

# 10. STUDY ON THE CONCENTRATION DISTRIBUTIONS OF SO<sub>2</sub> AND NO<sub>2</sub> IN THE CITY OF DHAKA, BANGLADESH IN WINTER 1995 - 96

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**Abstract :** 10-day-average concentrations of SO<sub>2</sub> and NO<sub>2</sub> were measured at 64 sites in Dhaka city and its suburbs during the period of December-January of 1995-96 using molecular diffusion tubes. This have made first systematic observation of air pollution over Dhaka area. The results showed extremely high SO<sub>2</sub> concentrations in the south-eastern industrial zone of Dhaka where the highest 10-day-average concentration was 104 ppb. Polluted zone, defined as the average SO<sub>2</sub> concentration over 40 ppb, extended along major route running from north-west to south-east, and also parallel to the Buriganga river in Dhaka area. In case of NO<sub>2</sub>, the highest 10-day-average was 35 ppb, and higher concentration appeared in the city center and along main roads of Dhaka, indicating traffic as major NO<sub>2</sub> source.

A preliminary estimation of SO<sub>2</sub> and NO<sub>2</sub> emissions in Dhaka for winter 1995-96 has been made, together with their spatial allocation to see their relations with SO<sub>2</sub> and NO<sub>2</sub> concentration distributions; estimated total emissions were 72 and 70 ton day<sup>-1</sup> for SO<sub>2</sub> and NO<sub>2</sub> respectively. It was speculated that typical meteorological conditions in this season such as very low wind speed (average less than 0.5 m/s), dry and stably-stratified air largely contributed to the severe air pollution.

**KEY WORDS :** molecular diffusion tube, SO<sub>2</sub>, NO<sub>2</sub>, air pollution, developing country, Dhaka.

## 1. INTRODUCTION

Dhaka, the capital and the biggest city of Bangladesh having a population of about 10 millions, is expanding very rapidly. Emissions from heavy traffic and many small industries and commercial complexes, newly developed in and around the city, have been polluting the air of Dhaka city. The air pollution is severe especially in winter due to adverse meteorological conditions. But so far no study of air pollution of Dhaka city has been done. In this study, we have first measured the concentrations of SO<sub>2</sub> and NO<sub>2</sub> in Dhaka city in a large scale, and derived their spatial distributions and also emission source inventories over Dhaka. We also analysed the relations of emission source distributions and meteorological conditions with SO<sub>2</sub>/NO<sub>2</sub> concentration distributions over Dhaka. In the context of urbanization, this study should be useful for emission control strategies, decision making processes, planning and management of Dhaka city.

## 2. EXPERIMENTAL

### 2.1. The Method

Molecular diffusion tubes, which do not require power sources, maintenance and are produced at low cost, have been used to measure the concentration distributions of SO<sub>2</sub>/NO<sub>2</sub> at 64 sites in Dhaka city and its suburbs during the period of December-January of 1995-96. In these measurements we have adopted the procedures described in Maeda et al.(1994), in which sodium carbonate/triethanolamine, coated on filter paper, is used to absorb the SO<sub>2</sub>/NO<sub>2</sub> gas from the air. The amount of sulfate/nitrite absorbed is then determined using ion-chromatograph/spectrophotometer, and this is converted to an air concentration of SO<sub>2</sub>/NO<sub>2</sub> using the length of exposure and calibration equation. The contamination of unexposed tubes under field conditions was determined, and the value of the blank test was subtracted from the measurements made by the diffusion tube samplers. Care was taken to ensure that blank value was always minimized (Miller, 1988). The effects of wind turbulence and temperature were reduced using polyflon filters.

### 2.2. Calibration of the Diffusion Tube Sampler

The diffusion tube samplers were calibrated using 6 automated air pollution monitoring stations in Aichi-prefecture, Japan. Three samplers were deployed at each automated air pollution monitoring station for 10 days to measure the concentration of one pollutant species. The regression line and the distribution of the concentration data (Fig.1) acquired by automatic measuring instrument at each location showed that the error range of measurements made by the molecular diffusion tube samplers after calibration was 2 ~ 27 %.

