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Long-term monitoring of airborne nickel (Ni) pollution in association with some potential source processes in the urban environment

Ki-Hyun Kim [a], Zang-Ho Shon [b,*], Puteri T. Mauulida [c], Sang-Keun Song [d]

[a] Department of Civil & Environmental Engineering, Hanyang University, Seoul 133-791, Republic of Korea
[b] Department of Environmental Engineering, Dong-Eui University, Busan 614-714, Republic of Korea
[c] Department of Environment & Energy, Sejong University, Seoul 143-747, Republic of Korea
[d] Department of Earth and Marine Sciences, Jeju National University, Jeju 690-756, Republic of Korea

HIGHLIGHTS

- The mean concentrations of Ni in urban air ranged from 3.71 to 12.6 ng m^{-3}.
- Ni levels were subject to gradual reductions over the 13 year period.
- Airplanes and ship industries are not likely to affect long-term levels of airborne Ni.

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ABSTRACT

The environmental behavior and pollution status of nickel (Ni) were investigated in seven major cities in Korea over a 13-year time span (1998–2010). The mean concentrations of Ni measured during the whole study period fell within the range of 3.71 (Gwangju: GJ) to 12.6 ng m^{-3} (Incheon: IC). Although Ni values showed a good comparability in a relatively large spatial scale, its values in most cities (6 out of 7) were subject to moderate reductions over the study period. To assess the effect of major sources on the long-term distribution of Ni, the relationship between their concentrations and the potent source processes like non-road transportation sources (e.g., ship and aircraft emissions) were examined from some cities with port and airport facilities. The potential impact of long-range transport of Asian dust particles in controlling Ni levels was also evaluated. The overall results suggest that the Ni levels were subject to gradual reductions over the study period irrespective of changes in such localized non-road source activities. The pollution of Ni at all the study sites was maintained well below the international threshold (Directive 2004/107/EC) value of 20 ng m^{-3}.

1. Introduction

Elemental nickel (Ni) is a malleable, silvery-white metal that is highly resistant to strong alkaline conditions (U.S. EPA, 1986). Ni is one of the numerous trace metals widely distributed in the environment. In general, the processes governing the fate of Ni in the atmosphere are comparable to those which can emit other metals and pollutants concurrently. As such, Ni is known to be released from both natural and anthropogenic sources (Clayton and Clayton, 1981). Natural sources of Ni to the atmosphere include soil dust, forest fires, particle releases from vegetation, sea salt, and meteoric dust (Nriagu, 1979). On the other hand, anthropogenic sources are dominated by fossil fuel (oil and coal) combustion, high temperature metallurgical operations, Ni primary production operations, and municipal waste incineration (Nriagu, 1979; Fishbein, 1981). In addition, the presence of Ni was also detected in vehicular exhaust, tobacco smoke, and indoor smoke from home-heating and cooking fuels (Board, 1991).

Due to the adverse effects of Ni on human health, it was classified as a human carcinogen by institutions around the world (e.g., WHO/IARC, 2012). Ni toxicity can affect various organisms, the properties of which vary considerably depending on its speciation, physical form, concentration level, exposure pathway, etc. Like many hazardous substances, the human intake route of Ni includes dermal contacts, dietary ingestion (of food and water), and inhalation. The health effect occurring most commonly is suggested as an allergic reaction like skin rash (e.g., Jennings, 2013). Ingestion of Ni can damage the blood, stomach, and kidneys, while its inhalation can pose several other adverse health effects (such as chronic

* Corresponding author. Tel.: +82 51 890 2078; fax: +82 51 890 2076.
E-mail address: zangho@deu.ac.kr (Z.-H. Shon).

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bronchitis, reduced lung function, and lung or nasal sinus cancer) (Schaumlöffel, 2012).

As the presence of toxic metal species can affect human health, an accurate quantitation of their concentration levels in ambient air is important to establish a sustainable control strategy for their management (CEPA, 1994). The pollution status of important airbone metal species (e.g., mercury, lead, cadmium, and others) has already been diagnosed in many urban areas of the world, as reported in several studies conducted in major cities of the world (Nguyen et al., 2010; Kim et al., 2011). As such, the bulk of the research on airborne metal species has focused on the cycling of a few critical components. Hence, there is the paucity of the available data for other harmful or commonly regulated metal species (e.g., Ni, As, Cu, and Zn).

This research has been conducted as part of a long-term monitoring of trace metal components in Korea aimed at expanding our knowledge base regarding the temporal and spatial distribution of important metal species in airborne particulate matter (Nguyen et al., 2010; Kim et al., 2011). For this purpose, the concentration data of airborne Ni measured from seven major cities (Seoul (SL), Busan (BS), Incheon (IC), Daegu (DG), Daejeon (DJ), Gwangju (GJ), and Ulsan (UL)) of Korea during the period of 1998–2010 were analyzed in a number of respects. (Note that the name of city is basically expressed hereafter by these abbreviations consisting of two capital letters for the sake of simplicity.) Based on our evaluation, we provide insight into the status of Ni pollution in the major urban areas of Korea. The results of our study will also be used to establish proper strategies to control Ni pollution in ambient air and its potential impact on air quality.

