Investigation of air pollution concentration in Kathmandu valley during winter season

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Abstract: The monthly concentrations of NO_2, NOx, SO_2 and O_3 measured by a passive sampler from February 2003 to January 2004 showed that the air pollution during the winter season in Kathmandu valley was higher than the summer season. The O_3 level was found the highest during April, May and June due to strong radiation. The hourly concentrations of NO_2, NOx, O_3 and suspended particulate matter(SPM) were also measured by automatic instruments on December 2003. Temperature at the height of 60 m and 400 m at Raniban Mountain in the northwest of Kathmandu valley was measured on February 2001 in the winter season and the average potential temperature gradient was estimated from observed temperature. Wind speed was also measured at the department of hydrology, airport section, from 18 February to 6 March 2001. It was found that the stable layer and the calm condition in the atmosphere strongly affected the appearance of the maximum concentrations of NO_2 and SPM in the morning, and that the unstable layer and the windy condition in the atmosphere was considerably relevant to the decrease of air pollution concentrations at daytime. The emission amounts of NOx, HCs and total suspended particle(TSP) from transport sector in 2003 were estimated from the increasing rate of vehicles on the basis of the emission amounts in 1993 to be 3751 t/a, 30570 t/a and 1317 t/a, respectively. The diurnal concentrations in 2003 calculated by the two-layers box model reproduced the characteristics of air pollution in Kathmandu valley such as the maximum value of O_3 and its time, the maximum value of NO in the morning, and the decrease of NO and NO_2 at daytime. The comparison with the concentrations in 1993 calculated suggested that the main cause of air pollution was the emission from transport sector.

Keywords: air pollution concentration; Kathmandu vallay; box model

Introduction

Kathmandu valley is surrounded by mountains and possesses the marvelous scenery of the Himalayas towards the northern side of the valley. It is located at the center portion of the east west running Himalayan belt with an elevation of about 1300 m to 1400 m above sea level. It is the largest urbanized area with a population of about 1.6 million inhabitants and covers an area of about 899 km^2 (CBS, 2002). Due to the geographical structure like a bowl, air pollution in Kathmandu easily becomes severe. Therefore, some recent researches have focused on the air pollution problems. Air pollutants have also been the main cause of decreasing tendency of the visibility distance in the valley. Shrestha(Shrestha, 1994) analyzed the visibility of Kathmandu valley from 1969 to 1993 and showed the deterioration from 1980. URBAIR (URBAIR, 1996) reported that it has the adverse effect on the tourism industry. Sapkota (Sapkota, 2002) also showed the deterioration in the visibility. Regarding the measurement of air pollutants, Sharma(Sharma, 1992) measured total suspended particle(TSP) concentration at 16 main roadside locations and reported that its concentration was in the range of 197—525 $\mu g/m^3$. Karmacharya and Shrestha(Karmacharya, 1993) also measured 24 h average concentration of TSP, SPM, SO_2, NO_2, CO and Pb at 9 roadside locations and found 182—555 $\mu g/m^3$, 64— 127 $\mu g/m^3$, < 13 $\mu g/m^3$, 12—36 $\mu g/m^3$, < 11 $\mu g/m^3$ and 0.18—0.55 $\mu g/m^3$, respectively. Mathur (Mathur, 1993) reported that the concentrations of TSP, SPM, SO_2, NO_2, CO and Pb from September to December were 102—867 $\mu g/m^3$, 53—201 $\mu g/m^3$, 13—225 $\mu g/m^3$, 14—126 $\mu g/m^3$, < 5 ppm and 2—5 ppm, respectively. ENPHO (ENPHO, 1993) concluded that lead concentration was 0.53 $\mu g/m^3$ while SO_2,

NO_2, and CO were within WHO guidelines. NESS (NESS, 1999) reported that TSP has already increased above the acceptable limits of WHO guidelines. However, the continuous measurements throughout a year or throughout a day have not been conducted. We measured monthly NOx, NO_2, SO_2 and O_3 concentrations by a passive sampling for a period of one year. In addition, we measured hourly NOx, NO_2, O_3 and SPM concentrations by automatic instruments on December 2003. The characteristics of the observed air pollution were discussed from atmospheric stability. Emission inventories in Kathmandu valley were conducted by Shrestha and Malla (Shrestha, 1996), Adhikari (Adhikari, 1997) and Sharma (Sharma, 2000). The present emission amounts of NOx, SOx, TSP and CHs in 2003 were estimated from the increasing rate of vehicles on the basis of the emission amounts in 1993. NO_2, NO, O_3 and SPM concentrations by using two-layer box model including photochemical reaction were calculated and compared with the measured concentrations. The aim of this study is to investigate the characteristics of air pollution in Kathmandu valley throughout the measurements, the emission inventories and the simulation.

