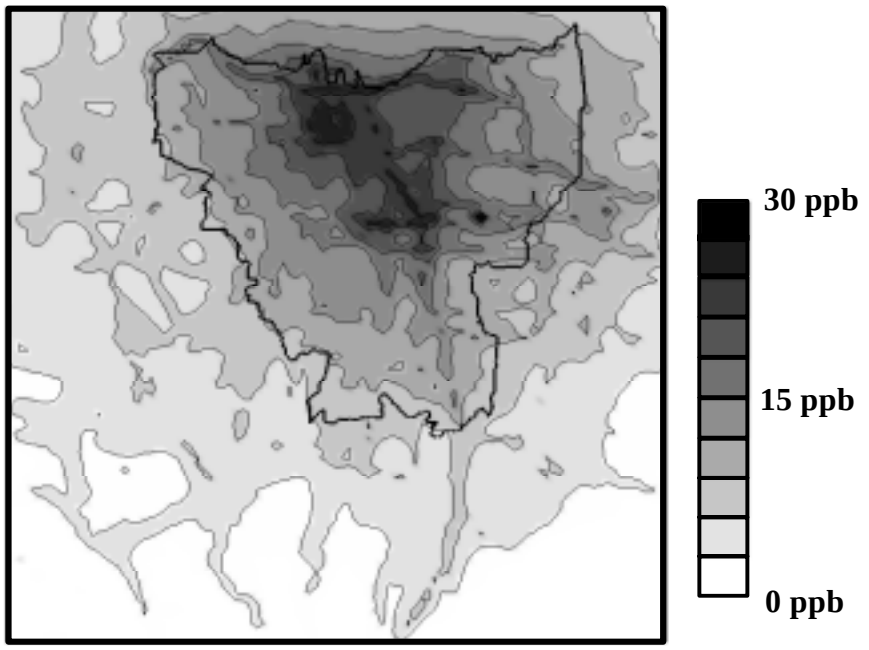

Figure 8a. Simulated annual average concentration of SO_2.

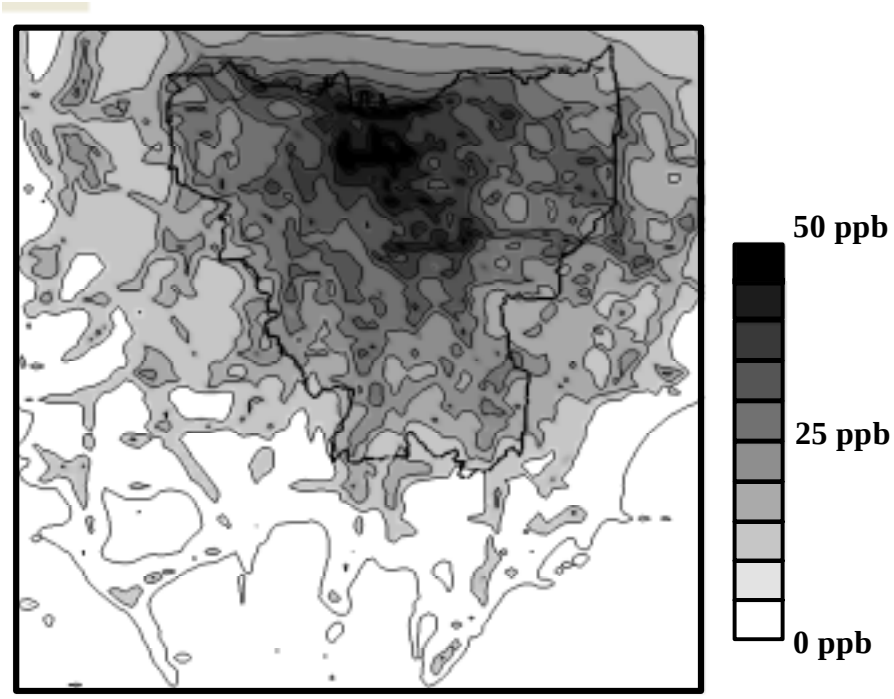

Figure 8b. Simulated annual average concentration of NO_x.

Comparison between Simulation and Observation

To verify the accuracy of estimated emission loads, simulated concentrations were compared with observed concentrations at the 20 sampling points. The correlation between simulated and observed SO_2 and NO_x levels is shown in Figures 9a and 9b, respectively. The solid line represents the line with the slope of one. Two dotted represent the line with a slope of two and of an half, respectively. As most data existed between two dotted lines, the calculated concentration generally agreed with the observed data within factor 2. These results suggest that the emission loads are quite accurate.

