

The distribution characteristics of trace elements of fine ambient particulate in Korea

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요약 : 기기 중성자방사화분석법을 이용하여 대전시 도로변 대기분진(PM2.5)을 대상으로 As, Mn, Se, V, Zn 등의 독성금속을 포함하여 약 30여종의 미량성분을 분석하였다. 도로변 PM 2.5내 미량성분들의 농도는 자연적 발생원에 기인한 원소가 높게 나타났으며, 특히 K과 Fe이 671과 653 ng/m³으로 높은 농도를 보였다. 반면, Lu과 Dy는 0.01과 0.04 ng/m³으로 가장 낮은 농도를 보여 최대농도와 최소농도 간에는 10⁵ 이상으로 차이가 벌어져 있음을 알 수 있었다. PM2.5와 미량성분간의 상관분석 결과, 도로변 지역에서 발생하는 PM2.5는 토양기원의 미량성분과 더 큰 상관을 보였다. 인자분석결과, 연구대상지역의 오염원은 제비산된 토양입자, 화석연료의 연소, 자동차 배기가스, 삼원촉매장치, 해염입자, 재련공장 등으로 확인되었다. 그리고 부회계수분석의 결과는 인자분석으로부터 발견된 사실과 부합함을 알 수 있었다.

Abstract : In this study, instrumental neutron activation analysis was used to measure the concentrations of about 30 trace elements in airborne particulate (PM2.5) samples at urban area of Daejeon city located in the southwestern region of Korea. An inspection of the measurement data indicates that the distribution patterns of trace elements could clearly distinguish the elements with their concentrations ranging over five orders of magnitude. The mean values for Lu and Dy were found to be the lowest at values of 0.01 and 0.04 ng/m³, while those for K and Fe showed the highest value of 671 and 653 ng/m³, respectively. The results of correlation analysis showed that PM2.5 concentrations can exhibit much more enhanced correlations with the elements of earth crustal components. The results of factor analysis further indicated that there are no more than six factors with statistical significance, which may exert dominant roles in regulating the elemental concentration levels in the study area. Enrichment factor analysis supports explicit interpretation of results found by this factor analysis.

Key words : instrumental neutron activation analysis, air pollution, PM2.5, factor analysis, enrichment factor analysis

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1. Introduction

An analytical method aiming to the quantitative determinations of trace elements in airborne particulate samples should be sensitive and precise, while being potent enough to identify the diversity of elements simultaneously. Instrumental neutron activation analysis (INAA) using both thermal neutrons in a nuclear reactor and high-resolution semiconductor detector is one of the most suitable methods that can meet the above mentioned requirements. Application of INAA to airborne particulate samples can allow quantification of metals at ppm-ppb concentration levels for up to 30-40 trace elements simultaneously.¹⁻³

The problem of atmospheric metal contamination by airborne particulate matter (PM_{2.5}, aerodynamic equivalent diameter, AED, less than 2.5 μm) has been worsened notably in the last ten years due to various factors (e.g., the increase in motor vehicles, extension of new roads, enhanced consumption of fossil fuels, and growth of industrial activities) in Daejeon city located in the southwestern region of Korea. The traffic, especially, is without doubt one of the most dominant source of particles in this area. High concentrations of particulate matter related with traffic at roadside could be emitted from tailpipe exhaust, brake/tire wear, and resuspended road dust.^{4,5} Yu *et al.*⁵ show that the greatest contributors to total PM₁₀ and PM_{2.5} mass were OC, sulfate, nitrate, ammonium, EC, Na, Cl, and crustal elements including Si, Ca, Al, Fe, K, and Mg by using X-ray fluorescence (XRF), ion chromatography (IC), and thermal/optical transmittance (TOT). In several studies, including those of Loranger *et al.*,⁶ Li *et al.*,⁷ Pakkanen *et al.*,⁸ and Fariseo *et al.*,⁹ various analytical methods such as ICP-AES, ICP-MS, SEM-EDX, and INAA have been used in estimating a distribution of chemical components of snow, air particulate, soil, and plant near roadside.

In this study, INAA (Instrumental Neutron Activation Analysis) was used to measure the concentrations of about 30 elements in airborne particulate (PM_{2.5}) samples that were collected from the roadside sampling station at moderately polluted urban area of Daejeon city. Based on the elemental measurement data, it was attempted to elucidate the elemental distribution characteristics of fine ambient particles, and also to examine the inter-element relation-

ships and the factors affecting source processes through the application of diverse statistical approaches.

