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Impact of Dust Transported from China on Air Quality in Korea –Characteristics of $PM_{2.5}$ Concentrations and Metallic Elements in Asan and Seoul, Korea

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Abstract: $PM_{2.5}$, particulate matter less than 2.5 um in a diameter, can penetrate deeply into the lungs. Exposure to $PM_{2.5}$ has been associated with increased hospital visits for respiratory aliments as well as increase mortality. $PM_{2.5}$ is a byproduct of combustion processes and as such has a complex composition including a variety of metallic elements, inorganic and organic compounds as well as biogenic materials (microorganisms, proteins, etc). In this study, the average concentrations of fine particulates $PM_{2.5}$ have been measured simultaneously in Asan and Seoul, Korea, by using particulate matter portable sampler from September 2001 to August 2002. Sample collection filters were analyzed by ICP-OES to determine the concentrations of metallic elements (As, Ni, Fe, Cr, Cd, Cu, Pb, Zn, Si). Annual mean $PM_{2.5}$ concentrations in Asan and Seoul were 37.70 and 45.83 $\mu g/m^3$, respectively. The highest concentrations of $PM_{2.5}$ were found in spring season in both cities and the concentrations of measured metallic elements except As in Asan were higher than those in Seoul, suggesting that yellow dust in spring could affect $PM_{2.5}$ concentrations in Asan rather than Seoul. The correlation coefficients of Pb and Zn were 0.343 for Asan and 0.813 for Seoul during non-yellow dust condition, suggesting that Pb and Zn were influenced with the same sources. The correlation coefficients between Si and Fe in the fine particulate mode were 0.999 (Asan) and 0.998 (Seoul) during yellow dust condition. It was suggested that these two elements were impacted by soil-related transport from China during the yellow dust storm condition.

Keywords: fine particulate, yellow dust, metallic elements

Introduction

The combination of high population density and rapid industrialization in Korea has inevitably led to an increase in air pollutant emissions. The increased emissions have exacerbated air pollution problems in large and medium sclae cities in Korea resulting in visibility reduction and health concern.[1)] Ambient particulate matter (PM) is largely responsible for the visibility deterioration in different areas[2,3)] and a number of steps are being taken to reduce PM pollution in Korea. For example, diesel buses are being converted to compressed natural gas and several steps are being taken to reduce dust from construction areas.

Atmospheric particulate matter is made up of solid and liquid particles, which enter into the atmosphere by natural pathways or by the anthropogenic activity.[4-6)] Atmospheric PM can have a range of sizes with PM generally classified in two size fractions PM_{10} (particulate matter less than 10 μm in aerodynamic diameter) and $PM_{2.5}$ (particulate matter less than 2.5 μm in aerodynamic diameter).[7)] PM_{10} and $PM_{2.5}$ have been associated with increased mortality, increased morbidity, and decreased lung function.[8,9)] The U.S. Environmental Protection Agency (USEPA) regulated $PM_{2.5}$ in 1997. At this time Korea has a PM_{10} standard only, but does not have one for $PM_{2.5}$. As a result, $PM_{2.5}$ monitoring is not routinely conducted in Korea.

It is well recognized that health effects of PM depend on many factors including their size, chemical composition, and reactivity. Metals are an important component of PM in general and $PM_{2.5}$ in particular. Industrial processes such as metal refining and fossil fuel combustion are

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important sources of metals in the atmosphere. Metals components have been broadly implicated as mediating PM-related toxicity.[10]

The purpose of this study is to characterize the impact of dust ($PM_{2.5}$) transported from China on air quality in Korea by comparing a medium city, Asan, with a large metropolitan city, Seoul in Korea. In addition, we have characterized metal composition of $PM_{2.5}$. This information provides an essential baseline for the regulation and management of fine particulate matter in a developing country such as Korea.

Methods

Airborne $PM_{2.5}$ was collected in two Korean cities, Seoul and Asan. Seoul, the capital of Korea, has a population of 10.3 million people in 605 km^2 area, while Asan about 0.18 million people in 540 km^2. Distance from Seoul to Asan is about 100 km. The sampling site in Seoul was located on the roof (approximately 20 m height) of the School of Medical Science, Hanyang University, about 200 m away from a road. The other sampling site was located on the roof (approximately 18 m height) of the School of Natural Sciences, Soonchunhyang University, Asan, 180 m away from a road. The climate of Asan and Seoul is similar and is characterized by a cold, relatively dry winter and a hot, humid summer. The prevailing wind for both cities is directed south easterly in summer and north westerly in spring and winter.