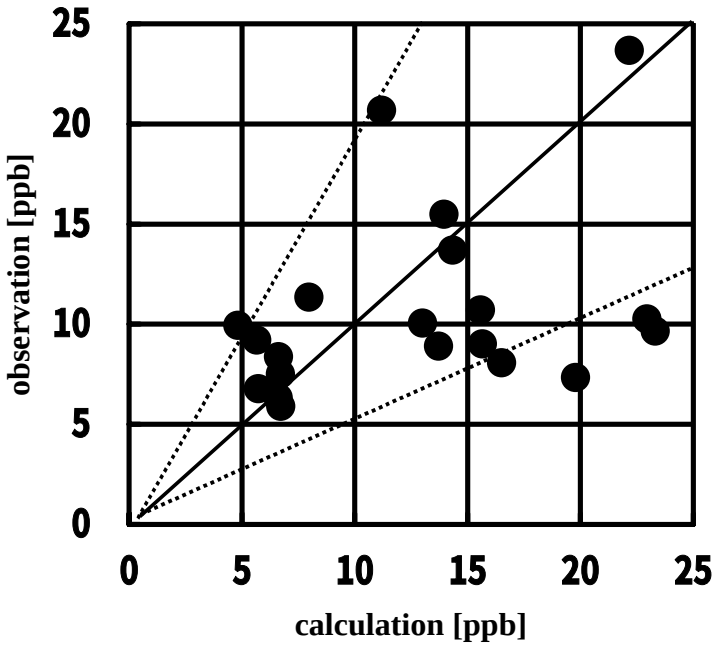

Figure 9a. Correlation between simulated SO_2 concentration and observed SO_2 concentration.

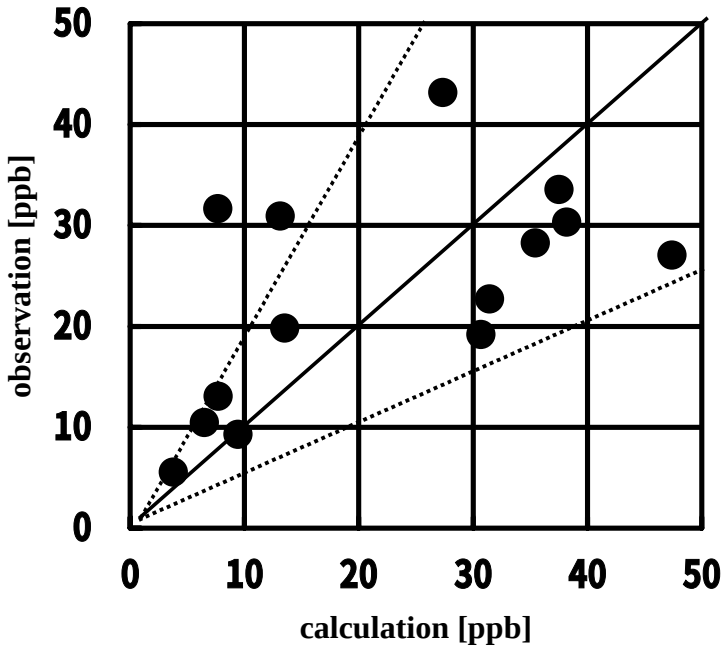

Figure 9b. Correlation between simulated NO_x concentration and observed NO_x concentration.

Conclusion

The measurements of SO_2, NO_2 and NO_x were carried out from July 2000 to July 2001 at 20 sampling points in Jakarta City. The highest concentration of SO_2 was found near the power plant in the northern part of Jakarta City, while the highest concentration of NO_x was found in the central part as well as near the power plant, due to high levels of motor vehicle emissions. The simulation results also showed the concentration of SO_2 near the power plant to be highest because of emissions from the power plant, and the concentration of NO_x in the central area to be higher than in other regions because of heavy traffic volume. The correlation between simulated and observed SO_2 and NO_x concentrations was found to be reasonably strong. However, as the correspondence of simulated and observed concentration wasn't enough, it is necessary to enhance the accuracy of emission loads and measurement method.

Acknowledgments

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