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Technical Information

Changes in SO_2 Concentration from Major Cities and Provinces in Korea: A Case Study from 1998 to 2003

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Abstract

The concentrations of sulfur dioxide (SO_2) were measured from seven major cities and nine provinces in Korea for the period covering 1998 to 2003. Its concentration data were analyzed to explore the possible influences of spatial and temporal factors on the SO_2 distribution characteristics. Examination of spatial trends of SO_2 distribution and behavior indicated several interesting features. Although its annual trends appeared to be affected by the changes in the surrounding environmental conditions (e.g., regulation on the use of S-containing fuels), the seasonal trends indicated a cyclic and systematic pattern that may be characterized as: a gradual decrease in concentrations across winter, spring, fall, and summer. The results showed the generally enhanced mean concentrations of SO_2 from Ulsan, Busan, and Daegu with 12.8, 10.1, and 8.80 ppb, respectively. On the other hand, notably reduced SO_2 concentrations were seen from Gwangju and Jeju sites with its mean values of 5.43 and 3.88 ppb, respectively. The overall results of our study indicate that a decrease in SO_2 concentration levels continued through time, while its spatial distribution appears to be affected most sensitively by such factor as city scale and industrial activities.

Key words : Sulfur dioxide, Pollution, Spatial, Temporal, Korea

1. INTRODUCTION

Environmental pollution is one of the most important issues in the modern Asia. The situation may be dramatically exacerbated as a consequence of accelerated consumption of fossil fuel in the Asian countries over the past several decades. An increase in the energy consumption was concentrated mainly in the industrial and/or highly populated residential areas. In the light of the fact that energy consumption and anthropogenic pollutant emissions in the region are projected to increase, air pollution problems are expected to grow significantly in their magnitude.

Sulfur compounds are released into the earth's atmosphere as a result of both natural and anthropogenic processes (Spiro *et al.*, 1992). The major fraction of anthropogenic S emissions is accounted for by SO_2. It was reported that about 80% of SO_2 (64.6 Tg S yr^{-1}) was derived from industrial emission (Koch *et al.*, 1999). Results of the Regional Air Pollution Information and Simulation (RAINS) - ASIA model study reported that under the conditions of continued economic development and industrial growth (with no changes in the environmental policies beyond those existing since 1990), annual emissions of SO_2 are expected to increase from 34

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(1990) to 110 Tg (2020) in Asia (Foell *et al.*, 1995). Even with a strong emphasis on energy efficiency improvements and a shift away from fossil fuels, SO_2 emissions in Asia are projected to grow up to 80 Tg without abatement measures in the year 2020 (Streets *et al.*, 2000).

In order to gain a better knowledge on the environmental behavior of the fundamental criteria pollutant, SO_2, we analyzed its concentration data obtained from seven major cities and nine provinces in Korea for the period from 1998 to 2003. To provide the detailed inspection on the basic factors controlling SO_2 distributions during the study period, the SO_2 data sets were analyzed at varying time scale such as yearly, seasonal, and monthly intervals. Moreover, in order to analyze the factors affecting SO_2 distribution at each site, statistical analysis was also made additionally.

2. MATERIALS AND METHODS

In this study, we investigated SO_2 concentration data sets collected from a total of up to 189 individual stations in Korea. To investigate the spatial and temporal distribution patterns of SO_2 concentrations, we used its monthly-based data measured routinely from all air quality monitoring stations after the adjustment through the following statistical modifications. (The SO_2 concentration data were initially measured at the hourly intervals but were released after modifications to the monthly intervals). It should also be noted that the number of stations varied gradually each year, as shown in Table 1; it started from as little as 128 (1998) and grew to 189 station (2003). However, considering the large number (abundance) of the air quality monitoring (AQM) stations, they were sorted out by categorizing into 16 major districts (seven major cities plus nine provinces). For this 6-year study period, most districts acquired up to 72 monthly data points. The SO_2 data sets from each individual station, once allocated to a given district, were then combined together to derive the fundamental statistical parameters for that specific district including the mean, minimum (min), and maximum (max) values at monthly intervals (Table 2).

In Table 1, the operating conditions of AQM stations are explained simply by means of comparing the total number of stations for a given

Table 1. The number of total SO_2 monitoring stations for 16 districts within Korea (seven major cites and nine provinces).