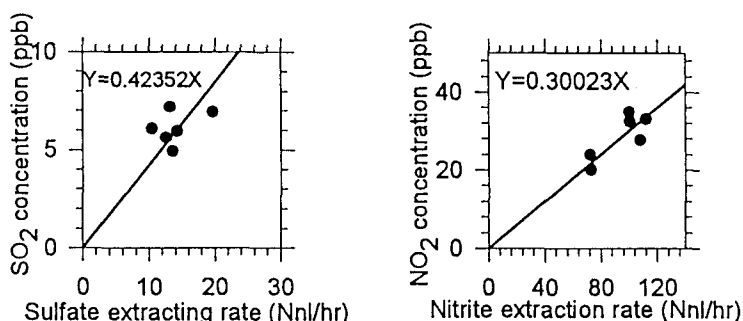


Fig. 1: Calibration line between sulfate/nitrite extraction rate and gaseous SO<sub>2</sub>/NO<sub>2</sub> concentration.

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### 2.3. Sampling Protocol

The sampling was carried out in the highly populated city of Dhaka, middle of Bangladesh, which has a vehicle population of around 120000, and the period ranged from 18 December 1995 to 16 January 1996. The sampling sites were selected to reflect the spatial distributions of the concentrations of the pollutants over all types of area and environment of Dhaka. One set of samples was exposed within 15~50m from major roads, another set was set up far away (>100m) from major roads. The third set of samples (largest set) was deployed in the planned and unplanned housing area, commercial area, industrial area, and suburban and other types of area to measure ambient concentrations of pollutants in these areas. Three samplers were exposed at a site for 7~10 days to measure the concentration of one pollutant species, and the samplers were sealed into plastic bag after recapping at the end of the exposure period. The tubes were attached to walls, windows, fences, poles and leaveless trees at man height.

### 3. EMISSION SOURCE INVENTORY

SO<sub>2</sub>/NO<sub>2</sub> emissions from various possible sources in winter 1995-96 are computed and compiled. Major sources of SO<sub>2</sub>/NO<sub>2</sub> emissions over Dhaka, the emission factors and amount of emissions from the sources are shown in Table 1. The emissions were spatially allocated on 2km x 2km square grids on the basis of road traffic flow rate, location of specific activity, population density, and land use type (Fig.6).

**Table 1.** Daily fuel consumption and estimated SO<sub>2</sub>/NO<sub>2</sub> emissions by various sources in Dhaka in winter1995-96\*

Source	Fuel		Emission factor (kg t <sup>-1</sup> )**		Amount of emission (t d <sup>-1</sup> )	
	Type	Amount (t d <sup>-1</sup> )	SO <sub>2</sub>	NO <sub>2</sub>	SO <sub>2</sub>	NO <sub>2</sub>
Traffic vehicle <sup>+</sup>	Diesel oil	1395	28.8	27.4	40.17 (55.8%)	38.22 (54.5%)
Brick field <sup>+</sup>	Coal	1430	9.61	7.5	13.74	10.72
	Wood	536	0.86 (kg toe <sup>-1</sup> )	6.0 (kg toe <sup>-1</sup> )	0.15	1.05
	Furnace oil	107	64	5.09	6.85	0.54
					20.7 (28.8 %)	12.3 (17.5%)
Industry <sup>++</sup>	Natural gas	390 x10 <sup>3</sup> (m <sup>3</sup> d <sup>-1</sup> )	9.6 x10 <sup>-6</sup> (kg m <sup>-3</sup> )	8800 x10 <sup>-6</sup> (kg m <sup>-3</sup> )	0.00374	3.43
	Coal	156	9.61	7.5	1.5	1.17
	Kerosene	49	4	7.46	0.196	0.365
	Diesel oil	98	28.8	9.62	2.82	0.942
	Residual oil	49	64	5.84	3.14	0.286
					7.6(10.5%)	6.19(8.8%)
Residential <sup>++</sup>	Natural gas	744 x10 <sup>3</sup> (m <sup>3</sup> d <sup>-1</sup> )	9.6 x10 <sup>-6</sup> (kg m <sup>-3</sup> )	8800 x10 <sup>-6</sup> (kg m <sup>-3</sup> )	0.0071	6.54
	Kerosene	10	4	2.49	0.04	0.025
	Diesel oil	20	28.8	3.21	0.576	0.064
					0.623(0.8%)	6.63(9.5%)
Navigation <sup>+</sup>	Diesel oil	100	28.8	54.1	2.88 (4%)	5.41 (7.7%)
Commerce <sup>++</sup>	Natural gas	160 x10 <sup>3</sup> (m <sup>3</sup> d <sup>-1</sup> )	9.6 x10 <sup>-6</sup> (kg m <sup>-3</sup> )	8800 x10 <sup>-6</sup> (kg m <sup>-3</sup> )	0.0015 (0.1%)	1.41 (2%)