The sampling campaign was conducted from September 2001 to August 2002. $PM_{2.5}$ samplers were collected on pall flex membrane filter (47 mm, Gelman Science) with MiniVol portable air sampler (Airmetrics, PAS 201). Membrane filters were conditioned in dry air for a 48 hour-period and weighed to precision of 0.01 mg in an analytical balance (Sartorius, BP 211D, Germany).

Samples were prepared for metal analysis using microwave (Questron Co., Qlab 6000) digestion. Filter samples were placed in a microwave vessel with 10 m*l* of mixture 1.03M HNO_3 and 2.23M HCl, then heated the microwave oven at 545 watt for 10 min and 344 watt for 5 min. Ten elements (As, Mn, Ni, Fe, Cr, Cd, Cu, Pb, Zn and Si) were analyzed for using inductively coupled plasma optical emission spectrometry (ICP-OES) (Optima 3000 DV, Perkin-Elmer Co.). Elemental metal concentrations were adjusted with blank values and limits of detection (LOD) were determined for each metallic element.

Fine particulate mass and metallic concentrations data were analyzed by SPSS software (Version 11.0). Correlations among measured metallic elements were analyzed by Spearman's rank correlation test and Mann Whitney U test was used to compare means for each city using two-tailed tests and a 5% level of significance.

Results and Discussion

$PM_{2.5}$ Concentrations during Yellow dust Conditions

Table 1 shows measured $PM_{2.5}$ concentrations in both cities according to yellow dust condition. The annual mean $PM_{2.5}$ levels were 37.70 ± 18.41 μg/m^3 and 45.85 ± 38.50 μg/m^3 in Asan and Seoul, respectively. The average $PM_{2.5}$ concentrations in Asan and Seoul were approximately 2~3 times higher than the annual average US standard of 15 μg/m^3.

Table 1. Concentrations (μg/m^3) of fine particles ($PM_{2.5}$) in non-yellow dust condition and yellow dust condition in Asan and Seoul

	Asan		Seoul		p^a
	n	Mean ± S.D. (Range)	n	Mean ± S.D. (Range)	
Yellow dust condition	7	58.33 ± 22.99 (33.10~89.81)	7	92.20 ± 54.32 (59.03~203.01)	0.225
Non-yellow dust condition	44	34.42 ± 15.50 (13.43~99.07)	24	32.31 ± 17.85 (2.78~87.50)	0.376
Total	51	37.70 ± 18.41	31	45.83 ± 38.50	0.785
p^b		0.009^{**}		0.000^{**}	

p^a (p-value): Mann-Whitney U test between concentrations of particles of Asan and Seoul.

p^b (p-value): Mann-Whitney U test between concentrations of particles of yellow sand condition and non-yellow dust condition.

Weather conditions were classified as non-yellow dust condition (non-Asian dust period) and yellow dust condition (Asian-dust period: i.e. Asian dust from the Takla Makan desert, the Gobi desert and the loess plateau of China). During the yellow dust storm pollutants are transported to Korea from China and Mongolia. The Asian dust storm has been well documented with Duce *et al.* (1980) and Bodhain *et al.* (1995) reporting on meteorological impact of Asian dust storm (yellow dust).[11,12] The measured average mass $PM_{2.5}$ during yellow dust condition in Asan and Seoul were 58.33 ± 22.99 μg/m^3 and 92.20 ± 54.32 μg/m^3, respectively. For comparison, the average $PM_{2.5}$ during the non-yellow dust condition were 34.42 μg/m^3 and 32.31 μg/m^3 in Asan and Seoul respectively. In general, the $PM_{2.5}$ concentrations at yellow dust condition were 2~3 times higher than those of non-yellow dust condition ($p<0.01$), demonstrating the importance of long range transported PM on air quality in Korea.