	City/Province		1998	1999	2000	2001	2002	2003
	Full name	Short name						
Seven cities	Seoul	SL	27	27	27	27	27	31
	Busan	BS	9	9	9	9	13	16
	Daegu	DG	6	7	6	6	7	11
	Incheon	IC	8	10	10	10	10	11
	Gwangju	GJ	4	4	4	4	4	4
	Daejeon	DJ	3	3	3	3	3	5
	Ulsan	US	7	7	11	12	12	13
Nine provinces	Gyunggi	GG	21	26	31	32	43	47
	Gangwon	GW	4	4	4	5	4	8
	Chungbuk	CB	4	4	4	4	4	5
	Chungnam	CN	3	3	3	3	3	3
	Jeonbuk	JB	6	6	6	6	6	6
	Jeonnam	JN	8	8	8	8	8	9
	Gyeongbuk	GB	9	9	9	10	10	10
	Gyeongnam	GN	8	8	8	8	8	8
	Jeju	JJ	1	1	1	1	2	2
Sum			128	136	144	148	164	189

Table 2. A statistical summary of SO_2 measurement data from 7 major cities and 9 provinces in Korea from 1998 to 2003.

Order	City/ Province	SO_2 concentration (ppb)				
		Mean	SD	Min	Max	N
1	SL	5.98	2.01	3.07	12.0	72
2	BS	10.1	4.11	4.82	21.8	72
3	DG	8.80	3.78	3.00	21.0	72
4	IC	7.42	1.69	4.00	12.0	72
5	GJ	5.43	2.10	2.00	11.3	72
6	DJ	6.55	2.95	2.33	15.7	72
7	US	12.8	3.25	7.22	21.3	72
8	GG	7.70	2.35	3.68	13.2	72
9	GW	6.02	2.57	2.25	12.8	72
10	CB	6.60	2.23	2.80	12.3	72
11	CN	6.55	1.53	3.33	10.7	72
12	JB	6.33	2.52	2.67	14.7	71
13	JN	8.50	2.52	4.60	14.5	72
14	GB	6.99	1.98	4.00	12.2	72
15	GN	7.65	3.43	3.86	19.5	72
16	JJ	3.88	1.61	2.00	8.00	69
	All	7.3	2.5	3.5	14.5	

Table 3. The maximum allowable level of criteria pollutants determined by the Korean Ministry of the Environment (KMOE). Considering more stringent changes on regulation standard through time, exceedance criteria set in 1995 were shown as one reference along with their measurement methods.

	Standard	Experimental method
SO_2	* yearly average < 0.02 ppm * 24-hour average < 0.05 ppm * 1-hour average < 0.15 ppm	Pulsed UV flourescence
CO	* 8-hour average < 9 ppm * 1-hour average < 25 ppm	Non-dispersive infrared
NO_2	* yearly average < 0.05 ppm * 24-hour average < 0.08 ppm * 1-hour average < 0.15 ppm	Chemiluminescence
PM-10	* yearly average < 70 $\mu g/m^3$ * 24-hour average < 150 $\mu g/m^3$	ß-Ray absorption
O_3	* 8-hour average < 0.06 ppm * 1-hour average < 0.1 ppm	UV photometric detection
Pb	* yearly average < 0.5 $\mu g/m^3$	Atomic absorption spectrometry

district investigated on annual basis. For instance, in the case of Seoul, the monthly representative values for mean, min, and max were derived by putting the results of 27 individual stations within its boundary (Jan., 1998); note that its sum grew to hit 31 stations in January, 2003. The same procedures were applied to estimate the monthly representative values for the remaining cities and provinces. Three different types of SO_2 concentrations, which were initially derived as the mean, min, and max values for a given district, were then used as the basic input data to generalize the temporal and/or spatial distribution of SO_2.

The raw SO_2 data for a given district were in the initial stage measured routinely at short intervals (e.g., 1 min interval) by the standard operation procedure (SOP) of KMOE (Table 3). Those original data are quality controlled and stored in the data management network system operated by the KMOE. In the course of this study, the SO_2 values for the monthly mean, min, and max obtained by the above procedure were examined further for both seasonal and inter - annual trends of SO_2 for each individual district.

3. RESULTS AND DISCUSSION

3.1 Spatial distribution patterns of SO_2 data

To examine the spatial distribution patterns of SO_2, the SO_2 concentration data representing 16 major districts (seven major cities and nine provinces) were evaluated both by the mean and by other basic parameters (like min and max). A statistical summary of the SO_2 distributions for all 16 districts is presented in Table 2. It should be noted that most AQM stations located in 16 districts may have different geofraphical characteristics to affect their air quality. However, as most of them are basically located on the top of local administrative buildings, they tend to maintain relatively similar properties. Among all sites investigated, the highest mean was found from Ulsan (12.8 ± 3.25 ppb, N = 72), followed by Busan (10.1 ± 4.11 ppb, N = 72). In contrast, the lowest mean was seen from Jeju (3.88 ± 1.61 ppb, N = 69). As compiled in the summary, the mean values in the major cities increased