2. Experimental

2.1. Site characteristics and sampling

The sampling site is located several kilometers from the heavy-traffic intersection of the four-lane Honam highway and Yuseong hot spring region. In front of the sampling site there are two main roads with ten-lanes crossing each other. Hence, if one considers the geographic location of our study site on an areal scale, the site can represent one of areas that are affected most significantly by traffic-related pollution sources in the Daejeon city.

For the collection of airborne particulates, a PM_{2.5} mini-volume air sampler (MiniVol version 4.2, Airmetrics, USA) with polycarbonate filter (Φ 47 mm, 0.4 μm pore size, Nuclepore) was used. 59 samples were collected from Dec. 2000 to May 2001. The fundamental meteorological conditions (including rainfall, temperature, relative humidity, wind direction, wind speed, etc.) were recorded at hourly intervals during the study period. The sampler was placed about 4 m above the ground at the roadside sampling station located in Gung Dong district. The air flow was adjusted to the rate of 5 L/min at the beginning of sampling, and the system ran for 48 hours to get enough particulate mass. The collected particulate mass weight of 59 samples ranged from 0.15 to 1.9 mg on the filter. Total volume of air sampled through a filter was computed using flow recorder from the start to the end of sampling. Whenever the cleaning of particle separator once a week, flow rate was adjusted by flow calibrator (MNF: 1022, Airmetrics, USA). The collected samples were pre-stored for 24 hours in a controlled atmosphere (20°C, 50% relative humidity) and transferred into polyethylene vials after weighing in the same conditions. Electrostatic charges are controlled by ²¹⁰Po radioactive source.

2.2. INAA

Collected samples were irradiated with thermal neutrons using the Pneumatic Transfer System (PTS, $\Phi_t = 1.75 \times 10^{13}$ $\text{ncm}^{-2}\text{s}^{-1}$, $R_{\text{cd}} 250$) at the HANARO research reactor at the Korea Atomic Energy Research Institute. Samples were irradiated at the same position to minimize geometric

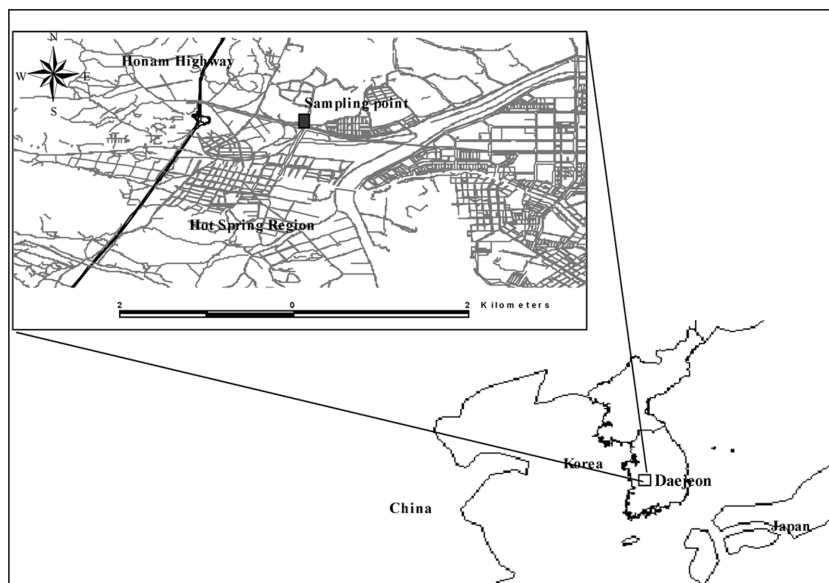


Fig. 1. Aerial maps for both Daejeon city in Korea and Gung-dong.

errors during 2 minutes and 4 hours for short and long-lived nuclides, respectively. The measurements were carried out using a high purity Ge detector with relative efficiency of 25%. This analytical system has 1.9 keV resolution (FWHM) at 1332 keV of ^{60}Co with the peak to Compton ratio of 45:1. The detector was connected to a personal computer and 8 k multichannel analyzer (EG&G ORTEC, 919A MCB). The calibration of energy and efficiency was performed using multi-nuclide reference sources (NEN Products Inc., NES-602, 1" diameter disc type) that are certified by the NIST (National Institute of Standards and Technology, USA). A Gamma Vision software (EG&G ORTEC) was used for such purposes as: (1) energy and efficiency calibrations, (2) the acquisition of gamma spectra, and (3) peak analysis.