The concentrations of $PM_{2.5}$ during the non-yellow dust season are comparable to concentrations typical of other large cities around the world. For example, the concentrations are 4~6 μg/m^3 higher than in Toronto, Canada.[13] The non-yellow dust season concentrations are considered excessive when compared to U.S. and European ambient air quality standards. The EU (European Commission) Directive 1999/30/EC established limit values for the annual mean $PM_{2.5}$ level. This limit value experiences a year-to-year decrease from 2001 to 2010, and is equal to 20 μg/m^3 in 2005. This indicates that a pollution control strategy for Asan and Seoul is needed by Korean Ministry of Environment.

Seasonal Concentration of $PM_{2.5}$

Table 2 presents the seasonal variation of $PM_{2.5}$. On seasonal annual basis, the average mass concentrations are 47.76 ± 19.07 μg/m^3 in spring, 29.44 ± 9.85 μg/m^3 in summer, 39.19 ± 24.57 μg/m^3 in fall, and 33.78 ± 12.62 μg/m^3 in winter in Asan, while the averages in Seoul are 61.53 ± 4.37 μg/m^3, 25.42 ± 8.10 μg/m^3, 45.60 ± 53.50 μg/m^3, and 42.92 ± 31.49 μg/m^3, respectively. The highest concentration was found in spring and the lowest was in summer demonstrating a strong seasonal effect. The elevated spring-time concentration is linked to the yellow dust condition.

The average $PM_{2.5}$ concentration in Seoul was significantly higher than those in Asan in spring ($p<0.05$). These results suggest that higher concentrations in Seoul could be attributed to other factors such as heavy traffic, increased construction activity, and other combustion activities (i.e., power generation and incinerators). Ferguson and Nicholas (1991) reported that the major fine particulate sources were construction work, automobile traffic, incineration, wind blown dust, coal-fired power plant and oil combustion sources.[14]

The lowest $PM_{2.5}$ concentrations were found in summer season period (Table 2). When wind blows from the Pacific Ocean in summer, the high convection air mass leads to vertical dispersion of pollutants. This in-flowing oceanic air to Korea and South China is relatively free from anthropogenic pollutant.[15] In addition to the subtropical high pressure, typhoons, which are frequently accompanied by high wind and unstable weather conditions, facilitate the dissemination of pollutants in summer. Frequent rains in summer are also an influential factor.

Table 2. Seasonal concentrations (μg/m^3) of fine particulates ($PM_{2.5}$) in Asan and Seoul

	Asan		Seoul		p^a
	n	Mean±S.D. (Range)	n	Mean±S.D. (Range)	
Spring	13	47.76±19.07 (20.14~89.81)	5	61.53±4.37 (58.10~68.75)	0.026*
Summer	12	29.44±9.85 (13.43~46.06)	2	25.42±8.10 (19.69~31.15)	0.584
Fall	13	39.19±24.57 (14.12~99.07)	12	45.60±53.30 (13.89~203.01)	0.430
Winter	13	33.78±12.62 (18.98~71.30)	12	42.92±31.49 (2.78~126.16)	0.231
p^b		0.017*		0.082	

p^a (p-value): Mann-Whitney U test between concentrations of particles of Asan and Seoul.
p^b (p-value): Kruskal-Wallis H test between concentrations of particles with regard to season.

Table 3. Concentrations (ng/m^3) of metallic elements in fine particulates ($PM_{2.5}$) in Asan and Seoul