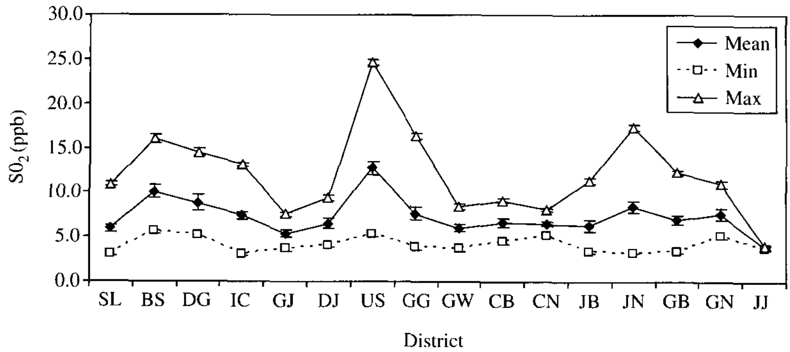

Fig. 1. Comparison of SO_2 concentrations among seven major cities and nine provinces in Korea for the period covering from 1998 to 2003. Refer to the text for the explanations of the 2nd stage statistical terms. Refer to *Table 1 for the full information of districts given in x-axis.*

on the order of Gwangju, Seoul, Daejeon, Incheon, Daegu, Busan, and Ulsan with their values covering from of 5.43 to 12.8 ppb. Likewise, if such comparison is made among different provinces, it increased on the order of Jeju, Gangwon, Jeonbuk, Chungnam, Chungbuk, Gyeongbuk, Gyeongnam, Gyunggi, and Jeonnam with the range of 3.88 to 8.50 ppb.

To make a meaningful comparison of the SO_2 spatial distribution patterns, we compared the SO_2 concentration levels of each district by all basic statistical terms. To explain how those parameters changed through time, the second-stage mean values were also calculated by pooling all the initial statistical terms (e.g., up to 72 monthly data points for each district with mean, min, and max) with the following notations: Mean', Min', and Max'. Fig. 1 compares those second stage mean values by putting all the initial monthly values of mean, maximum, and minimum. The results for the major cities again indicate that the highest Max' occurred from Ulsan with 24.7 ppb (N = 72), while the lowest Min' from Seoul at 3.0 ppb (N = 72). For nine provinces, both the highest Max' and the lowest Min' were found simultaneously from Jeonnam with 17.3 (N = 72) and 3.3 ppb (N = 72).

To investigate the SO_2 occurrence patterns for different districts, their frequency distribution patterns were also examined using the monthly mean data sets for each district (Fig. 2). It was apparent that seven major cities including Seoul, Gwangju, Incheon, Daegu, and Daejon exhibited their maximum frequency occurring near 6~8 ppb. However, quite contrasting pattern was seen from Ulsan with its maximum frequency occurring at ~14 ppb. This abnormal frequency pattern in Ulsan city is not surprising, if one considers that it recorded the highest mean value among all cites investigated. In the case of nine provinces, the peak frequency occurred in a more broad range such as in the range near 4~8 ppb. It thus suggests that the differences in SO_2 distribution patterns between cities and provinces can be distinguished probably due to the differences in the magnitude of man-made activities.

To further describe SO_2 distribution patterns among different sites, its monthly mean values were also compared as seen in Fig. 3. The highest SO_2 concentration value was 21.8 ppb at Busan, followed by Ulsan with 21.3 ppb. In contrast, the lowest value of 2 ppb, were seen from both Gwangju and Jeju sites. Comparison of our data clearly showed that the spatial patterns of SO_2 among different districts are not simply determined by the results of arbitrary (or random) processes. It is reasonable to expect that the record high SO_2 levels in Ulsan city can reflect the presence of strong local sources due to strong industrial (and economic) activities. However, the significantly reduced SO_2 levels in Gwangju and Jeju may directly represent the background environmental conditions in which where sources of SO_2 are not abundant enough.

