RETRIEVAL OF EMISSION LOADS FROM MEASURED NITROGEN OXIDE CONCENTRATIONS IN JAKARTA CITY

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Abstract

From July 2000 to December 2001, NO_2 and NO_x concentrations at 20 sampling points throughout Jakarta City were measured using passive samplers. The ratio of NO/NO_2 was over 0.5 at most monitoring points. Therefore high concentrations of NO_x in the central area suggested that motor vehicles were the major contributor. Although the distribution of the calculated concentrations also indicated the same tendency, the correlation between the calculations and the observations was not strong because of the inaccurate measurement of emission loads. Therefore the emission loads that were based on measured concentrations were retrieved by the genetic algorithm. The correlation coefficient between the re-calculated concentrations using the retrieved emission loads and the measured concentrations improved to 0.62 from 0.59. This retrieval method is able to modify the inaccurate emission loads in areas where estimation using accurate source inventory is difficult.

Key words: emission load, genetic algorithm, retrieval, passive sampler, nitrogen oxide

Introduction

Jakarta, the capital city of the Republic of Indonesia, belongs to the island of Java and is located south of the equator, the south latitude of 6.07 and the longitude of 106.44. Jakarta has a fast growing population and has the eleventh largest population of the world's cities. 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. Transportation sources are estimated to emit 80% of total nitrogen oxides in Jakarta (Achmadi 1996, 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 each 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, nitrogen oxides, total suspended particulate matter (TSP) in Jakarta have been monitored under several projects: (1) Bapedal and East Java Pollution Control Implementation Project (Cohen et al., 1997); (2) Environmental Management Center (EMC) Air Quality Laboratory in Indonesia (EMC 1994); (3) Japan International Cooperation Agency-Environmental Impact Management Agency of Indonesia (JICA et al., 1995); and, (4) Kantor Pengkajian Perkotaan Dan Lingkungan DKI-Jakarta (KPPL 1997), the projects had only a few monitoring points and had not investigated the relationship between the pollutant concentration and emission loads. In the present study, monitoring was conducted at 20 sampling points in Jakarta City throughout the year to obtain a more detailed depiction of NO_x concentrations. The results obtained using Plume and Puff model will be described later were compared with measured concentrations to evaluate the accuracy of NO_x emission loads estimated from the statistical data for fuel consumption, population and traffic volume. However, the correlation between the calculated and observed values was not strong because of the inaccuracy of the observed emission loads. Recently, several methods retrieving the input data (Zickus et al., 2001) were developed to coincide with the calculated concentrations to the measured concentrations. In the present paper, we proposed a method retrieving the inaccurate emission loads using the genetic algorithm (Zbigniew 1996).

Measurement of air pollution concentration

Sampling points

The concentrations of NO_2 and NO_x were measured at 20 sampling points in Jakarta City as shown in Fig.1. NO_x is the sum of NO and NO_2.

Sampling method

Passive samplers were used to collect gaseous NO_2 and NO_x from ambient air. These samplers are inexpensive and easy to operate and have good sensitivity and accuracy (Sun 2001, 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. Glasius (1999) reported that NO_2 reacts with Triethanol Amine (TEA) to give triethanol amine nitrite and triethanol amine nitrate. The amount and concentration of air pollutant gas collected is integrated over the time exposure. The Ogawa passive sampler(PS 115) used, which adopted TEA as an absorbent, has two collection elements equipped with filters for the collection of gaseous substances. One filter is used for the collection of gaseous NO_2, and the other for the collection of gaseous NO_x. The collection of measurements was started in July 2000 and continued until December 2001. The passive samplers were prepared and installed by EMC staff at the 20 sampling points. The filters were exposed to the air for two weeks, then collected, put into vials and packed in an aluminum bag. Each month, the 160 collected filters (20 sampling points × 2 filters × 4 weeks) were sent to Japan and were analyzed to determine the concentrations of NO_2 and NO_x.

Analysis method

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.

Measured air pollution concentration

Figures 2a and 2b show the annual average concentrations of NO_2 and NO_x from July 2000 to June 2001, respectively. Measurements were not collected in August 2000 because of a traffic accident. The highest concentrations of NO_x appeared in the central area. As the effective stach height from surveyed factories is over 100 m and the pollutants are diluted, the contribution to ambient air concentration is minor. Moreover the ratio of NO/NO_2 was over 0.5 at most monitoring points. These NO/NO_2 ratios suggested that motor vehicles were the major contributor of NO_x concentration.