The optimum analytical conditions for various operating conditions including neutron flux, irradiation facilities, irradiation time, cooling time, counting time, etc were pre-estimated following the procedures established from previous studies.^{10,11} For the short-lived nuclides, the first measurement (10 minutes after irradiation, counting time about 500 seconds) led to the determination of Al, Ca, Cu, Mg, Ti, and V. The second counting was done for 1200 seconds, after cooling about 40 minutes for the determination of Ba, Cl, I, K, Mn, and Na. In these short-lived

nuclides measurement, weights of irradiated samples were about 50~200 μg of particulates collected on a quarter of whole filter, while those were about 100~400 μg (a half of whole filter) for the long-lived nuclides. And, for the long-lived nuclides, the first measurement (5~6 days after irradiation, counting time about 4000 seconds) led to the determination of As, Br, Dy, La, and Sb. The second counting was done for 10000 seconds, after cooling about 10~16 days for the determination of Ce, Co, Cs, Fe, Hf, Lu, Rb, Sc, Se, Th, and Zn. The elemental concentrations of both samples and blank filters were determined under the same analytical conditions. The absolute concentrations of elements were estimated by the absolute approach of Tolgyessy and Klehr with an aid of the Labview software with the nuclear data library.¹²⁻¹⁴

2.3. Analytical quality control

In our previous study,¹⁵ the standard reference material (SRM: NIST, the National Institute of Standards and Technology, USA, SRM 1648, urban particulate matter) was used for analytical quality control. The concentrations of 24 elements were compared statistically with the certified or recommended values. The relative errors of Al, Ba, Br, Cl, Co, Cs, K, Mg, Mn, Na, Rb, Th, Ti, and V fell below 5%, while those of Fe and Zn are less than 10%. These

relative error of Ce, Cu, Hf, La, Sb, Sc, and Se were within 20%, while those of As was less than 30%. All RSD (relative standard deviation, %) of trace elements fell below 5% except Ba (7.5%), Mg (11.7%), Rb (7.9%), and Ti (5.5%) which means that analytical results were very precise.

3. Results and Discussion

3.1. Mass concentrations of PM2.5 and trace elements

A statistical summary of the PM2.5 and elemental concentrations measured during the whole study period is provided in *Table 1*. To constrain uncertainties involved in the measurements, some outlying data sets were eliminated prior to statistical analysis via two different screening steps.¹⁶ As a first step, about 5.2% of data sets were removed on the basis of signal-to-noise (S/N) ratio of less than 2. Following this treatment, the data sets with the values exceeding ± 3 SD from the mean were also excluded to rule out the possibility that the distribution patterns of certain element are distorted by the presence of a few extreme values. Loss of data was about 2.5% at this secondary stage.

According to the summary provided in *Table 1*, the distribution patterns of elements were clearly distinguished among elements with their concentrations ranging over five orders of magnitude. The means for Lu and Dy were found to be the lowest at values of 0.01 and 0.04 ng/m^3 , while those for K and Fe showed the highest value of 671 and 653 ng/m^3 , respectively. To make comparison of the data on a similar scale, the mean concentrations for each element were also plotted on a logarithmic scale. Based on a simple comparison of the magnitude, the data sets can be grouped into five different categories: 1) $< 10^{-1}$ ng/m^3 : Lu, Dy, and Hf; 2) $< 10^0$ ng/m^3 : Sc, Th, Cs, Co, and La; 3) $< 10^1$ ng/m^3 : Ce, Se, V, Rb, I, and As; 4) $< 10^2$ ng/m^3 : Cu, Sb, Mn, Ba, Ti, Br, and Zn; and 5) $< 10^3$ ng/m^3 : Mg, Ca, Cl, Na, Al, Fe, and K.