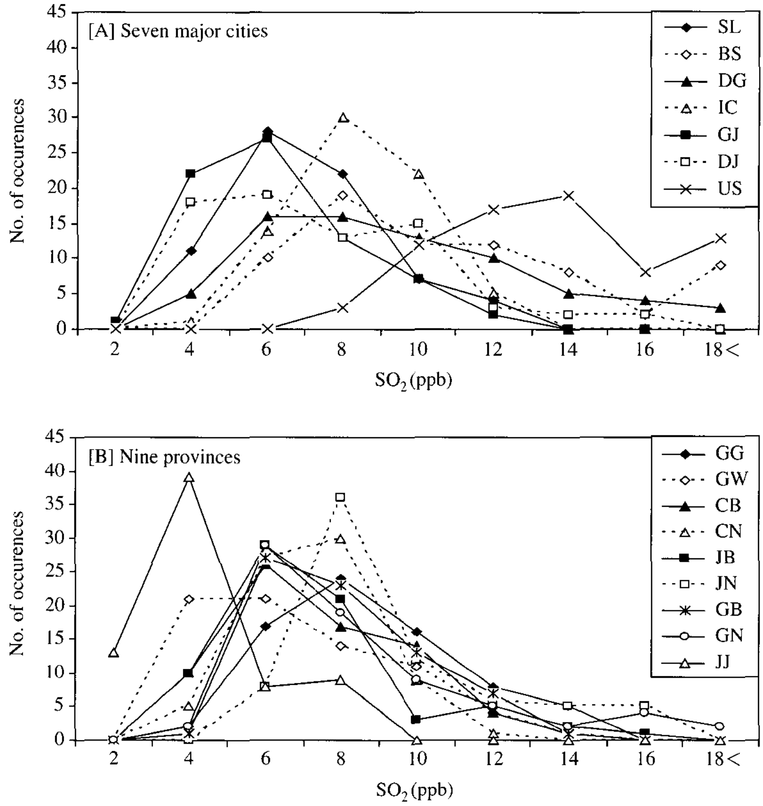

Fig. 2. Comparison of the frequency distribution patterns of SO_2 concentration data.

3.2 Seasonal patterns

Since the SO_2 measurement data were collected continuously to cover the whole four seasons of the year for the period from 1998 to 2003, these data are apt to be examined with respect to the seasonal variations. Fig. 4 depicts the comparison of seasonal mean concentrations of SO_2 for all 16 districts. As we noticed from the comparison, SO_2 concentration at these sites tends to decrease across winter, spring, fall, and summer. Except for a complicated pattern seen in Ulsan, the data from most sites exhibit the similar cycle with a notable increase during winter (and spring) and a drop in summer (and fall). For seven major cities, the highest seasonal mean value was recorded in Deagu during winter (10.2 ppb), while the lowest in Deajon during summer (3.8 ppb). At nine provinces, the highest seasonal mean concentration was found in Gyeongnam (9.9 ppb) during winter but the lowest mean in Jeju during summer (2.7 ppb).

The results of our comparison generally indicate that SO_2 concentration tends to increase near winter; this is in general compliance with the combination of such factors as the seasonal fuel consumption pattern and the meteorological conditions. In fact, the climate of Korea is characterized by a cold, relatively dry winter followed by a hot and humid summer. More than half of the annual precipitation occurs during the summer monsoon. Therefore, the energy demand for heating is expanded during the winter, and its precipitation based removal is at its maximum in summer (Hong *et al.*, 2002). The seasonal mean SO_2 concentration in summer is significantly lower than other seasons, due mainly to strong precipitation in summer months which is commonly seen from many other countries as well