	Yellow dust condition			Non-yellow dust condition			Total				
	Asan	Seoul		Asan	Seoul		Asan	Seoul		p^a	p^b
	Mean±S.D. (Range)		p	Mean±S.D. (Range)		p	Mean±S.D.		p		
As	4.19±6.32 (0.001~14.53)	7.89±7.41 (0.001~19.06)	0.319	7.58±8.45 (0.001~26.28)	8.92±9.54 (0.001~29.86)	0.637	7.11±8.22	8.69±9.00	0.552	0.259	0.962
Mn	31.70±18.91 (13.53~61.82)	25.76±23.18 (4.07~74.89)	0.482	17.52±15.02 (4.51~89.14)	5.98±5.01 (0.003~19.78)	0.000^{**}	19.47±16.16	10.45±14.05	0.000^{**}	0.012^{*}	0.002^{**}
Ni	2.73±4.70 (0.007~10.65)	N.D.	N.A.	9.95±12.95 (0.007~60.00)	N.D.	N.A.	8.96±12.37	N.D.	N.A.	0.070	N.A.
Fe	889.29±759.08 (225.44~2058.22)	731.87±1042.57 (83.61~3034.95)	0.406	221.48±181.54 (0.006~793.03)	70.22±57.98 (0.006~225.80)	0.000^{**}	313.14±389.04	219.62±546.86	0.000^{**}	0.001^{**}	0.001^{**}
Cr	4.44±2.23 (0.02~6.27)	2.28±1.96 (0.003~5.62)	0.085	8.15±10.37 (0.003~55.11)	1.01±1.19 (0.003~4.24)	0.000^{**}	7.64±9.74	1.29±1.46	0.000^{**}	0.681	0.088
Cu	84.48±34.36 (51.70~153.41)	81.31±78.33 (1.62~208.11)	0.565	113.07±68.72 (18.17~411.14)	97.27±52.73 (0.01~225.76)	0.281	109.15±65.59	93.67±58.35	0.331	0.112	0.479
Cd	2.71±1.38 (1.28~4.87)	2.28±2.71 (0.001~7.57)	0.224	1.99±1.96 (0.001~9.31)	0.97±1.15 (0.001~4.40)	0.015^{*}	2.08±1.90	1.27±1.67	0.023^{*}	0.125	0.313
Pb	52.72±23.63 (37.18~104.12)	40.84±44.51 (0.001~132.56)	0.225	44.05±46.72 (8.94~329.24)	21.14±22.75 (0.001~79.08)	0.000^{**}	45.24±44.20	25.59±29.38	0.027^{*}	0.180	0.217
Zn	101.24±35.41 (68.97~172.53)	91.51±93.17 (0.08~235.99)	0.565	108.22±53.11 (0.011~292.90)	111.16±61.00 (0.011~261.94)	0.974	107.26±50.81	106.72±68.25	0.837	0.603	0.450
Si	2,118.68±1922.00 (461.52~5038.67)	1,193.18±2653.71 (0.15~7126.34)	0.045^{*}	329.05v169.67 (6.86~763.94)	6.98±29.54 (0.15~143.80)	0.000^{**}	574.69±924.60	274.83±1289.69	0.000^{**}	0.000^{**}	0.022^{*}

p^a: Mann-Whitney U test between concentrations of metallic elements in particle in yellow dust and non-yellow dust condition of Asan.
p^b: Mann-Whitney U test between concentrations of metallic elements in particles in yellow dust and non-yellow dust condition of Seoul.
N.D.: Not Detectable.
N.A.: Not Applicable.

Metallic Composition of Measured $PM_{2.5}$

Table 3 summarizes the concentrations of the measured elements in the $PM_{2.5}$ samples collected at both cities. Because the presence of yellow dust is such a major contributor to ambient pollution, we also compared metallic concentrations during both yellow dust and non-yellow dust conditions.

Elemental concentrations were highly variable both within and between cities. The average elemental concentrations in the $PM_{2.5}$ in Seoul were generally lower than those in Asan regardless of the yellow dust condition. Manganese, iron, chromium, cadmium, lead, and silicon concentrations were all statistically greater in Asan. In contrast, arsenic, copper, and zinc concentrations were similar in Seoul and Asan. These significant differences disappear during the "yellow dust condition" however. The airborne metallic concentrations during the yellow dust conditions are similar between the two cities. The one exception is silicon which is significantly higher in Asan when compared to Seoul during the yellow dust condition. These results indicated that airborne metallic element concentrations during the non-yellow dust conditions were influenced by local sources. The average concentration of most metal elements except As, Cu and Zn were higher in Asan than in Seoul. This may due in part to the increased impact of soil-related or crustal sources in Asan where there is more agricultural activity and a higher prevalence of unpaved roads.

When comparing metal concentrations across cities and between yellow and non-yellow dust conditions, the concentration of elements commonly associated with a crustal source. Si, Fe, and Mn were higher than the other elements during yellow dust condition at both sampling cities. These results are consistent with the crustal nature of yellow dust source.