1 Air pollutant concentration and meteorological condition in Kathmandu valley

The air pollution of Kathmandu valley was studied by measuring the air pollutant level and the meteorological condition. The monthly concentrations of NO_2, NOx, SO_2 and O_3 were measured by a passive sampler for a period of one year. The hourly concentrations of NO_2, NOx, O_3 and SPM were also measured by automatic instruments on December 2003. The hourly temperature and the hourly wind speed were measured in winter season of another year. Although the year of the concentrations measured is different

from the year of the meteorological condition measured, the characteristic of the air pollution in Kathmandu valley can be discussed from data in the different years.

1.1 Annual air pollutant concentration

Passive samplers of NO_2, NOx, SO_2 and O_3 manufactured by Ogawa Incorporated, Japan, were used to know the monthly air pollution trend of Kathmandu valley from February 2003 to January 2004. The gaseous air pollutions were measured at Institute of Engineering, Tribhuvan University(IOE), Pulchok and Department of Hydrology and Meteorology(DHM), Babarmahal. The sampling locations are shown in Fig.1. Both locations are enough away from road and the passive samplers were placed at approximately 10 m above the ground level. These two locations were approximately 5 km separated. The filters of these passive samplers were changed after every 15 d.
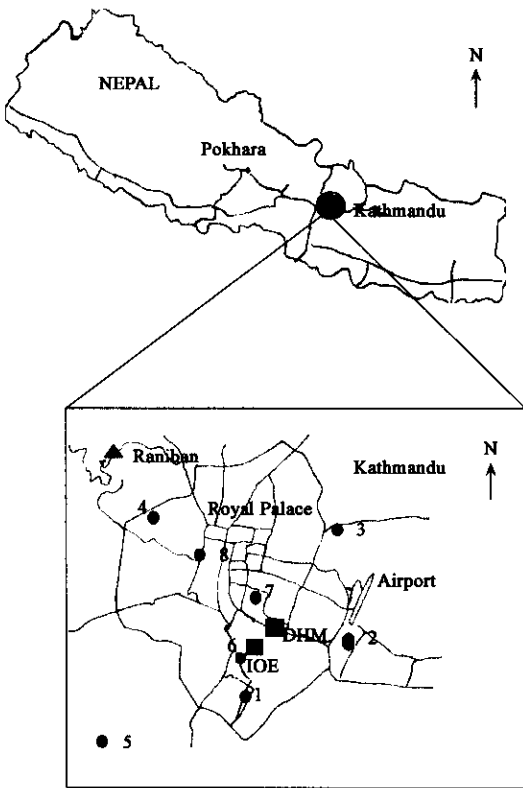

Fig.1　Measurement locations in Kathmandu valley

The methods of the analysis (Ogawa, 1997) are as follows. NOx and NO_2 filter was kept in 8 ml of ultra pure water shaking properly for more than 10 min and 2 ml of color reagent(solution of sulfanilamide and NEDA in 10 : 1 ratio) was mixed in it. After cooling in ice water for 10 min and returning to room temperature, the solution was analyzed by a spectrophotometer. SO_2 was analyzed by keeping SO_2 passive filter in 8 ml of pure water and 0.2 ml of 1.75% H_2O_2, and occasional shaking was done. This SO_2 was analyzed by an ion chromatography. Similarly, O_3 passive filter was also kept in 5 ml pure water for 30 min while shaking occasionally and it was analyzed by an ion chromatography(ICS-1000, DIONEX, USA).