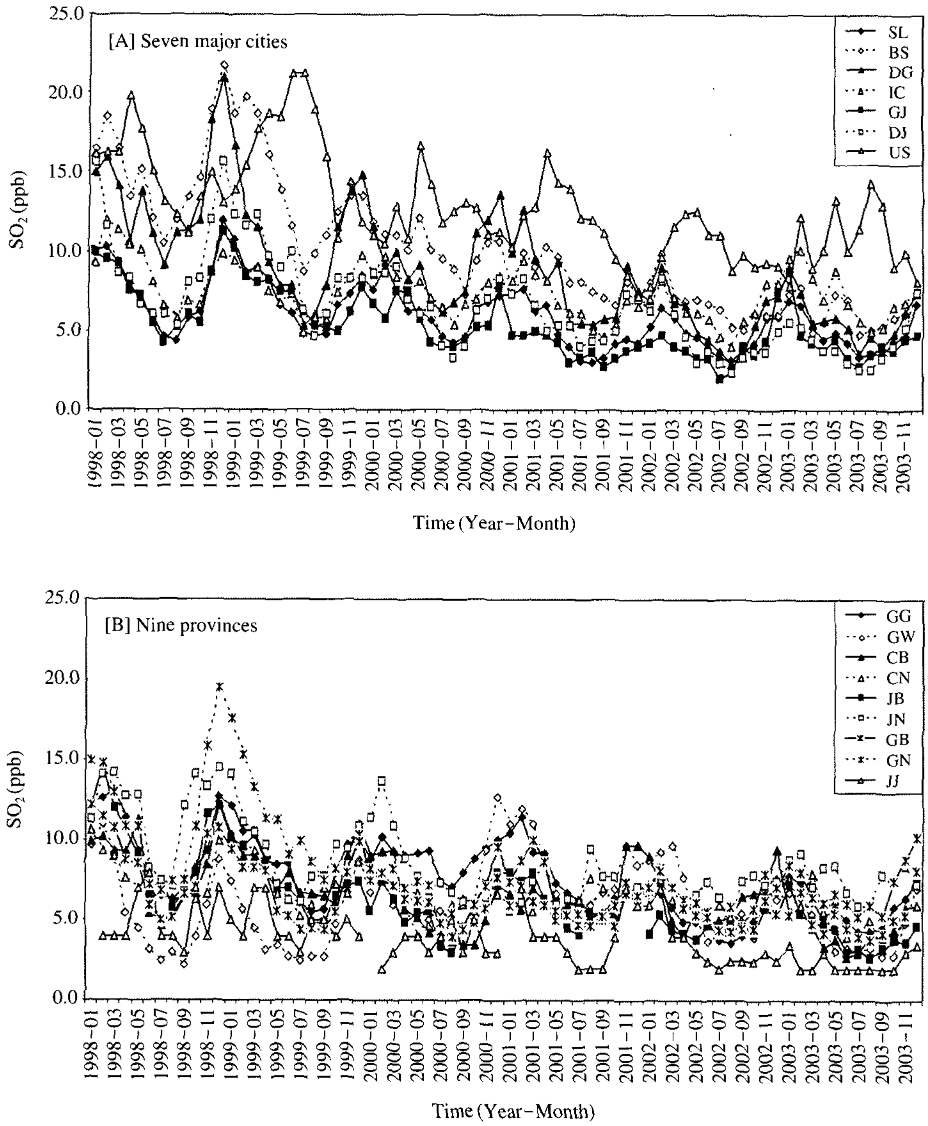

Fig. 3. Comparison of the monthly mean concentrations of SO_2 (ppb) from major cities and provinces in Korea.

(Monkkonen *et al.*, 2003). The observations of a distinct seasonal variation which reached its peak in winter and its lowest concentration in summer are a kind of common findings (Jo *et al.*, 2000).

3.3 Annual patterns

The annual trend of SO_2 concentrations during the study period was also examined in Fig. 5. As seen in 7 major cities, the overall trend of SO_2 concentrations tends to decrease through time from 1998 to 2003. However in some cities (Seoul, Incheon, and Gwangju), there were slightly opposing patterns due to a slow reduction of the SO_2 concentrations in 2002 (compared to that in 2003). Similar to 7 major cities, the annual SO_2 concentration trend from 9 provinces generally exhibited gra-

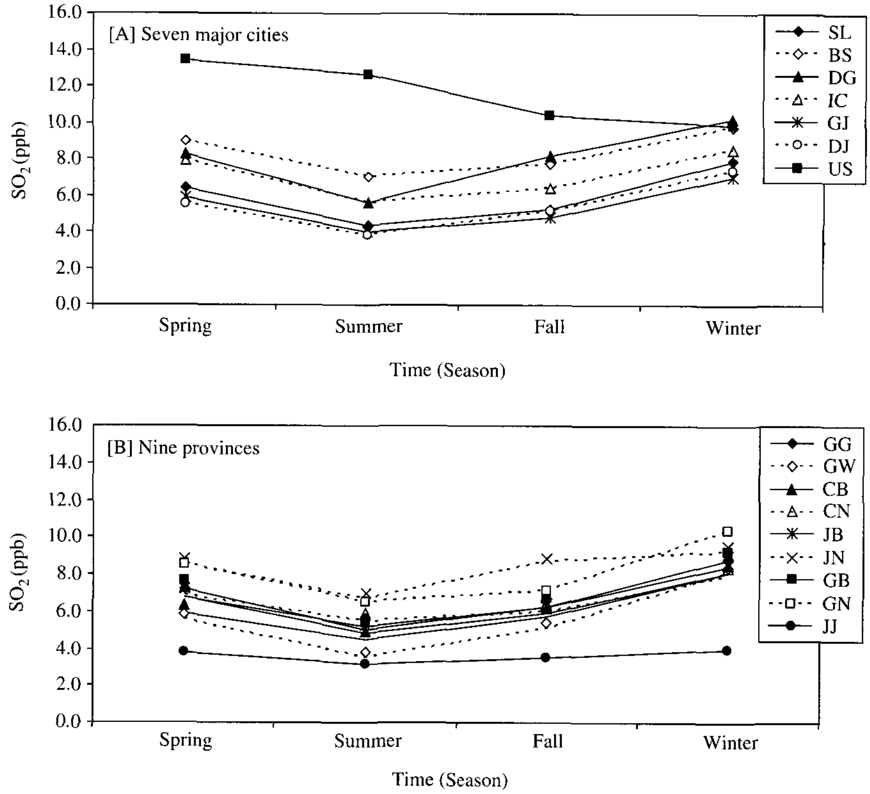

Fig. 4. Comparison of seasonal mean concentrations of SO_2 (ppb) measured from both major cities and provinces.