Si, Fe, K and Ca were usually identified to relate with soil. K, Ca, Zn, Pb and Mn were associated with oil source, while K, Zn, and Pb were related with motor vehicle.[16,17] The concentrations of Si, Fe, Mn and Pb in Asan were measured higher than those in Seoul. This implied that Asan area is impacted by agriculturally related activities and anthropogenic sources such as vehicle fuel combustion.

According to the results of this study, it suggests that the heavy metal pollution of fine particulates in Asan area is mainly influenced by emissions from vehicle and soil. Sergio *et al.* (2004) reported that Cu and Zn were associated with brake lining particles from road traffic, and Pb was related with vehicle exhausts.[18] Cd, Mn, Cr and Fe were mainly related to vehicle exhausts. Fe, Cu and Zn were derived from wear and tear of brakes, tires, and motor-oil impurities.[19] Cr, Mg, Fe, Mn, K, Zn, and Cu were attained by PM components associated with mineral dust from road transportation and clay treatment.[20] The concentrations of most metallic elements in fine particulates at Asan site exceeded those measurements at Seoul site. The difference between metal elements levels of the fine particulates in Asan and Seoul areas is likely to be caused by lack of the management in Asan. For example, the road dust in Seoul managed with water spray and a vacuum suction by using vehicles. Hence, Asan needs to plan a long-term effective strategy to reduce metallic elements source and proper management for fine particulates.

Seasonal Concentrations of Metallic Elements

Table 4 shows the metallic elements concentration in Asan and Seoul by season of the year. It was found that the mean Si and Fe concentrations were 1301.85 $\mu g/m^3$ and 552.24 $\mu g/m^3$ in spring in Asan, respectively. The highest concentration of Mn, Ni, and Pb are found in summer at Asan site. In Asan area, Mn, Ni, Cr, Cu, Pb, Zn, and Si concentrations were statistically significant in difference by season.

The concentrations of Si, Fe, and Mn are 1670.45 $\mu g/m^3$ and 926.74 $\mu g/m^3$, 27.34 $\mu g/m^3$ at Seoul site, respectively. According to seasonal average metal elemental concentration of the fine particulates in Asan and Seoul, the concentrations of Si and Fe measured high values during spring in both cities. It could be considered that high concentration of Si and Fe is mainly influenced by soil related with yellow dust from China in spring. Iwasaka *et al.* (1983) reported the yellow sand made dust particles uplifted as high as 6 km.[21] The study of Husar *et al.* (2001) showed the information that storms were raised over Mongolia and north-central China on April 19, 1998.[22] The particulate

Table 4. Seasonal concentrations (ng/m^3) of metallic elements in fine particulates ($PM_{2.5}$) in Asan and Seoul