Though our measurements were made over relatively short period of time, the PM2.5 clearly showed the higher mean concentration of 43.6 $\mu\text{g}/\text{m}^3$ during spring than 30.2 $\mu\text{g}/\text{m}^3$ during winter with the range of 11.7 to 133 $\mu\text{g}/\text{m}^3$. This enhanced PM2.5 level during spring season can be

Table 1. A statistical summary of the elemental concentrations of PM2.5 samples collected in a urban area of Daejeon city in Korea^A. All concentration units in ng/m^3

	Mean	SD	Min	Max	N	N ^B
Al	644	503	93.7	2116	57	59
As	6.79	4.42	1.26	19.8	59	59
Ba	19.2	9.60	0.97	47.6	58	59
Br	57.6	38.6	18.3	206	58	59
Ca	367	267	59.0	1127	57	59
Ce	2.06	2.52	0.31	15.7	58	59
Cl	514	468	45.3	1996	57	59
Co	0.47	0.25	0.12	1.39	57	59
Cs	0.27	0.16	0.06	0.82	55	57
Cu	13.5	6.89	1.77	36.7	58	59
Dy	0.04	0.03	0.00	0.14	56	58
Fe	653	523	199	3632	58	59
Hf	0.08	0.06	0.00	0.30	46	47
I	5.19	1.98	0.28	9.05	58	59
K	671	335	193	1818	55	58
La	0.86	0.68	0.22	3.71	57	59
Lu	0.01	0.01	0.00	0.05	52	53
Mg	161	151	11.3	737	57	59
Mn	16.3	8.09	3.46	37.6	56	58
Na	545	329	162	1646	58	59
Rb	4.15	2.82	0.13	13.9	55	56
Sb	14.4	12.5	1.62	49.8	59	59
Sc	0.15	0.12	0.03	0.55	57	59
Se	2.23	1.17	0.94	6.58	42	44
Th	0.18	0.14	0.01	0.68	57	59
Ti	43.5	37.6	12.5	202	43	44
V	2.75	1.08	0.45	6.63	58	59
Zn	70.2	28.4	36.4	172	56	57
PM2.5 ($\mu\text{g}/\text{m}^3$)	38.1	22.9	11.7	133	59	59
Σ (all element)	3674	1773	927	9270	59	59
^C Ratio	10.6	3.62	2.03	24.9	59	59

^ANumber of samples = 59; averaging time = 48 h

^BNumbers of data prior to removing the OL data sets; the OLs were determined on the basis of $\pm 3\sigma$ from the mean

^CRatio is percentage of all elemental concentration for PM2.5 concentration

caused by the frequent intrusion of Asian dust from China. In fact, this kind of intrusion was occurred on Jan. 2, March 3 to 7, March 20 to 25, April 10 to 12, April 24 to 26, and April 28 in 2001. During the intrusion of Asian dust (*Table 2*) the mean PM2.5 level was 78.8 $\mu\text{g}/\text{m}^3$, while that during without intrusion was 31.8 $\mu\text{g}/\text{m}^3$, respectively. Both major elements (like Al, Ca, Fe, K, Mn, and

Ti) and minor elements (like Co, Dy, Hf, La, Lu, Sc, and Th) of crustal origin also showed much higher concentration levels even in fine ambient particles (AED less than 2.5 μm) during the period of the intrusion. To reflect realistically the enhanced effects of Asian dust in 2001 data sets prior to removing the outlying data sets were used for the computation in *Table 2*.

Table 2. The enhanced effects of Asian dusts in 2001. All concentration units in ng/m^3

	With Asian dust			Without Asian dust			^c Ratio
	Mean	SD	N ^A	Mean	SD	N ^A	
Al	2334	1504	8	537	389	51	4.35
As	6.68	2.01	8	6.80	4.70	51	0.98
Ba	35.2	16.3	8	17.7	8.57	51	1.99
Br	59.6	41.1	8	59.9	42.3	51	1.00
Ca	1267	904	8	314	218	51	4.04
Ce	4.22	3.03	8	1.89	2.60	51	2.23
Cl	868	771	8	551	603	51	1.58
Co	0.87	0.45	8	0.44	0.24	51	1.95
Cs	0.56	0.37	8	0.27	0.19	49	2.10
Cu	14.0	5.55	8	14.0	8.19	51	1.00
Dy	0.15	0.12	8	0.03	0.02	50	4.67
Fe	1745	1167	8	537	283	51	3.25
Hf	0.16	0.16	8	0.07	0.05	39	2.09
I	6.83	2.71	8	5.06	1.99	51	1.35
K	1313	635	8	666	403	50	1.97
La	1.87	1.15	8	0.91	1.17	51	2.05
Lu	0.03	0.02	8	0.01	0.01	45	2.35
Mg	506	272	8	136	129	51	3.73
Mn	38.8	20.2	8	14.6	7.17	51	2.66
Na	766	248	8	549	431	51	1.39
Rb	7.50	4.81	8	3.85	2.64	48	1.95
Sb	13.5	12.6	8	14.5	12.6	51	0.93
Sc	0.60	0.44	8	0.12	0.09	51	4.93
Se	2.09	0.81	6	2.55	1.75	38	0.82
Th	0.61	0.41	8	0.16	0.12	51	3.81
Ti	120	96.4	8	34.3	25.9	36	3.51
V	4.82	2.19	8	2.55	0.89	51	1.89
Zn	71.3	22.6	8	72.9	35.8	49	0.98
PM2.5 ($\mu\text{g}/\text{m}^3$)	78.8	33.3	8	31.8	12.1	51	2.48
Σ (all element)	9187	4814	8	3516	1681	51	2.61
^B Ratio	11.7	2.33	8	11.3	3.47	51	1.04