The monthly average concentrations of NOx, NO_2, SO_2 and O_3 are shown in Fig.2, 3, 4 and 5, respectively. Air pollutant levels of NOx, NO_2 and SO_2 were observed higher in winter season(Dec. to Feb.) than the summer season(May to

Aug.). The NOx level in the valley was found from 21 ppb to 31 ppb during winter season and the lowest level of 4.5 ppb was observed during summer season. The NO_2 level was found from 11 ppb to 19 ppb during winter season and the lowest level of 4 ppb was observed during summer season. The SO_2 level was found from 13 ppb to 23 ppb during winter season and the lowest level of 3 ppb was observed during summer season. The concentration levels measured at IOE and DHM were below the WHO guidelines. The study of the Leaders Nepal (Leaders, 1998) had also reported that the gaseous air pollutants measured were below WHO guidelines. The O_3 level was found the highest during April, May and June. The cause is that solar radiation during these periods is very strong, though NO_2 level is lower than winter season. This result suggests that the effect of solar radiation is more dominant than NO_2 level in order to generate O_3. As the concentration levels of both IOE and DHM were almost similar, these concentrations are thought to be representative values in Kathmandu valley.
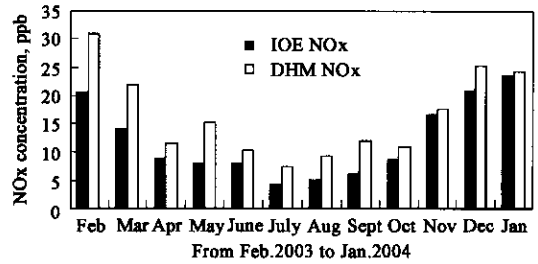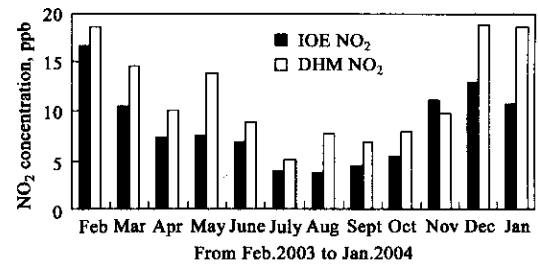

Fig.2　Monthly average of NOx concentration

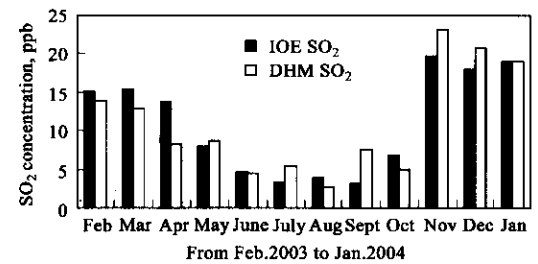Fig.3　Monthly average of NO_2 concentration
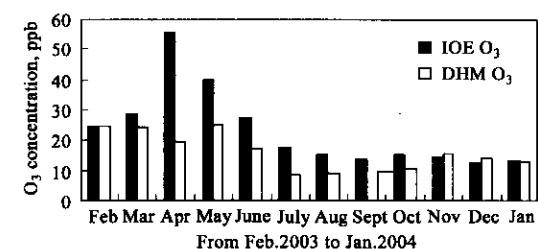

Fig.4　Monthly average of SO_2 concentration

Fig.5　Monthly average of O_3 concentration

1.2 Diurnal air pollutant concentration

The air pollutants of NO_2, NOx, O_3 and SPM have been also measured by two automatic instruments(Kimoto, NA-623 and OA-683, Japan) from December 2003 at IOE. As we have concern to the period air pollution concentration becomes high, the diurnal average variations of NO_2, NO and O_3 concentration on December are shown in Fig.6. NO was calculated by subtracting NO_2 concentration from NOx concentration. The highest concentration of NO appeared at 8 a.m. and then the highest concentration of NO_2 appeared at 9 a.m. After that the concentrations of NO and NO_2 decreased and became minimum at 12 a.m. to 2 p.m. The concentration of NO_2 increased again and had the second peak at 6 p.m. However, the concentration of NO was still low. The high concentration in the morning results from exhaust gas of automobile, because most nitrogen oxide emitted from exhaust gas is emitted as NO. However, the high concentration in the evening does not result from exhaust gas of automobile, because NO concentration is not high. This phenomenon is one of the characteristics of air pollution in Kathmandu valley. O_3 concentration became minimum at 7 a.m., increased rapidly, had the maximum value of 48 ppb at 12 a.m. and decreased lineally. The time that O_3 concentration attains to the maximum value is 3 h faster than Japan. The early time of the maximum concentration is also one of the characteristics of air pollution in Kathmandu valley.
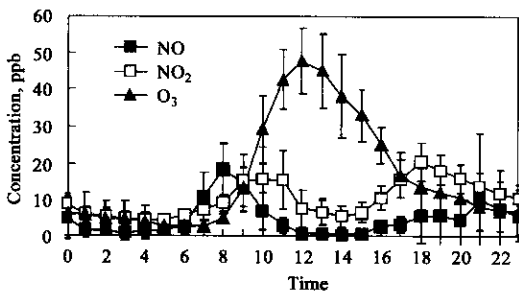