	Spring			Summer			Fall			Winter				
	Asan	Seoul		Asan	Seoul		Asan	Seoul		Asan	Seoul		p^a	p^b
	Mean ± S.D. (Range)		p	Mean ± S.D. (Range)		p	Mean ± S.D. (Range)		p	Mean ± S.D. (Range)		p		
As	9.67±10.09 (0.001~26.28)	7.57±7.96 (0.001~19.06)	0.581	3.02±4.20 (0.001~11.18)	13.81±8.81 (7.58~20.04)	0.057	5.33±7.00 (0.001~19.57)	7.96±9.18 (0.001~23.55)	0.399	10.12±8.80 (0.001~25.47)	9.04±10.02 (0.001~29.86)	0.699	0.184	0.082
Mn	22.64±17.37 (8.42~61.82)	27.34±27.90 (2.12~74.89)	0.657	32.11±22.02 (6.42~89.14)	6.74±3.40 (4.33~9.14)	0.045*	13.37±5.89 (4.51~23.86)	6.87±5.38 (1.18~19.78)	0.009**	10.72±3.75 (7.24~21.26)	7.62±8.37 (0.003~29.08)	0.012*	0.001**	0.799
Ni	4.37±6.43 (0.007~22.47)	N.D.	N.A.	25.25±15.66 (0.007~60.00)	N.D.	N.A.	1.75±3.11 (0.007~8.36)	N.D.	N.A.	5.71±2.48 (1.01~10.65)	N.D.	N.A.	0.000**	N.A.
Fe	552.24±663.92 (96.22~2058.22)	926.74±1211.14 (28.87~3034.95)	0.588	327.20±240.92 (0.006~793.03)	79.94±31.79 (57.46~102.43)	0.144	229.62±182.51 (18.70~622.08)	80.72±58.78 (0.006~186.91)	0.019*	144.57±53.54 (63.45~272.84)	87.18±87.38 (0.006~284.07)	0.014*	0.218	0.121
Cr	3.60±2.62 (0.003~8.08)	2.50±2.13 (0.003~5.62)	0.324	13.90±14.34 (2.35~55.11)	1.83±0.05 (1.80~1.86)	0.028*	10.59±10.17 (0.003~39.62)	0.73±0.98 (0.003~3.12)	0.000**	2.95±2.40 (0.003~8.38)	1.26±1.47 (0.003~4.24)	0.038*	0.001**	0.207
Cu	71.27±36.91 (18.17~144.84)	40.98±43.29 (0.01~114.79)	0.183	157.14±105.34 (61.24~411.14)	89.96±5.42 (86.13~93.79)	0.201	119.62±39.19 (47.15~169.76)	109.39±53.47 (22.53~225.76)	0.415	92.25±23.86 (61.11~153.41)	100.52±64.48 (1.62~224.57)	0.957	0.003**	0.156
Cd	2.38±1.43 (0.80~4.87)	1.95±3.19 (0.001~7.57)	0.153	3.24±3.02 (0.001~9.31)	0.82±0.75 (0.29~1.35)	0.359	1.10±1.21 (0.001~3.15)	1.06±1.04 (0.001~2.50)	0.826	1.70±0.69 (0.69~2.87)	1.26±1.58 (0.001~4.40)	0.102	0.088	0.997
Pb	43.55±10.35 (21.96~63.76)	19.16±14.54 (0.001~38.15)	0.009**	50.60±88.73 (11.47~329.24)	21.62±9.78 (14.70~28.54)	0.715	33.88±19.98 (8.94~74.74)	26.29±25.78 (0.001~79.08)	0.115	48.35±18.16 (26.18~104.12)	28.22±39.67 (0.001~132.56)	0.019*	0.049*	0.967
Zn	73.87±43.43 (0.011~135.93)	44.95±59.95 (0.011~146.32)	0.324	129.96±67.11 (60.94~292.90)	103.61±8.34 (97.71~109.51)	0.855	124.05±43.45 (52.69~187.78)	124.86±60.15 (30.08~257.22)	0.828	102.91±28.40 (67.01~172.53)	114.83±74.87 (5.14~261.94)	0.913	0.049*	0.132
Si	1301.85±1640.62 (338.39~5038.67)	1670.45±3093.01 (0.15~7126.34)	0.257	295.95±176.07 (106.43~758.06)	N.D.	0.028*	275.56±177.17 (6.86~503.96)	11.98±41.51 (0.15~143.80)	0.000**	403.95±177.67 (150.10~753.82)	1.98±6.85 (0.15~23.73)	0.000**	0.006**	0.027*

p^a: Kruskal-Wallis H test between concentrations of metallic elements in particulate with regard to season of Asan.

p^b: Kruskal-Wallis H test between concentrations of metallic elements in particulate with regard to season of Seoul.

N.D.: Not Detectable.

N.A.: Not Applicable.

concentration was near the maximum permissible health standard in USA in the west coast of Korea. It is observed frequently in spring in Korea.[23] Considering the characterization of four seasons, average Pb concentration of fine particulate in Asan was significantly higher than that of Seoul in spring ($p<0.01$).

Average concentrations of Mn, Fe, Cr in summer and Si in fall ($p<0.05$), and average concentration of Mn, Fe, Cr, Pb and Si in winter ($p<0.05$) in Asan were higher than those of Seoul. In particular, the concentration of Si was highly dominated among fine particulate from fall to winter in Asan. As noted above, Si is related with soil source which is the most important contributor to the level in Asan. This result suggested that the potential toxicity of smaller particulate is increasing and the particle pollution is becoming serious in Asan. It could be seen clearly that a further study is needed to improve the mass balance and to obtain the source profile from sampling sites.