\* Energy consumption data compiled from the report and personal communication to the respective departments.

\*\* Kato and Akimoto (1992), except natural gas who's emission factors have been adopted from EPA (1973, 1985).

+ Estimated from total number of cars, brick fields and navigation vessels, and energy consumption by one unit of each type.

++ Estimated from total energy consumption by each sector.

% Represents total percent from a sector with respect to total SO<sub>2</sub>/NO<sub>2</sub> emissions in Dhaka.

### 4. METEOROLOGICAL ASPECTS OF DHAKA FOR THE DISPERSION OF THE POLLUTANTS

Meteorology has a great influence on the dilution and distributions of pollutants, and subsequent effect on air quality. The pollution of the atmosphere would have a less serious problem, if the weather is consistent. The meteorological data of Dhaka of winter season for five years (1990-1994) were collected from the weather station located at the Department of Meteorology, Dhaka and analysed. Details of the meteorological conditions of Dhaka for winter season are given in Table 2, which shows dry air (average humidity 74%) with little rainfall (monthly average 15.5 mm) accompanied by very low wind speed (average 0.91 knots).

Mean wind affects the air quality by advection and diffusion of the pollutants. To observe the prevailing wind direction and velocity, wind roses for day and night in the winter season (1990-1994) of Dhaka city have been derived (Fig.3), which show high frequency of very low wind speed at night (87% calms), and north, north-westerly blowing

as the predominant wind in winter. The diurnal patterns of wind speed (Fig.2) depicts relatively high wind speed during day time.

Table 2. Meteorological conditions in Dhaka in winter , 1990 - 1994.

Month	Average temperature ( ° C )		Average rainfall (mm)	Average relative humidity ( % )	Prevailing wind direction	Average wind velocity (knots)	% Calms <1 knot	% Winds >3 knots
	Maximum	Minimum						
December	26	14	22	74	N, NW	0.79	76	7
January	25	13	9	74	N, NW	1.03	68	10
Mean	25.5	13.5	15.5	74	N, NW	0.91	72	8.5

Mixing height which controls the dispersion of pollutants in the vertical direction, has been calculated for winter season using the vertical temperature profiles (Holzworth,1967) from morning (0000GMT) aerological data and the surface temperature at 0600 GMT (1200 Bangladesh Standard Time). The average mixing depth at 0600 GMT in December and January was 700 and 750 m respectively.

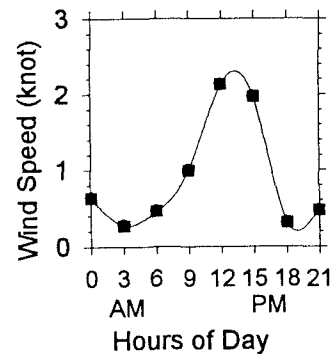


Fig.2: Diurnal patterns of wind speed at Dhaka in winter, 1990-94.  
(1 knot = 0.51 m/s)