Fig.6 Diurnal variations of NO, NO_2 and O_3 concentration on December 2003

The diurnal average variation of SPM concentration on December is shown in Fig.7. The highest concentration of 150 $\mu g/m^3$ appeared at 9 a.m. After that the concentrations decreased and reached the lowest of 35 $\mu g/m^3$ at 2 p.m. The concentration increased again and had the second peak of 105 $\mu g/m^3$ at 9 p.m. as well as NOx. This high concentration in the evening is presumed that the emission from household for cooking is the suspicious cause.
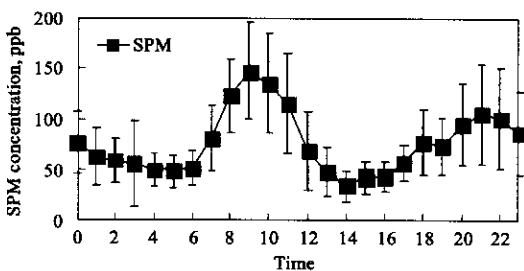

Fig.7 Diurnal variations of SPM concentration on December 2003

1.3 Diurnal atmospheric stability and wind speed

The temperature on February 2001 was measured at two different altitudes of Raniban Mountain, which located at the northwest of Kathmandu valley (Fig. 1). This place was selected, as access is easy. Digital thermometer (MR5300, Chino Inc., Japan) was used for the temperature measurement. Two thermometers were placed at altitude of 1380 m and 1720 m from the sea level, respectively. The measurements were done at the interval of 10 min for 9 d. From these two temperatures, the potential temperature gradient, which is well used as the index of atmospheric stability, was obtained as the following method. If temperature at altitude z is T, potential temperature θ at dry adiabatic condition is expressed by

$$\theta = T + 0.0098z \qquad . \qquad (1)$$

The potential temperature gradient G is roughly determined by

$$G = \frac{D\theta}{Dz} = \frac{\theta_1 - \theta_2}{z_1 - z_2} \qquad . \qquad (2)$$

The diurnal average variation of potential temperature gradient for 9 d is shown in Fig.8. The positive value shows the stable condition of the atmosphere while the negative value shows the unstable atmosphere. The atmosphere of Kathmandu valley is strongly stable until 9 a.m., changes to unstable condition, continues until 6 p.m. and again changes to stable condition. The time when the concentrations of NO_2 and TSP become high in the morning coincides with the stable period of atmosphere. The time when the lowest concentration appears on the contrary coincides with the unstable period of atmosphere. The relation between air pollution concentration and atmospheric stability can be obviously recognized, because the daily difference of temperature in winter season is intense.
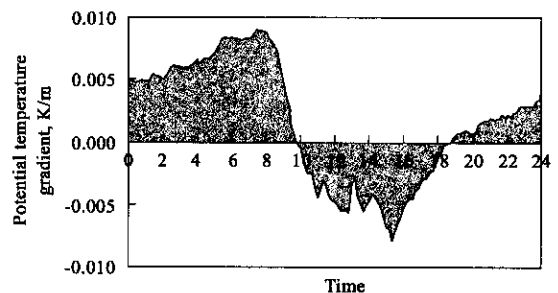

Fig.8 Diurnal variations of potential temperature gradient on February 2001

The wind velocity was measured at the department of hydrology, airport section, from 18 February to 6 March 2001. The diurnal average wind velocity is shown in Fig.9. Wind velocity was almost calm at night time and became gradually windy after 9 a.m. The maximum wind velocity of 3.5 m/s was observed at 4 p.m. and it became calm again. Potential temperature gradient and wind velocity measured suggested that the inversion layer is strongly formed in the morning and the mixing layer is formed in daytime. These meteorological conditions are also strongly associated with air pollution concentration.