^ANumbers of data prior to removing the OL data sets; the OLs were determined on the basis of $\pm 3\sigma$ from the mean

^BRatio is percentage of all elemental concentration for PM2.5 concentration

^CMean concentration ratio for with/without the intrusion of Asian dust

3.2. Factors affecting elemental concentrations in the study area

As described previously, the study site for the present research is placed on the roadside with heavy traffic volume. It is also suspected that the site may be affected by the burning of fossil fuels from hot spring region. It is hence expected that the site is strongly impacted by the inflow of various airborne pollutants including vehicle exhausts. The earth's crust matters (and the sea salts) can be significant contributors to the determination of the aerosol composition near the earth's surface. Comparison of aerosol compositions in relation with crustal composition can help discriminate the contribution of man-made source processes. The concept of enrichment factor (EF) is based on the fact that elements originating from relatively well-defined sources (such as Al (or Fe) mainly originating from the earth's crust) can be distinguished from other elements derived by different source processes.¹⁷ Hence, by comparing the Al-based, relative concentration ratio, one can evaluate the extent of enrichment for a given element such as:

$$EF = \frac{(X/Al)_{\text{aerosol}}}{(X/Al)_{\text{reference}}} \quad (1)$$

where X denotes an element of interest.

In this study, aluminum was used as the crustal reference for the derivation of enrichment factor. This is because its quantitative analysis was more reliable than others, while the pollution sources were relatively scarce. Results of EF computation are presented in *Table 3*. EF value of trace element is associated with some degree of uncertainty related to the natural variation of the crustal composition. This is the reason why the EF value should be more than an order of magnitude higher than unity to inform anthropogenic origin. Thus, if the basis for enrichment is set as the EF value of more than 50, we can sort out such elements as Sb, Se, Br, I, Cl, As, Zn, and Cu to be enriched in PM2.5 samples of our study site. It is noteworthy that most of those elements are the major components of anthropogenic input. Their EF values were quite contrasting with those of both major (Ca, Fe, K, Mn, and Ti) and minor (Co, Dy, Hf, La, Lu, Sc, and Th) crustal components. Most of those crustal elements consistently exhib-

Table 3. A statistical summary of enrichment factor (EF) values derived using the element concentrations

	Mean	Median	SD	Min	Max	N
Sc	0.86	0.83	0.20	0.49	1.50	57
Ti	0.96	0.88	0.34	0.53	2.17	42
Mg	0.97	0.92	0.51	0.22	2.74	57
Ca	1.44	1.28	0.71	0.31	4.17	57
Fe	1.83	1.54	0.81	0.94	5.58	57
Dy	1.86	1.68	1.31	0.11	8.86	56
Mn	2.70	2.42	1.41	1.32	9.14	56
Co	3.27	2.45	2.37	0.90	12.8	57
V	3.40	3.02	1.79	1.03	9.14	57
Th	3.46	3.29	1.67	0.63	9.28	57
Na	3.67	2.61	3.82	0.80	22.0	56
La	3.93	3.24	2.27	1.95	13.1	55
K	4.18	3.51	2.46	1.42	14.9	55
Hf	4.60	3.41	5.19	0.10	29.5	45
Lu	5.03	3.06	7.46	0.15	52.3	51
Ce	6.15	2.86	15.6	0.94	118	56
Ba	7.67	6.38	5.45	0.43	33.1	57
Rb	7.83	5.42	8.54	0.37	59.5	54
Cs	14.9	12.3	9.48	1.53	45.1	54
Cu	51.9	31.3	54.4	3.70	279	56
Zn	183	154	135	29.6	814	54
As	728	412	713	125	3187	57
Cl	771	422	1055	50.3	6285	55
I	1914	1780	1125	106	5012	56
Br	4413	2838	5013	410	34359	56
Se	8335	6412	7620	1153	36731	41
Sb	14667	8390	23621	672	174895	57