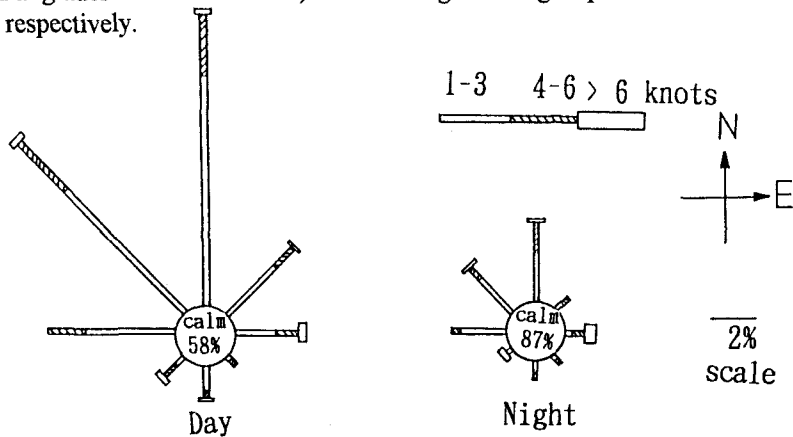


Fig.3: Wind roses for the winter season (Dec.-Jan.), 1990-94 for Dhaka

5. RESULTS AND DISCUSSION

5.1. Concentration Distributions of SO<sub>2</sub> and NO<sub>2</sub> Over Dhaka and Correlation Between Them

Spatial distribution of SO<sub>2</sub> concentration over Dhaka (Fig.4(a)) shows extremely high SO<sub>2</sub> concentration in the south-eastern industrial and brick field zone, where the highest 10-day-average concentration was 104 ppb, which is around 10 times larger than those at polluted area in Nagoya in the same season. Polluted zone, in which the average

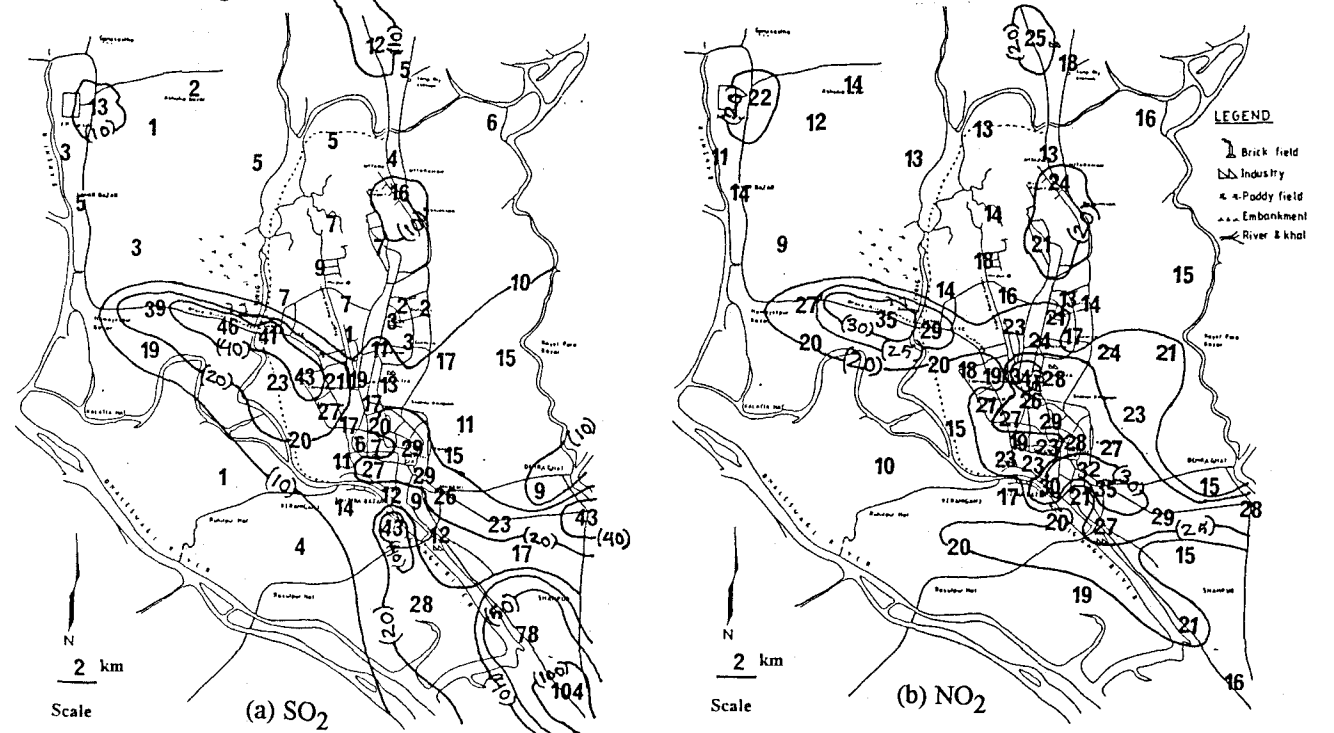


Fig.4: Spatial distributions of SO<sub>2</sub> and NO<sub>2</sub> concentrations over Dhaka in winter 1995-96.