2 Emission inventories in Kathmandu valley

2.1 Emission amounts of TSP, NOx, and SOx

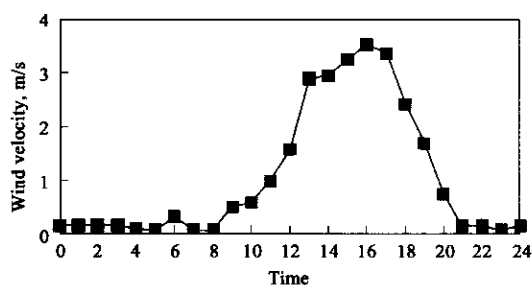The main sources of TSP, NOx, and SOx are transport, household and industries. Vehicles of transport section are

Fig.9   Diurnal variations of wind speed on February 2001

classified into trucks, buses, minibuses, jeeps, tractors, cars, 3-wheeles and 2-wheels. The chief industrial were brick and cement but the cement factory stopped the operation at 2000. Brick is classified into Bull Trench type and Chinese type. Shrestha and Malla(Shrestha, 1996) estimated emission

amounts of TSP, NOx, and SOx for above categories from energy use in 1993. Regmi (Regmi, 2003) also estimated emission amounts of TSP, NOx, and SOx from energy use in 2001. URBAIR (URBAIR, 1996) estimated re-suspension amount of TSP from mileage data in 1993 using a emission factor of 2 g/km. The summary of these emission amounts is shown in Table 1. The number of vehicles from 1993 to 2000 is increasing at the increase rate of 12%/a(BZTMO, 2001). This increase of emission amounts from transport in Table 1 approximately associate with the increase of the number of vehicles. The emission amounts from transport in 2003 when we measured air pollution concentrations were estimated from the increasing rate of vehicles. These results are also shown in Table 1. The re-suspension emission amount in 2002 becomes 3153 t/a using this increasing rate. The emission amounts from household and industrial are assumed to be the same as 2001.

Table 1   Emission amounts of TSP, NOx, and SOx

	TSP, t/a			NOx, t/a			SOx, t/a		
	1993[1]	2001[2]	2003	1993[1]	2001[2]	2003	1993[1]	2001[2]	2003
Transport	475	977	1317	1353	3069	3751	133	258	369
Re-suspension	1530[3]	—	4242						
Household	2382	2988	2988	213	260	260	503	623	623
Industrial	3574(615)	4835	4835	628(127)	539	539	1349(308)	1266	1266

Notes: [1] Shrestha, 1996, a numeral in the parentheses from cement; [2] Regmi 2003; [3] URBAIR, 1996

2.2 Emission amounts of HCs

Shrestha and Malla (Shrestha, 1996) estimated that emission amounts of HCs from transport, household and industrial were 11024, 1281 and 1492 t/a. The emission amount from transport accounted for almost 80% of the total amount. HCs concentrations were measured 8 roadside locations on November 2003. The locations are shown in Fig. 1. The emission amount of each HCs was estimated from the proportional allotment of each HCs concentration and two assumptions. One assumption is that HCs concentration is linearly related to its emission amount from vehicles near roadside. Another assumption is that the present emission

amounts of HCs have increased at the increasing rate of vehicles. The emission amounts in 2003 became 30570 t/a. HCs concentrations and HCs emission amounts are shown in Table 2. The emission amounts of PAR, OLE, TOL and XYL, which mean paraffin, olefin, toluene and xylene, respectively and are chemical substances in CBMIV (Carbon Band Mechanism IV; Gerry, 1989) which is one of the photochemical reaction model, were also estimated by the conversion rate in Table 2 and were 33440, 912, 8098 and 4216 t/a, respectively. Paraffin is much emitted from isopentane, methyl-pentane and pentane.