Estimation of NO_x emission loads

NO_x Emission loads from factories

In 1995 and 1996, JICA and EMC conducted measurements such as the concentrations of SO_x, NO_x and TSP, temperature of exhaust gas, diameter of stack and stack height at 36 factories such as power plant, glass, and cement. The emission loads from these factories occupy about 75% of whole emission loads from all factories. These data were used as the emission loads from surveyed facilities. The emission load from un-surveyed factories was estimated based on the type of fuel consumed using the following equation:

$$E_{uns} = \sum E_{sur} \times (F_{uns}/F_{sur}) \quad (1)$$

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 1. The emission load from un-surveyed factories was distributed in proportion to population density of Jakarta City.

NO_x Emission loads from 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. The traffic volumes per day were estimated, assuming that the diurnal variation of the traffic volume in 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 approximately same as the traffic volumes of nearby roads. The investigations of the traffic volumes were mainly performed at the center of Jakarta. Therefore this method may overestimate the traffic volume at the suburbs of Jakarta. The 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, $f_{veh,i}$ [g/km/vehicle] 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. The emission factors using data for the year 1980 in Japan were set up (NRI 1997). The emission factors and the number of vehicles for each type of motor vehicle are shown in Table 2.

NO_x Emission loads from households

The statistical data for fuel consumption and the emission factor for fuel combustion were used to estimate the emission load from households. The emission load from households due to the consumption of two types of fuel was estimated by

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

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 3. The emission load from households was distributed in proportion to the population density of Jakarta City.

Total NO_x emission loads

The emission load rate for NO_x from each source is shown in Fig.3. The NO_x emission load from motor vehicles occupied 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.

Comparison of measured air pollution concentrations with calculated air pollution concentrations

Plume and Puff model

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

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

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

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.

Meteorological conditions

Meteorological data from the Sukarno-Hatta Airport for the year 2000 were used in the Plume and Puff models. Wind direction was divided into 16 directions and calm conditions. Wind speed was divided into 7 ranks: $0 \sim 0.9$, $1 \sim 1.9$, $2 \sim 2.9$, $3 \sim 3.9$, $4 \sim 5.9$, $6 \sim 7.9$, and 8m/s (EAJ 1993). The stability of the atmosphere was divided into moderately unstable conditions (daytime) and stable conditions (nighttime) (EAJ 1993). The wind direction from the south to the west was dominant and the average wind speed was about 3m/s.

Calculated pollution concentration

The calculated concentrations of NO_x are shown in Fig.4. NO_x concentrations in the center of Jakarta City were higher than those in other regions because of the heavy traffic volume. NO_x concentrations were also found to be high along roads, though they cannot be seen in Fig.4.

Comparison of measurement with calculation

To verify the accuracy of the estimated emission loads, calculated concentrations were compared with measured concentrations at the 20 sampling points. The correlation between the calculated concentrations and the measured concentrations is shown in Fig.5. The disagreement between the calculated concentrations and the measured concentrations is considered to be a result of the inaccuracy of estimated emission loads and the meteorological data and/or the measurement error. In the next section, a method of retrieval of the most inaccurate parameter among the parameters used for the calculation of air pollution concentration will be described.

Retrieval of emission loads by genetic algorithm

Retrieval of vehicle emission loads by genetic algorithm

The NO_x emission load from vehicles, which is the most dominant among other emission loads, was retrieved. The emission load from vehicles is given by Eq. (2). The emission coefficient is suggested to be most inaccurate among the parameters in Eq. (2), because the original data for the emission coefficient of vehicles running in Indonesia do not exist. The emission coefficient rate, f'_i, minimizing the evaluation function *Fitness* defined by Eq. (6) was determined by the genetic algorithm.