SO<sub>2</sub> concentration was over 40 ppb, extended along major roads running from north-west to south-east, and also parallel to the Buriganga river in Dhaka area. Brick fields and industries along the traffic and navigation routes as major emission sources, and north-westerly blowing along the river, as prevailing wind in winter eliminate have formed this particular high SO<sub>2</sub> zone. In case of NO<sub>2</sub> (Fig.4(b)), the highest 10-day-average concentration was 35 ppb, which is about the same as those in urban Nagoya, and higher concentration appeared in the city center and along main roads of Dhaka, indicating traffic as major NO<sub>2</sub> source. The 10-day-average ambient SO<sub>2</sub> concentrations and standard deviations were  $18 \pm 9$  ppb in the city centre,  $31 \pm 24$  ppb within 15~50m along major routes and  $10 \pm 8$  ppb in the suburban area, and those for NO<sub>2</sub> in the cited areas were  $26 \pm 5$  ppb,  $26 \pm 6$  ppb and  $16 \pm 4$  ppb respectively.

In order to assess the observed relationships between SO<sub>2</sub> and NO<sub>2</sub> concentrations, we have plotted scatter diagram as in Fig.5. In general, SO<sub>2</sub> and NO<sub>2</sub> are not highly correlated (correlation coefficient = 0.35). Table 1 suggests that this discrepancy is due to the difference of relative importance of emission sources of "brick field" and "residential" in total emission of SO<sub>2</sub> and NO<sub>2</sub>.

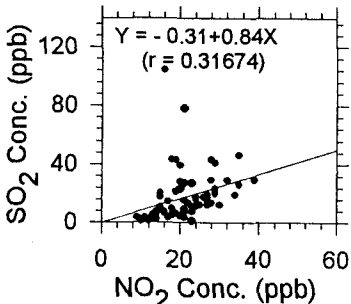


Fig.5: Scatter diagram of ambient SO<sub>2</sub> & NO<sub>2</sub> concentrations.

### 5.2. Emission Inventory and Spatial Distributions of Emissions

Table 1, which summarizes the amounts of SO<sub>2</sub>/NO<sub>2</sub> emissions due to fuel combustion by various activities, shows the primary source of SO<sub>2</sub> is traffic vehicle (55.8%) ; followed by brick field (28.8%) and industry (10.5%). The remainder (about 5%) are due to navigation vessel in the Buriganga river, residential activities and commerce. Using of high sulfur containing petroleum products as fuel in cars, together with the lower maintenance quality, lead to high emission of SO<sub>2</sub> from traffic vehicle. The primary source of NO<sub>2</sub> emission is also traffic vehicle (54.5%), indicating its most liability to severe air pollution of Dhaka city. Brick field is the second most important source, contributing 17.5%, residential 9.5%, industry 8.8%, navigation 7.7% and commerce 2%. The overall per day emissions for Dhaka city in winter 1995-96 are 72 tonnes for SO<sub>2</sub> and 70 tonnes for NO<sub>2</sub>.

Fig. 6, which depicts the spatial distributions of emissions of SO<sub>2</sub> and NO<sub>2</sub> , shows grids with the highest SO<sub>2</sub> emissions are mostly centralized in the south-eastern industrial and brick field belt along a major road, together with the navigation route in the Buriganga river, and along a highly traffic congested inter-district road (Dhaka-Aricha Highway) running in the north-western side of Dhaka. The average SO<sub>2</sub> emission rates for these areas are more than 1000 kgd<sup>-1</sup> on 2km x 2km grid. Other high SO<sub>2</sub> emitting grids with more than 500 kgd<sup>-1</sup> are seen in the city centre. In case of NO<sub>2</sub>, the grids with the highest NO<sub>2</sub> emissions are concentrated in the city centre and along major roads with emissions more than 600 kgd<sup>-1</sup>.