Correlation Matrix Among Metallic Elements

Mn, Fe, Cr, and Cd are highly correlated in Seoul and Asan ($p<0.05$). Cu and Zn were positively correlated (R=0.866; R=0.993) in Asan and Seoul, respectively. The correlation coefficients of Pb and Zn were 0.813 and 0.343 in Seoul and Asan during non yellow dust condition, respectively. The correlation coefficient between Pb and Mn in fine particle was 0.917 in Seoul. It suggested that the elements were influenced with the same anthropogenic sources. Si and Mn are highly correlated during yellow dust condition in Asan (R=0.983) and Seoul (R=0.943). Si and Fe were mostly found in fine particulate mode and the correlation coefficients were 0.999 for Asan and 0.998 for Seoul in yellow dust condition. As it was reported in the literatures, Si and Fe were identified to associate with soil. These results showed that

Table 5. Correlation matrix among metallic elements in yellow dust days in Asan

	As	Mn	Ni	Fe	Cr	Cu	Cd	Pb	Zn
Mn	−0.553								
Ni	0.987**	−0.496							
Fe	−0.619	0.986**	−0.573						
Cr	0.149	−0.476	0.183	−0.452					
Cu	0.582	−0.342	0.631	−0.493	0.035				
Cd	−0.397	0.958**	−0.305	0.908**	−0.406	−0.112			
Pb	0.613	−0.227	0.625	−0.371	0.118	0.858*	−0.059		
Zn	0.542	−0.257	0.594	−0.413	−0.040	0.995**	−0.030	0.859*	
Si	−0.586	0.983**	−0.541	0.999**	−0.439	−0.503	0.907**	−0.369	−0.425

$^{*}p<0.05$ (2-tailed).
$^{**}p<0.01$ (2-tailed).

Table 6. Correlation matrix among metallic elements in yellow dust days in Seoul

	As	Mn	Fe	Cr	Cu	Cd	Pb	Zn
Mn	−0.405							
Fe	−0.332	0.963**						
Cr	0.211	0.753	0.820*					
Cu	−0.300	0.345	0.128	0.114				
Cd	−0.594	0.890**	0.800*	0.573	0.636			
Pb	−0.386	0.184	−0.075	−0.190	0.923**	0.473		
Zn	−0.416	0.376	0.169	0.105	0.984**	0.703	0.908**	
Si	−0.325	0.943**	0.998**	0.820*	0.084	0.775*	−0.128	0.128

$^{*}p<0.05$ (2-tailed).
$^{**}p<0.01$ (2-tailed).

these two elements are strongly affected with soil related to Asian dust storm (yellow-dust) from China.[24,25]

Conclusion

Average concentrations of fine particulate ($PM_{2.5}$) and metallic elements (As, Mn, Ni, Fe, Cr, Cu, Cd, Pb, Zn, and Si) were measured from September 2001 to August 2002 in Asan and Seoul, Korea. The annual average mass concentrations of fine particulates were 37.70 and 45.83 $\mu g/m^3$ in Asan and Seoul, respectively. When the weather conditions were classified by yellow dust condition and non-yellow dust condition, measured average mass concentration of fine particulates during yellow dust condition was significantly higher than that of non-yellow dust condition in both cities ($p<0.05$). In addition, the $PM_{2.5}$ mass concentrations showed a strong seasonal modulation with higher values in spring. This seasonal variation is related to yellow dust condition.

Cu and Zn were mostly measured in fine particulates mode in both cities. Cu and Zn were positively correlated (R=0.866, R=0.993) in Asan and Seoul, respectively. The concentration coefficients of Pb and Zn were 0.343 for Asan and 0.813 for Seoul during non-yellow dust condition. It suggested that Pb and Zn were influenced with the same sources. The correlation coefficients between Si and Fe in the fine particulate mode were 0.999 for Asan and 0.998 for Seoul during yellow dust condition, suggesting that these two elements were impacted by soil-related transport from China during the yellow dust storm condition. Also, these results suggested that the particulate pollution is becoming serious health problem in both Asan and Seoul. The higher concentrations of metallic elements in the fine particulate in Asan indicated that the city should receive special attention for air quality management.

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