Table 2   Concentration of HCs and emission amount of HCs

Name	Measurement, ppb									MW[1], EA[2],		Conversion rate				Emission amount, t/a			
	1	2	3	4	5	6	7	8	mean	g	t/a	PAR	OLE	TOL	XYL	PAR	OLE	TOL	XYL
Propene	4.79	9.52	5.22	1.99	0.17	0.82	10.24	22.97	6.97	42	874	1	1			874	874		
n-Propane	2.9	3.81	2.29	0.54	0.21	0.57	3.64	5.43	2.42	44	319	1.5				478			
Isobutane	2.21	3.14	1.79	0.34	0.07	0.33	2.89	6.59	2.17	58	376	4				1505			
n-Butane	2.63	3.39	2.66	0.55	0.1	0.35	4.09	9.07	2.86	58	495	4				1980			
Isopentane	6.08	6.53	8.18	1.61	0.13	0.48	13.42	28.1	8.07	72	1736	5				8679			
Acetone	6.29	3.95	5.44	2.66	2.49	2.1	2.65	2.72	3.54	58	613	3				1840			
n-Pentane	3.13	3.36	4.09	0.87	0.09	0.28	6.6	14.21	4.08	72	878	5				4389			
2-Methylpentane	2.22	2.37	2.9	0.55	0.06	0.22	4.88	11.55	3.09	86	795	6				4771			
3-Methylpentane	1.57	1.68	2.06	0.39	0.05	0.14	3.34	8.01	2.16	86	554	6				3323			
n-Hexane	1.89	2.04	2.47	0.45	0.06	0.16	4.28	10	2.67	84	670	6				4020			
Benzene	4.94	5.81	6.39	1.84	0.26	0.55	10.04	24.44	6.78	78	1581	1				1581			
	15.4	18.0	21.3																
Toluene	2	3	4	4.52	0.4	1.33	59.56	91.11	26.46	92	7277			1				7277	
Ethylbenzene	1.43	1.84	2.03	0.42	0.03	0.12	3.26	9.72	2.36	106	746			1				746	
m-Xylene	2.76	3.97	3.88	0.93	0.06	0.22	7.1	20.85	4.97	106	1575				1				1575
p-Xylene	2.76	3.96	3.88	0.93	0.06	0.22	7.1	20.84	4.97	106	1574				1				1574
Styrene	0.1	0.21	0.13	0.07	0.01	0.04	0.34	1.02	0.24	104	75	0.5	1				37	75	
o-Xylene	2.02	2.77	2.88	0.65	0.05	0.17	4.86	14.68	3.51	106	1112				1				1112
Total																33440	912	8098	4261

Notes: [1] Molecular weight; [2] emission amount

3   Simulation by box model

3.1   Model equations

In order to calculate air pollutant concentrations, we used the two-layer box model(Kim, 2001), which is based on the principle of mass conservation. It is composed of two layers in a box where the lower one is considered as the mixing layer of atmosphere and the upper layer is considered the atmosphere above the mixing layer. Four processes i.e. ventilation, surface deposition, air pollutant emissions and chemical reactions were considered in the lower layer. Two processes i. e. ventilation and chemical reactions were considered in the upper layer. The pollutants transfer process between the lower and upper layer due to the daily change in the height of the lower layer was also considered. The concept of the physical process occurring in the two layers is shown in Fig.10.
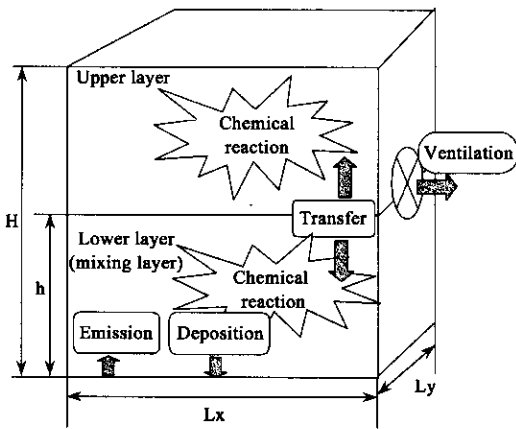