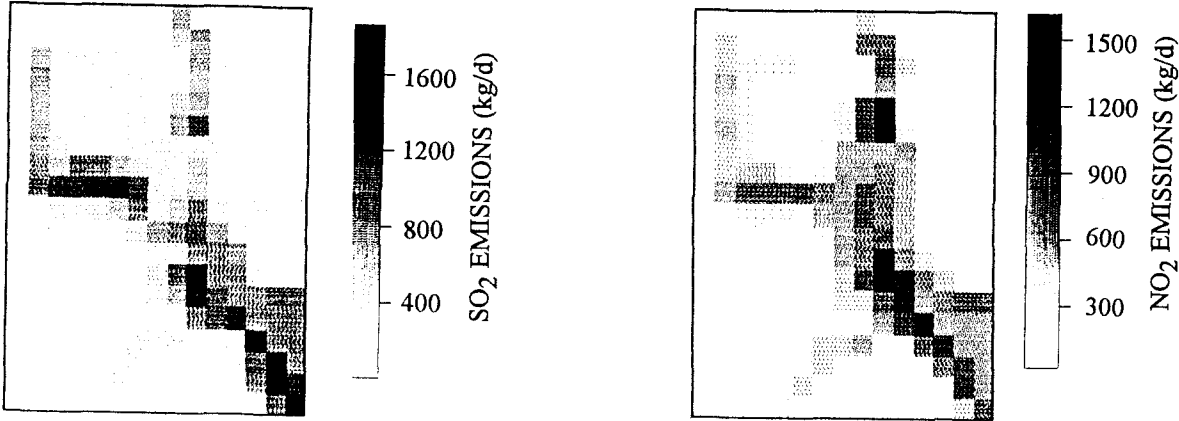


Fig.6: Spatial distributions of SO<sub>2</sub>/NO<sub>2</sub> emissions over Dhaka for winter 1995-96 (2km x 2km grid).

### 5.3. Comparison of SO<sub>2</sub>/NO<sub>2</sub> Concentrations to the SO<sub>2</sub>/NO<sub>2</sub> Emissions

Scatter diagrams of estimated SO<sub>2</sub>/NO<sub>2</sub> emissions (kg/day) for each grid against observed SO<sub>2</sub>/NO<sub>2</sub> concentrations in the corresponding grid, are prepared for all measurement sites (Fig.7). Clear relations are observed between estimated emissions and measured ambient concentrations, with some deviation at sites with very low and very high concentrations. Most probably,

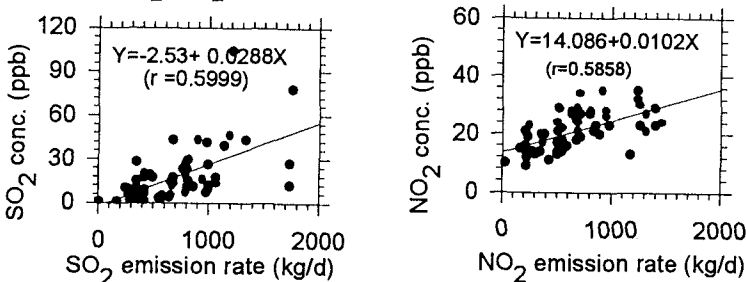


Fig.7: Linear regression of measured SO<sub>2</sub> & NO<sub>2</sub> concentrations against estimated SO<sub>2</sub> & NO<sub>2</sub> emission rates.

this is due to the effect of transport and chemistry : because the ratios of  $\text{NO}_x : \text{NO}_2$  and  $\text{SO}_x : \text{SO}_2$  vary considerably with distance from the source.

5.4. Comparison of Emissions with Previous Study

Specific published data of Dhaka city are not available for the comparisons of the emissions of  $\text{SO}_2$  and  $\text{NO}_2$ . A comparison with the data adapted from the study of Kato and Akimoto (1992) is shown in Table 3, the data which was calculated on the basis of the ratio of the population of Dhaka to whole Bangladesh.