2. Materials and methods

2.1. Site characteristics

In Table 1, an overview of the seven major cities of Korea selected for this investigation is briefly summarized with respect to the basic statistics (e.g., area, population, population density, temperature, and humidity). All of the cities selected in this study belong to the seven largest cities in South Korea. SL is well known as the capital city of Korea, BS is the second largest city with the biggest port and largest river. IC is also well known as a big port city, while recording and maintaining the largest airport facility in Korea. In addition, UL is the most industrialized area with gigantic-scale manufacturing facilities of automobiles and ships. Among major cities, DJ, DG, and GJ are known to exhibit the least air pollution in terms of criteria pollutants (Kim and Baik, 2004). The area map of all target cities is presented in Fig. 1S (in Supplementary Material).

2.2. Sampling and analysis

In this research, the concentrations of airborne Ni (and relevant parameters) were measured by following the standard air quality measurement procedure of the Korean Ministry of Environment (KMOE, 2008). Ni data sets were measured routinely at monthly intervals from up to 42 monitoring stations dispersed all across the seven target cities. As stated above, all the selected cities are known to have fairly large populations (e.g., above a half million) and/or strong industrial activities (Fig. 1S).

According to the standard procedure of the KMOE, total suspended particulate (TSP) samples are collected on silica fabric (or glass fiber filters) by high-volume samplers. All the measurements from each monitoring site are basically conducted over 24 h intervals (starting around 9 AM). These filter samples were then brought into the laboratory and treated by the hot acid extraction method with the mixture of nitric and hydrochloric acid. The amount of Ni from each TSP sample was finally determined by atomic absorption spectrometry at a wavelength of 228.8 nm (e.g., Kim et al., 2003). Detection limits (DL) of Ni were typically found in 0.6 μg (in absolute mass (AM)) or 0.3 ng m^{-3}. Reproducibility of data, if assessed in terms of relative standard error, were generally below 3%. The accuracy of Ni analysis evaluated in terms of relative recovery (against NIST SRM 1648a – urban praticulate matter) generally fell in the range of 95%.

The original concentration data for Ni and other important metals were initially quality controlled by the basic quality assurance (QA) procedures developed by KMOE (2008). The final data sets were pooled together for each city and stored in its data management network system. To assess the spatiotemporal factors controlling the distribution of Ni, its monthly concentration data for each city were then grouped further into either seasonal or annual temporal scales. Finally, the data sets of Ni collected from each city were examined with emphasis on its long-term trends over the whole study period between 1998 and 2010.

3. Results and discussion

3.1. Ni concentration in major cities

In this study, the status of airborne Ni pollution was investigated using the data sets obtained from seven major cities of Korea during 1998–2010. Table 1S provides a statistical summary of Ni data measured during the entire study period. The mean concentrations (in ng m^{-3}) of Ni in each city derived for the whole period are found in the following descending order: IC (12.6) > BS (11.7) > UL (8.85) > SL (8.60) > DG (7.79) > DJ (5.50) > GJ (3.71).

The observed maximum concentration of Ni in IC (12.6 ng m^{-3}) is suspected to reflect the effect of strong non-road source processes (such as aircraft emissions). In fact, the relative ordering between cities can be assessed for six other metal species measured concurrently over the entire study period. The results of this comparison confirm that IC records the highest values in three metals (Fe, Pb, and Mn) and the second highest values in two metals (Cd and Cr). This common occurrence of the maximum (or near-maximum) levels may thus be considered to reflect the prevalence of strong man-made sources in IC relative to other cities. The city of

Table 1
Basic information of major metropolitan cities of Korea.

Order	Name of city	Area (Km^2)[a]	Population (million)[a]	Population density (km^{-2})[b]	Yearly average temp. (°C)[b]	Yearly average humidity (%)[b]
1	Seoul (SL)	605	9.80	16000	8.6–17	64.4
2	Busan (BS)	767	3.61	4700	11.3–18.9	64.7
3	Daegu (DG)	884	2.54	2800	9.5–19.5	61.6
4	Incheon (IC)	1029	2.71	2600	8.7–16.4	68.6
5	Gwangju (GJ)	501	1.48	2900	9.5–19.1	69.5
6	Daejeon (DJ)	540	1.54	2800	8.3–18.4	66.7
7	Ulsan (UL)	1059	1.08	1000	9.8–19.2	64.2

[a] <http://kosis.nso.go.kr/cgibin/sws_888.cgi?ID=DT_1IN0001&IDTYPE=3&A_LAN=2&FPUB=4&SELITEM>.
[b] Korea Meteorological Administration (KMA), 2010.