$$
\begin{aligned}
Fitness &= \sum_k \left(\Big|\sum_i f'_i \times c_{i,k} - m_k\Big|^2 \right) \quad if \ \Big|\sum_i f'_i \times c_{i,k} - m_k\Big| > c_{err} \\
&= \sum_k \{0\} \quad if \ \Big|\sum_i f'_i \times c_{i,k} - m_k\Big| < c_{err}
\end{aligned} \tag{6}
$$

where $c_{i,k}$ is the concentration contributed by the emission load from a type of motor vehicle, assuming the emission coefficient to be a constant of 1 g/km/vehicle; k represents the sampling points; m_k is the presumed contribution from motor vehicles, calculated by subtracting the concentration of factories and households from the measured concentration; and, c_{err} is the range of the measurement error and was assumed to be 2.5 ppb at all sampling points. The tolerance of the emission coefficient rate f'_i is assumed to be 0.5 $\sim$ 2 times the values shown in Table 2.

Comparison of measurement with re-calculation by genetic algorithm

The retrieved emission coefficients and the emission load are shown in Table 4. The value of the retrieved emission coefficients is approximately equivalent to those of 1990 in Japan (NRI 1997). 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 retrieved emission coefficients is reasonable. The values of the retrieved emission factors became smaller than the values adapted in section 3.2. As a result, the emission load from motor vehicles decreased, accounting for 38% of the total emission load. The authors think that the emission load from motor vehicles, reported by the World Bank to be 80% of the total emission load, were overestimated. The correlation between the re-calculated concentration using the retrieved emission load and the measured concentration is shown in Fig.6. The evaluation of this retrieval method is shown in Table 5. The coefficient of correlation and the root of mean squared error were modified by this method. This method was found to be useful for retrieving the inaccurate emission loads in an area where the estimation of an accurate source inventory is difficult.

Conclusions

The measurements of NO_2 and NO_x were carried out from July 2000 to July 2001 at 20 sampling points in Jakarta City. The ratio of NO/NO_2 was over 0.5 at most monitoring points. Therefore high concentrations of NO_x in the central area suggested that motor vehicles were the major contributor. The simulation results also showed the concentration of NO_x in the central area to be higher than in other regions because of heavy traffic volume. The correlation between the calculated and the measured emission load was not strong because of the inaccurate original emission loads. Therefore, the vehicle emission load based on the measured concentration was retrieved by the genetic algorithm. The value of retrieved emission coefficients was approximately equivalent to those observed in 1990 in Japan. This retrieval method was found to adequately modify inaccurate emission loads when the estimation of accurate source inventory is difficult. Future studies could apply this method to all the emission sources and to other air pollutant concentrations.

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Table 1: Emission load from factories.

Fuel type	Consumption		Emission load [t/yr]	
	survey(1)	un-survey(2)	survey(1)	un-survey
HSD [kl/yr]	295,886	72,446	1,429	350
IDO [kl/yr]	153,021	37,466	299	73
MFO [kl/yr]	498,109	121,957	5,740	1,405
NG $\times 10^6$ [m^3/yr]	4,060	994	256	63
Total			7,727	1,891

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

Table 2: Emission load from vehicles.

Vehicle type	$f_{\mathsf{veh}}^{(1)}$ [g/km/vehicle]	$T \times L$ 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 3: Emission load from households.

Fuel type	Consumption(1)	$f_{\mathsf{hsd}}{}^{(2)}$	Emission load [t/yr]
Kerosene	1,284,683 [kl/yr]	2.1 [kg/kl]	2,698
LPG	157,906 [t/yr]	2.06 [kg/t]	325
Total			3,023

(1) JSO 1997; (2) JICA et al, 1995

Table 4: Retrieved emission load from vehicles.

Vehicle type	Retrieved f_{veh} [g/km/vehicle]	$T \times L$ 10^6 [km]	Emission load [t/yr]
Passenger car	0.15	875	131
Taxi	0.15	12,076	1,811
Van	1.29	794	1,024
Microbus	2.01	690	1,386
Bus	1.97	431	849
Small truck	1.04	1,060	1,102
Truck with 2 axles	1.96	278	545
Truck with 3 axles	2.15	24	51
Motorcycle	0.08	13,408	1,073
Total			7,972

Table 5: Model performance evaluation.

Performance measures	Original emission loads	Retrieved emission loads
$Fitness$	4,682	2,105
$RMSE$	260	118
r	0.59	0.62

$RMSE$: root of mean squared error
r: coefficient of correlation