Table 3. Comparisons of the emissions of  $\text{SO}_2$  and  $\text{NO}_2$  with the study of Kato and Akimoto (1992)

Studies	$\text{SO}_2$ emissions ( t d <sup>-1</sup> )	$\text{NO}_2$ emissions ( t d <sup>-1</sup> )
This study (winter, 1995-96)	72	70
Kato and Akimoto (1992)	8.7	11.7

The  $\text{SO}_2$  and  $\text{NO}_2$  emissions calculated in this study for Dhaka city are 7 and 5 times higher than those values adapted from the study of Kato and Akimoto (1992). This may be ascribed to the higher per capita fuel consumption in Dhaka city than the rural area, where the only fuel consumption are the oil burning for lighting at night and vegetal fuels used for cooking. According to Carl R. Bartone (1995), the cities in the developing countries consume as much as seven times more energy per resident than the rural population, which gives support for higher  $\text{SO}_2/ \text{NO}_2$  emissions in this study than those of Kato and Akimoto. In their study the total emission of  $\text{NO}_2$  (11.7 td<sup>-1</sup>) is higher than the total emission of  $\text{SO}_2$  (8.7 td<sup>-1</sup>), which is quite opposite to our study. Traditional vegetal fuels, which are not used in Dhaka, but extensively used in rural area for cooking, could be the reason for the higher  $\text{NO}_2$  emission in his study.

5.5. Mapping of Spatial Distributions of  $\text{SO}_2$  and  $\text{NO}_2$  Concentrations over Dhaka

Although the measurements in this study cover a large number of urban and suburban areas, there are still many areas where  $\text{SO}_2/ \text{NO}_2$  measurements have not been undertaken. It is likely that some of these unmonitored areas may have high  $\text{SO}_2/ \text{NO}_2$  concentrations. In order to attempt to identify such areas, interpolation mapping techniques using emission distributions (Fig.6) have been used. The 10-day-average ambient concentrations were regressed against emissions in the 2km x 2km square grid (Fig.7), and the regression equations (Fig.7) were then used to produce concentration maps from the spatial distributions of emissions, shown in Fig.8. The effect of background concentration has not been considered in this interpolation, because the wind speed is very low (72% calms and average wind speed is 0.91 knots) and the effect is not same on all grids.

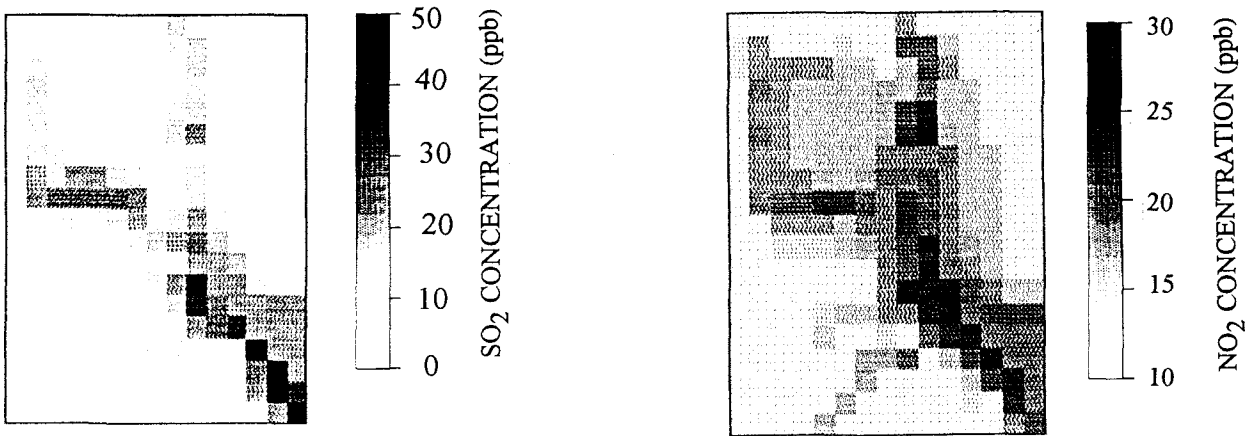


Fig.8 : Map of  $\text{SO}_2/ \text{NO}_2$  concentration distributions, winter 1995-96, based on estimated emissions.