Fig.10   Outline of two-layer box model

The mass conservation equations for the lower and upper layer can be written by

$$\frac{\mathrm{d}c_{1i}}{\mathrm{d}t} = R_{1i} + Q_i - D_i - V_{1i} + \left(\frac{\mathrm{d}c_{1i}}{\mathrm{d}t}\right)_{trans}, \qquad (3)$$

$$\frac{\mathrm{d}c_{2i}}{\mathrm{d}t} = R_{2i} - V_{2i} + \left(\frac{\mathrm{d}c_{2i}}{\mathrm{d}t}\right)_{trans}, \qquad (4)$$

where the subscripts 1 and 2 represented the lower layer and the upper layer. The subscript i represented chemical species. R, Q, D, V, and $\left(\frac{\mathrm{d}c}{\mathrm{d}t}\right)_{trans}$ represent chemical reaction, emission, deposition, ventilation and transfer terms, respectively. Each term is given by

$$Q = \frac{E}{h}, \qquad (6)$$

$$D = \frac{c}{h} \cdot V_g, \qquad (7)$$

$$V = N \cdot c, \qquad (8)$$

$$\left(\frac{\mathrm{d}c_1}{\mathrm{d}t}\right)_{trans} = \begin{cases} \frac{c_2 - c_1}{h} \cdot \frac{\mathrm{d}h}{\mathrm{d}t} & : \frac{\mathrm{d}h}{\mathrm{d}t} > 0 \\ 0 & : \frac{\mathrm{d}h}{\mathrm{d}t} \leqslant 0 \end{cases},$$

$$\left(\frac{\mathrm{d}c_2}{\mathrm{d}t}\right)_{trans} = \begin{cases} 0 & : \frac{\mathrm{d}h}{\mathrm{d}t} > 0 \\ \frac{c_2 - c_1}{H - h} \cdot \frac{\mathrm{d}h}{\mathrm{d}t} & : \frac{\mathrm{d}h}{\mathrm{d}t} \leqslant 0 \end{cases}, \qquad (9)$$

where E represents the emission flux, h represents the height of the lower layer (the mixing layer), V_g is the deposition velocity, N is the ventilation rate, and H is the vertical height

of a box. CBMIV(Gerry, 1989) was used as chemical reaction model.

3.2   Model parameters

The parameter values were given as follows. The length, the width and the vertical height of a box are 1.8 km, 1.8 km and 1300 m, respectively. The height of the mixing layer is made lineally increase from 8 a.m., reaches to the maximum height of 1200 m at 2 p.m., and is made lineally decrease until 8 p.m. The height of the mixing layer from 8 p.m. to 8 a.m. is the constant of 100 m. The ventilation rate is 0.26 h^{-1} from the average wind speed in Fig. 9. The deposition velocities of NO, NO$_2$, O$_3$, RHs, and TSP are 0.1, 0.1, 0.6, 0.2 and 0.8 cm/s, respectively. The average emission fluxes of NOx and TSP are 0.0220×10^{-9} m^3/(m$^2 \cdot$s) and 0.133 μg/(m$^2 \cdot$s) from Table 2, respectively. The average emission fluxes of PAR, OLE, TOL and XYL are 0.465×10^{-9} m^3/(m$^2 \cdot$s), 0.0127×10^{-9} m^3/(m$^2 \cdot$s), 0.113×10^{-9} m^3/(m$^2 \cdot$s) and 0.0592×10^{-9} m^3/(m$^2 \cdot$s), respectively. The hourly emission pattern from transport was decided by traffic volume data. The hourly emission pattern from household was decided by energy use in house. The hourly emission pattern from industry was assumed to be a constant.
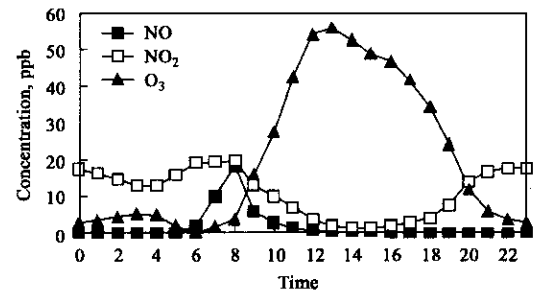