ited low EF values of less than 5. Consequently when judged from the computed EF values, the cases with pronounced enrichment of elements are rather confined to a number of elements with anthropogenic origin.

Table 4 presents the results of correlation analysis between different elements. The results of the correlation analysis indicate two distinctive patterns. The existence of positive correlations among elements of no enrichment in the study site, while much more abundant, is seen quite consistently from the investigations of inter-element relationships. On the other hand, the existence of positive correlations among elements enriched is much less abundant. It is seen that PM2.5 exhibits strong correlations with most of elements of no enrichment. To the contrary, the reverse is true for the relationships between PM2.5 and elements enriched. Most importantly, PM2.5 concentrations exhibit more enhanced correlations with the elements of both major and minor crustal components. The findings of strong correlations between PM2.5 and elements of major crustal components may be directly compatible with the dominant role of those species by constituting the major fraction of even PM2.5 as well as PM10 at the roadside area.

As a means to assess the major sources affecting element distributions in the study area, we conducted varimax

Table 4. Result of correlation analysis between different elements

	Al	Ca	Fe	K	La	Na	Sc	Th	As	Br	Cl	Se	Sb	Zn	PM2.5
Al	1.00	0.90"	0.93"	0.71"	0.85"	0.20	0.98"	0.88"	0.12	0.22	-0.02	0.05	0.00	0.09	0.79"
Ca		1.00	0.89"	0.71"	0.80"	0.28'	0.87"	0.86"	'0.19	0.28'	0.10	0.08	0.07	0.11	0.74"
Fe			1.00	0.82"	0.94"	0.25	0.95"	0.91"	0.14	0.10	-0.02	0.26	-0.00	0.05	0.80"
K				1.00	0.79"	'0.25	0.72"	0.73"	0.29'	0.32'	0.08	0.40"	0.18	0.48"	0.67"
La					1.00	0.39"	0.87"	0.80"	0.18	0.10	0.14	0.18	0.01	0.22	0.84"
Na						1.00	0.18	0.15	-0.04	-0.11	0.65"	0.17	-0.18	0.07	0.46"
Sc							1.00	0.90"	0.14	0.19	-0.07	0.09	-0.00	0.10	0.78"
Th								1.00	0.16	0.14	0.01	0.07	-0.02	0.16	0.72"
As									1.00	0.11	0.05	0.47"	0.02	0.57"	0.08
Br										1.00	-0.08	0.38'	0.82"	0.21	-0.07
Cl											1.00	0.07	-0.05	0.13	0.28'
Se												1.00	0.52"	0.34'	0.00
Sb													1.00	0.14	-0.15
Zn														1.00	0.24

' and " denote the cases whose probabilities of no correction are less than 0.05 and 0.01, respectively.

Table 5. Factor loadings (F), communalities (h^2) and standard deviations of the loading (SD) after varimax rotation. For clarity, factor loadings less than two SDs are ignored