dual decreases through time. The major reason for such a decrease in the observed SO_2 concentrations can be ascribed to the enforcement of the control policy (e.g., the desulfurization on various oil products). By comparing fuel consumption and pollutant emissions between 1991 and 2000, total emissions of five pollutants (including SO_2) have been reduced by about 26.7%, nonetheless, fuel consumption has increased by 79.1% during this period (Kang, Korea Environment Institute: personal communication). In the early 1990s, there was a report that the sulfur content of heavy fuel oil was reduced to the 1.0% level in major metropolitan areas, while the sulfur content of light fuel oil was regulated by 0.2% for Seoul/Incheon, Busan, and other large cities (Street *et al.*, 2000). In addition, if the patterns for the nine provinces are compared, there have been a few exceptional years when the pattern fluctuated to a degree (in Gwangju, Chungbuk, Jeonnam, and Gyeongbuk). Although several factors (including meteorological factors, the an-thropogenic activities, and the changes in the fossil fuel types used in each year) are suspected to be important, it is yet unclear to explain the case of such results. It should also be noted that most basic statistical parameters of SO_2 for all nine provinces were systematically smaller than their respective counterparts for the seven major cities.

3.4 Factors affecting SO_2 distribution

To provide some insights into the processes governing SO_2 concentration levels among different study areas, we investigated the relationships among the monthly SO_2 concentration data sets collected from all different districts (seven major cities and nine provinces) via correlation analyses (Table 4).

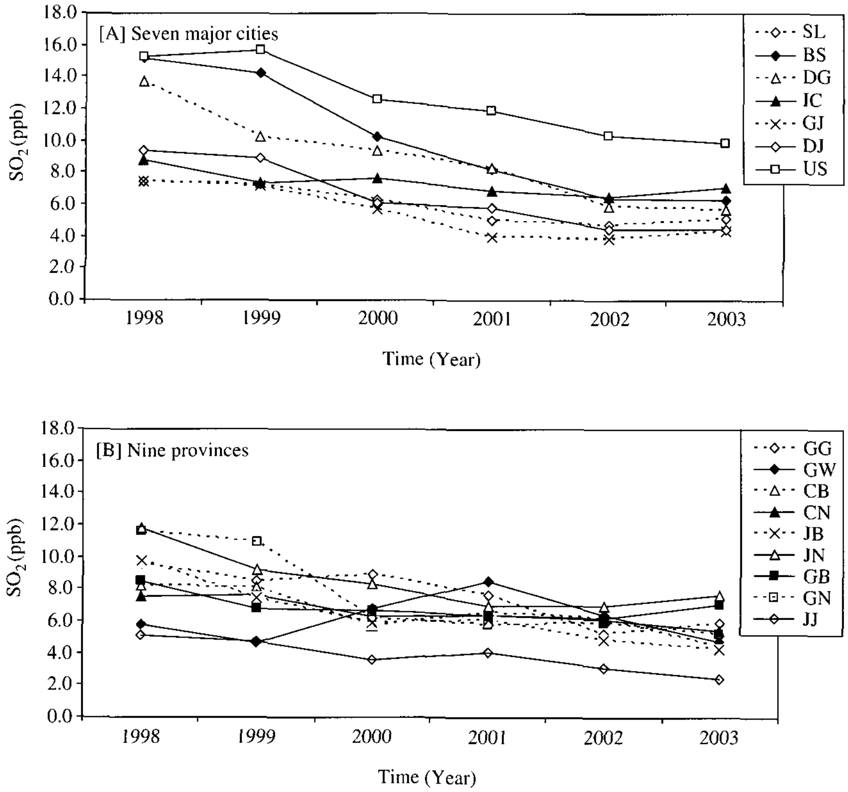

Fig. 5. Comparison of the annual mean concentrations of SO_2 (ppb) from the major cities and provinces.