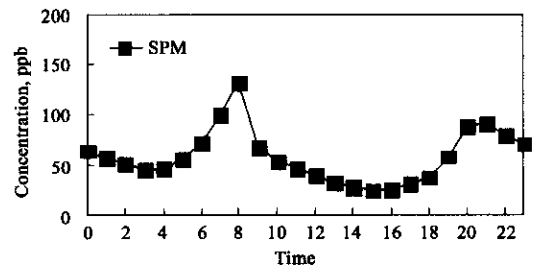Fig.11   Diurnal variations of NO, NO$_2$ and O$_3$ concentration calculated

Fig.12   Diurnal variations of SPM concentration calculated

3.3   Simulation results

The air pollutant concentrations using the two-layer box model were calculated for three days of December 2003. The results of the day 3 are shown in Fig. 11 and 12, which corresponded to the measurement concentrations in Fig.6 and Fig.7. The maximum value of O$_3$ and its time, the maximum value of NO at 8 a.m. and the decrease of NO and NO$_2$ at daytime were reproduced by this model. Generally the daily patterns of air pollutant concentrations by this model could be duplicated compared with the measurement concentrations. Some disagreement can be seen in the high concentration of NO$_2$ during the night time and in the decreasing rate of O$_3$ concentration. These causes are supposed to be in that the height of the mixing layer was unsuitable. However, these

suggested that the emission amounts estimated in the section 2 were fairly good. Also regarding SPM concentration, two peaks at 8 a.m. and 9 p.m. and the daily pattern could be well reproduced by this model, though the concentration was a bit low. The cause of the high concentration at 8 a.m. is from transport, while the cause at 9 p.m. is from household owing to the formation of the stable layer, though its amount is small, This proved also that the emission amount of SPM including re-suspension was fairly good. Using the emission amounts in 1993, air pollution concentrations in 1993 were calculated by the same model. The maximum concentration of SPM increased from 74 $\mu g/m^3$ in 1993 to 132 $\mu g/m^3$ in 2003 and the maximum concentration of O_3 increased from 38 ppb in 1993 to 56 ppm in 2003 and the time when the maximum concentration of O_3 appears was 2 h fast. These simulation results suggest that the reduction of emission amounts from transport is most required in order to improve air quality in Kathmandu valley.

4 Conclusions

The monthly concentrations of NO_2, NOx and SO_2 measured by a passive sampler from February 2003 to January 2004 were 15, 26 and 18 ppb in the winter season, respectively and were 4, 4.5 and 3 ppb in the summer season, respectively. The O_3 level was found the highest during April, May and June due to strong radiation. The hourly concentrations of NO_2, NOx, O_3 and SPM were also measured by automatic instruments in December, 2003. Temperature at the height of 60 m and 400 m at Raniban Mountain in the northwest of Kathmandu valley was measured in February 2001 in the winter season and the average potential temperature gradient was estimated from temperature. Wind speed was also measured at the department of hydrology, airport section, from 18 February to 6 March 2001. It was found that the stable layer and the calm condition in the atmosphere strongly affected the appearance of the maximum concentrations of NO_2 and SPM at 9 a.m. and that the unstable layer and the windy condition in the atmosphere was considerably relevant to the decrease of air pollution concentrations at daytime. The low concentration of NO suggested that the maximum concentrations of NO_2 and TSP in the evening resulted from the emission from household.

The emission amounts of NOx, HCs and TSP from transport sector in 2003 were estimated from the increase rate of vehicles and were 3751, 30570 and 1317 t/a, respectively. The emission amounts of PAR, OLE, TOL and XYL, which were chemical species in photochemical model, were estimated from the assumption that HCs concentrations measured near roadside were linear to those emissions. The diurnal concentrations in 2003 calculated by the two-layer box model reproduced the characteristic of air pollution in Kathmandu valley such as the maximum value of O_3 and its time, the

maximum value of NO at 8 a.m. and the decrease of NO and NO_2 at daytime. The calculations in 1993 and in 2003 showed the increase of maximum concentration of SPM from 74 $\mu g/m^3$ to 132 $\mu g/m^3$ and the increase of the maximum concentration of O_3 from 38 ppb to 56 ppm. It suggested that the main cause of air pollution was the emission from transport sector. If vehicles increase at the same increase rate, the air quality in Kathmandu valley will be worse. The maintenance of vehicles for the reduction of the emission and the improvement of roads for the reduction of re-suspension are urgently required to recover the beautiful view of Himalayan.

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