	F1	F2	F3	F4	F5	F6	SD	h^2
Al	0.96						0.04	0.93
As		0.72					0.09	0.59
Ba	0.68		0.41		0.17	0.40	0.06	0.83
Br		0.17	0.93				0.04	0.89
Ca	0.89				0.13		0.05	0.85
Ce	0.25	0.14		0.91	0.16	0.10	0.03	0.94
Cl					0.92	0.20	0.04	0.89
Co	0.65	0.23		0.39		0.18	0.08	0.67
Cs	0.67	0.55					0.07	0.77
Cu		0.20		0.32		0.77	0.07	0.76
Dy	0.87	0.12				0.21	0.06	0.84
Fe	0.91			0.27			0.04	0.91
Hf	0.63	0.18		0.36	0.20		0.09	0.61
I	0.31	0.29				0.75	0.07	0.76
K	0.77	0.50	0.13	0.16	0.12		0.04	0.90
La	0.54	0.13		0.79	0.15	0.09	0.03	0.96
Lu	0.70					0.21	0.09	0.58
Mg	0.92			0.18			0.05	0.88
Mn	0.86	0.30		0.13		0.17	0.04	0.90
Na	0.23			0.23	0.84		0.05	0.86
Rb	0.66	0.22		0.26		0.23	0.08	0.64
Sb			0.92			0.13	0.05	0.89
Sc	0.96			0.10			0.03	0.94
Se		0.78	0.47	0.15			0.05	0.86
Th	0.93					0.11	0.05	0.89
Ti	0.92			0.19			0.04	0.89
V	0.87	0.19					0.06	0.80
Zn	0.13	0.81	0.21		0.15	0.29	0.06	0.83
PM2.5	0.86	0.06		0.15	0.30	0.11	0.05	0.88
Variance	12.81	2.86	2.29	2.26	1.90	1.82	-	23.94
Variance (%)	44.16	9.85	7.91	7.81	6.56	6.28	-	82.57
Source	Resuspended soil/road dust	Burning of coal and fuel oil	Vehicular emission	3-way catalytic converter	Sea-salt	Copper smelting		

rotation factor analysis on our measurement data. Before analyzing major factors, our data set was checked by several statistical tests provided by the SPSS (version 7.5). Three tests were performed on the data set: 1) Kaiser-Meyer-Olkin test that measure the sampling adequacy by calculating the partial correlations among variables, 2) Bartlett's test of sphericity tests to check whether the correlation matrix is an identity matrix; this can indicate whether the factor model is appropriate or not, 3) calculation of the anti-image correlation matrix. It was found

that the data set has passed all these three statistical criteria.

Factor standard deviations were computed according to the procedure of Heidam.¹⁸ For clarity, factor loadings less than twice the factor standard deviations were left out. The results of factor analysis indicate that there are no more than six factors (with statistical significance) which appear to be significant in regulating the element concentration levels in the area. These six factors can cover as much as 82.6% of total variance. The first factor was dominated by both many major/minor crustal elements and PM2.5. It can

explain 44.2% of variance. This factor indicates the contribution of resuspended soil and road dust. The elements originating from the burning of coal and fuel oils (like As, Se, and Zn) appeared to be the most important components of the second factor with the additional 9.9% of variance. The third factor, while comprising 7.9% of variance, was characterized by vehicular emissions - the term applied to both gasoline and diesel emissions. The fourth factor with an additional 7.8% of variance was dominated by the elements of Ce and La. This factor means 3-way catalytic converter of vehicles. The fifth and sixth factors were affected mostly by sea salt of Na and Cl and copper smelting of Cu and I, respectively.

In fact, the results of EF analysis are in line with results found by this factor analysis. The dominant fraction of the first factor (such as Ca, Fe, K, Mn, Ti, and many rare earth elements) had consistently low enrichment factors ($EF < 5$). Most of them are found to be of crustal origin. Most of the elements of anthropogenic origin (like Sb, Se, Br, I, As, Zn, and Cu) were enriched with their EF values greater than 50. Thus, the results of EF analysis support the idea that there are a number of source processes (including vehicle-related emissions) which control the elemental concentration levels in the study area.

4. Conclusions

To examine the distribution characteristics of elements at moderately polluted urban area of Korea, we undertook the measurements of about 30 elements in airborne PM_{2.5} samples that were collected from the roadside sampling station in Daejeon city by using the INAA technique. The patterns of distribution were clearly distinguished between elements with their concentrations ranging over five orders of magnitude. The means for Lu and Dy were found to be the lowest at values of 0.01 and 0.04 ng/m³, while those for K and Fe showed the highest value of 671 and 653 ng/m³, respectively. The results of correlation analysis showed that PM_{2.5} concentrations can exhibit much more enhanced correlations with the elements of earth crustal components. The findings of strong correlations between PM_{2.5} and elements of major crustal components may be directly compatible with the dominant role of those species by constituting the major fraction of even PM_{2.5} as well

as PM₁₀ at the roadside area. The results of FA analysis further indicated that there are six factors with statistical significance, which appeared to play roles in regulating the elemental concentration levels in the study area. These six factors can cover as much as 82.6% of total variance. Enrichment factor analysis supports explicit interpretation of results found by this factor analysis.

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