The strengths of correlations among the matching district pairs were estimated arbitrarily by dividing all results into five different classes of probability (P = probability of no correlation) such as: (1) class 0 (the weakest correlation range): $P \geq 10^{-3}$; (2) class I (weak correlation): $10^{-5} \leq P < 10^{-3}$; (3) class II: $10^{-10} \leq P < 10^{-5}$; (4) class III: $10^{-15} \leq P < 10^{-10}$; (5) class IV (the strongest correlation range): $P < 10^{-15}$. This type of analysis was extended to: A (city-by-city), B (province-by-province), C groups (city-by-province) as shown in Table 5. The strengths of correlation were investigated for all matching site pairs for all possible combinations. The results indicated that there are several different trends in the 'site-by-site' relationships. For a total of 21 correlation cases (group A), the existence of the strongest correlation (class IV) is consistently found from 11 pairs. The most dominant trend appears to come from the ones matching with Seoul (five other cities). When the strengths of correlation were compared among those pairs, only one case was found with the relatively poor correlation. On the other hand, the weakest correlation pairs mainly occurred from those matching with Ulsan. In the case of B group, a total of 36 correlation cases exist between. If we compare these results, there are 2 cases with the strongest correlations (class IV), 8 cases in class I, and 5 with class 0. Therefore, when the results are compared between cites and provinces, the correlation pairs made by provinces were generally poor relative to cities. The weakest correlations were seen at pairs made by Gwangwon and Jeju. In the case of C group results, there are a total of 63 matching pairs between cites and provinces. It was seen that, there were 18 cases of the strongest correlation (class IV), 4 in class I, and 13

Table 4. Results of correlation analysis on the SO_2 concentration data set: their relationships are compared after being categorized into: (A) city-by-city, (B) province-by-province, (C) city-by-province.

Category A

		SL	BS	DG	IC	GJ	DJ	US
SL	N	72	72	72	72	72	72	72
	r	1.000	0.826 (IV)	0.865 (IV)	0.853 (IV)	0.883 (IV)	0.889 (IV)	0.322
	P		3.37E-19	8.63E-23	1.41E-21	7.51E-25	1.30E-25	5.79E-03
BS	N		72	72	72	72	72	72
	r		1.000	0.867 (IV)	0.607 (II)	0.831 (IV)	0.875 (IV)	0.557 (II)
	P			5.27E-23	1.51E-08	1.32E-19	6.77E-24	3.63E-07
DG	N			72	72	72	72	72
	r			1.000	0.731 (III)	0.812 (IV)	0.848 (IV)	0.281
	P				2.75E-13	4.02E-18	4.22E-21	1.68E-02
IC	N				72	72	72	72
	r				1.000	0.727 (III)	0.647 (III)	0.201
	P					4.29E-13	7.72E-10	9.04E-02
GJ	N					72	72	72
	r					1.000	0.847 (IV)	0.452 (I)
	P						5.23E-21	6.64E-05
DJ	N						72	72
	r						1.000	0.375
	P							1.16E-03
US	N							72

Category B

		GG	GW	CB	CN	JB	JN	GB	GN	JJ
GG	N	72	72	72	72	71	72	72	72	69
	r	1.000	0.535 (I)	0.645 (II)	0.683 (II)	0.836 (IV)	0.636 (II)	0.755 (III)	0.721 (III)	0.426 (I)
	P		1.25E-06	9.05E-10	3.55E-11	9.15E-20	1.82E-09	1.60E-14	8.23E-13	2.60E-04
GW	N		72	72	72	71	72	72	72	69
	r		1.000	0.394 (I)	0.412 (I)	0.408	0.13	0.583 (II)	0.204	0.216
	P			6.12E-04	3.20E-04	4.09E-04	2.76E-01	7.42E-08	8.56E-02	7.46E-02
CB	N			72	72	71	72	72	72	69
	r			1.000	0.726 (III)	0.724 (III)	0.668 (II)	0.611 (II)	0.746 (III)	0.465 (I)
	P				4.79E-13	8.69E-13	1.35E-10	1.14E-08	4.83E-14	5.60E-05
CN	N				72	71	72	72	72	69
	r				1.000	0.73 (III)	0.655 (II)	0.6 (II)	0.743 (III)	0.422 (I)
	P					4.53E-13	4.04E-10	2.43E-08	6.91E-14	3.01E-04
JB	N					71	71	71	71	68
	r					1.000	0.734 (III)	0.719 (III)	0.848 (IV)	0.443 (I)
	P						2.91E-13	1.48E-12	8.02E-21	1.53E-04
JN	N						72	72	72	69
	r						1.000	0.624 (II)	0.753 (III)	0.275
	P							4.49E-09	2.06E-14	2.22E-02
GB	N							72	72	69
	r							1.000	0.632 (II)	0.278
	P								2.47E-09	2.07E-02
GN	N								72	69
	r								1.000	0.49 (I)
	P									1.89E-05
JJ	N									69

Table 4. Continued.