The highest  $\text{SO}_2$  concentrations are at the navigation terminal in the Buriganga river and along the major road running parallel to the navigation route in the Buriganga river in south-east direction, where many brick fields and small industries are also situated. The highest  $\text{NO}_2$  concentrations are in the airport area and city centre together with the major road running to the south-east direction. As can be seen from the scatter plots

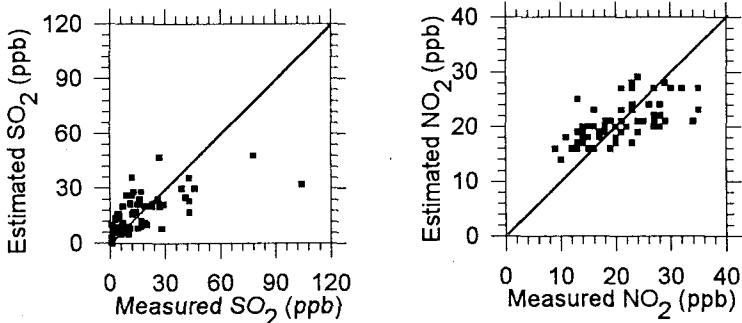


Fig.9: Comparison of estimated and measured concentrations.

(Fig.9), this approach leads to an overestimation of the mean concentrations in some areas with values less than 20 ppb, and underestimates in some areas where concentrations are above 20 ppb.

## 6. CONCLUSIONS

Ambient SO<sub>2</sub> and NO<sub>2</sub> concentrations have been measured in Dhaka city at 64 sites using diffusion tube samplers. Emission distributions of SO<sub>2</sub>/NO<sub>2</sub> have been derived and their relations with SO<sub>2</sub>/NO<sub>2</sub> concentration distributions over Dhaka have been analysed, together with meteorological conditions. The overall results of the study may be summarised as follows :

(1) Dhaka city is highly polluted by SO<sub>2</sub>. At some places SO<sub>2</sub> concentrations are more than two times to the Japanese ambient SO<sub>2</sub> concentration standard, which is 0.04 ppm for daily average ; but NO<sub>2</sub> concentrations are moderately high.

(2) SO<sub>2</sub> concentrations are high in the south-eastern industrial and brick field zone together with the routes running from north-west to south-east, and also parallel to the Buriganga river; whereas NO<sub>2</sub> concentrations are high in the city center and along the major roads.

(3) The major sources for SO<sub>2</sub> emissions are traffic vehicle (55.8%) followed by brick field (28.8%), industry (10.5%) and navigation vessel (4%); for NO<sub>2</sub>, they are traffic vehicle (54.5%) followed by brick field (17.5%), residential activity (9.5%), industry (8.8%) and navigation vessel (7.7%). The overall SO<sub>2</sub> and NO<sub>2</sub> emissions in Dhaka in winter 1995-96 were 72 and 70 tonnes/day respectively.

(4) SO<sub>2</sub> and NO<sub>2</sub> concentration distributions are not highly correlated (correlation coefficient is 0.35 ); whereas emissions and concentration distributions of SO<sub>2</sub>/NO<sub>2</sub> are clearly correlated (correlation coefficients are 0.6 for SO<sub>2</sub> and 0.59 for NO<sub>2</sub>).

(5) The discrepancy in the concentration distributions of SO<sub>2</sub> and NO<sub>2</sub> over Dhaka (Fig.4) is due to the difference of relative contributions of source types of brick field (28.8% SO<sub>2</sub> & 17.5% NO<sub>2</sub> ) and residential activity (0.8% SO<sub>2</sub> & 9.5% NO<sub>2</sub> ) in total emissions of SO<sub>2</sub> and NO<sub>2</sub>.

(6) The meteorology of Dhaka city in winter season is not consistent to dilute and disperse the pollutants from the sources sufficiently. The mean wind velocity is very low having more than 70% calm conditions, followed by minute rainfall and low humidity.

(7) Very small differences in the location of the sampler can lead to large differences in average concentrations and this can become crucial in determining whether or not the concentrations of a site represent the ambient concentrations of that area.

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