Category C

		GG	GW	CB	CN	JB	JN	GB	GN	JJ
SL	N	72	72	72	72	71	72	72	72	69
	r	0.906 (IV)	0.461 (I)	0.706 (III)	0.769 (III)	0.849 (IV)	0.738 (III)	0.823 (IV)	0.834 (IV)	0.43 (I)
	P	4.86E-28	4.53E-05	3.91E-12	2.62E-15	6.48E-21	1.24E-13	5.84E-19	7.38E-20	2.24E-04
BS	N	72	72	72	72	71	72	72	72	69
	r	0.789 (IV)	0.145	0.667 (II)	0.71 (III)	0.849 (IV)	0.764 (III)	0.575 (II)	0.914 (IV)	0.547 (II)
	P	1.55E-16	2.24E-01	1.47E-10	2.60E-12	6.48E-21	5.07E-15	1.23E-07	2.39E-29	1.12E-06
DG	N	72	72	72	72	71	72	72	72	69
	r	0.842 (IV)	0.439 (I)	0.672 (III)	0.688 (III)	0.848 (IV)	0.71 (III)	0.723 (III)	0.798 (IV)	0.544 (II)
	P	1.49E-20	1.13E-04	9.52E-11	2.24E-11	8.02E-21	2.60E-12	6.64E-13	3.93E-17	1.32E-06
IC	N	72	72	72	72	71	72	72	72	69
	r	0.819 (IV)	0.502 (II)	0.607 (II)	0.641 (II)	0.74 (III)	0.663 (II)	0.833 (IV)	0.584 (II)	0.306
	P	1.20E-18	6.89E-06	1.51E-08	1.24E-09	1.47E-13	2.07E-10	8.97E-20	6.96E-08	1.05E-02
GJ	N	72	72	72	72	71	72	72	72	69
	r	0.803 (IV)	0.24	0.712 (III)	0.75 (III)	0.821 (IV)	0.722 (III)	0.693 (III)	0.842 (IV)	0.383
	P	1.78E-17	4.22E-02	2.12E-12	2.98E-14	1.48E-18	7.39E-13	1.40E-11	1.49E-20	1.15E-03
DJ	N	72	72	72	72	71	72	72	72	69
	r	0.831 (IV)	0.374	0.747 (III)	0.776 (III)	0.852 (IV)	0.676 (III)	0.699 (III)	0.891 (IV)	0.544 (II)
	P	1.32E-19	1.20E-03	4.29E-14	1.01E-15	3.40E-21	6.69E-11	7.82E-12	7.06E-26	1.32E-06
US	N	72	72	72	72	71	72	72	72	69
	r	0.372	-0.269	0.228	0.224	0.439 (I)	0.265	0.088	0.486	0.256
	P	1.28E-03	2.23E-02	5.40E-02	5.85E-02	1.27E-04	2.44E-02	4.62E-01	1.48E-05	3.37E-02

in class 0. The absence of strongly correlated cases in this C group appeared to come most dominantly from the pairs of Ulsan and nine provinces. According to the results of this study, we were able to find that the compound, SO_2 can be used as a good indicator to diagnose man-made activities such as the observed differences in its spatial distribution patterns among different districts.

4. CONCLUSIONS

To describe the temporal and spatial distribution characteristics of SO_2, we analyzed SO_2 data sets measured from 16 major districts of Korea during 1998 to 2003. The spatial distribution patterns for the study area were generally characterized by the high SO_2 concentration at Ulsan (city) and low concentration at Jeju (province). If the frequency distribution patterns are compared among different sites, the maximum frequency at seven major cities occurred near 6~8 ppb, while that at nine provinces about 4~8 ppb.

Table 5. A summary of correlation results for all SO_2 concentration data collected from 7 cities and 9 provinces in Korea during the study period. Refer to Table 4 for the original raw correlation analysis results. All correlation results were divided arbitrarily on the basis of correlation strengths.

Class of correlation strength	Category		
	A	B	C
0	4	5	13
I	1	8	4
II	2	10	10
III	3	11	18
IV	11	2	18
Sum	21	36	63

If the seasonal mean concentrations of SO_2 are compared across all seasons, the highest value was found in winter, followed by spring, fall, and summer. The cause of such seasonal pattern may be best accounted for as the combined effect of the enhanced fuel consumption and the concurrent meteorological conditions. For instance, it is evident that the summer monsoon phenomena also contributed directly to the low SO_2 concentration in summer. It is noted that due to the governmental policies of desulphurization on the fossil fuels, the analysis of the annual trend indicates that the SO_2 concentration decreased gradually throughout the study period (1998～2003). Moreover, the results of correlation analysis among all those 16 districts indicated that correlations from 'city-by-city' data sets were the strongest while that of 'province-by-province' were generally weak. The results of this analysis thus clearly indicate that enhanced man-made activities in more urbanized regions may contribute more significantly to the total S budget in Korea.

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