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Airborne iron across major urban centers in South Korea between 1991 and 2012

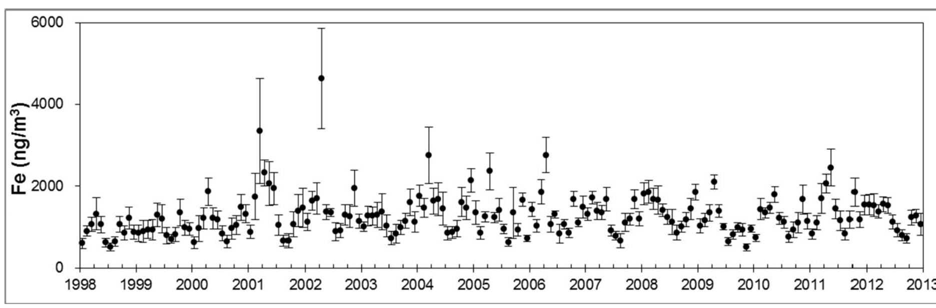
Ki-Hyun Kim [a,*], Yoon-Jung Hong [a], Jan E. Szulejko [a], Chang-Hee Kang [b], Scott Chambers [c], Xinbin Feng [d], Akash Deep [e], Yong-Hyun Kim [a]

[a] *Atmospheric Environment & Air Quality Management Lab., Department of Civil & Environmental Engineering, Han Yang University, 222 Wangsimni-Ro, Seoul 133-791, Korea*
[b] *Dept. of Chemistry, Jeju National University, Jeju, Korea*
[c] *ANSTO Institute for Environmental Research, Locked Bag 2001, Kirrawee DC, NSW 2232, Australia*
[d] *Institute of Geochemistry, Chinese Academy of Sciences, Guiyang 550002, PR China*
[e] *Central Scientific Instruments Organisation (CSIR-CSIO), Sector 30 C, Chandigarh, 160030, India*

HIGHLIGHTS

- The atmospheric metal levels reflect the intensity of industrial activities.
- Anthropogenic processes substantially increased emission of Fe.
- The atmospheric behavior of Fe is yet poorly known.
- The impact of various sources on Fe distribution was evaluated.
- The man-made sources influenced Fe more evidently than PM.

GRAPHICAL ABSTRACT



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ABSTRACT

In this study, the distribution of airborne iron (Fe), one of the most abundant heavy metals in the Earth's crust was investigated to describe the basic features of i'ts pollution in various urban locations. The spatiotemporal distribution of Fe concentrations in seven major South Korean cities exhibited unique patterns to reflect differences as to Fe sources reflected in the relative enrichment in coastal relative to inland areas. In addition, the analysis of long-term trends of different metal species indicated that Fe levels maintained a fairly constant trend, while there had been a noticeable decline in concentrations of other metals (Cd, Cr, Cu, Mn, and Ni). The relative robustness of our correlation analysis was assessed by comparing (1) the Fe concentrations among cities, and (2) Fe with other metals at a given city. Fe concentrations were also partly explainable by the frequency of Asian dust events in most cities, with the observed spatial gradients in such relationships.

* Corresponding author.
E-mail address: kkim61@hanyang.ac.kr (K.-H. Kim).

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1. Introduction

Trace amounts of some metals are essential for life, playing a part in various metabolic processes (e.g., Fe in hemoglobin; Puntarulo, 2005). However, many types of heavy metals are toxic to human health and ecological systems. When released into the atmosphere, heavy metals are easily bound to fine particles (particulate matter, PM) and can remain suspended in the atmosphere for extended periods. Human exposure to heavy metals typically occurs as a result of respiratory deposition via inhalation. These metals can then act as carcinogens or toxins by binding to biomolecules. High-risk groups, such as children and the elderly, are particularly vulnerable (Berggren et al., 1990; Lippmann et al., 2006; Lippmann and Chen, 2009; Bollati et al., 2010). Consequently, considerable research effort has been directed toward identifying the sources and distribution of atmospheric heavy metals and assessing the degree of their ingestion by biota (including humans).

Natural sources of airborne metals include the emission of crustal material (e.g. Fe and Al) to the atmosphere via volcanic eruptions and the weathering of rocks or as a result of microbial activity. Anthropogenic sources of atmospheric heavy metals (e.g., As, Cd, Cr, Ni, and Pb) are primarily a result of particulate matter deriving from industrial activities (Dockery et al., 1993). The analysis of metallic component levels, when evaluated in relation to the presence/absence of a major source event (e.g., Asian dust (AD)) and PM sizes, indicated that such events are prominent sources for major crustal components like Al and Fe in both fine and coarse particle fractions (Kim et al., 2003; Wang et al., 2015). Consequently, many studies have tried to estimate heavy metal contamination levels in relation to PM size and to assess the extent of correlations between different metals (Samara and Voutsa, 2005; Ragosta et al., 2006). Globally, about 95% of the airborne Fe in PM is attributable to arid region dust emissions (in particular the Sahara and Gobi deserts), with the remaining 5% attributable to the combustion of biomass and fuels (Luo et al., 2008; Mahowald et al., 2009). As such, the airborne Fe concentration measured from eight U.S. states (CA, AZ, MN, KY, FL, TX, PA, and NY), showed that its levels in an arid area of AZ recorded the highest of all sites (e.g., 17 times) (Han et al., 2012).

It is generally known that Asian PM_{10} mainly consists of silica, feldspar, aluminum, iron, calcium, etc. (Donaldson et al., 2001). Record of Asian dust demonstrated that windblown dust storms originating in the deserts of Mongolia and China should travel to populated cities in East Asia (including Korea, Japan, and Taiwan) in spring (Kang et al., 2012; Kwon et al., 2002). In Korea, Asian dust particles of around 5 μm are typically observed between March and May (Choi et al., 2000). According to observations in Taean-gun Chungnam, South Korea, heavy metal concentrations were more than three times higher during Asian dust periods than in all other periods (Bae et al., 2005). Especially, it

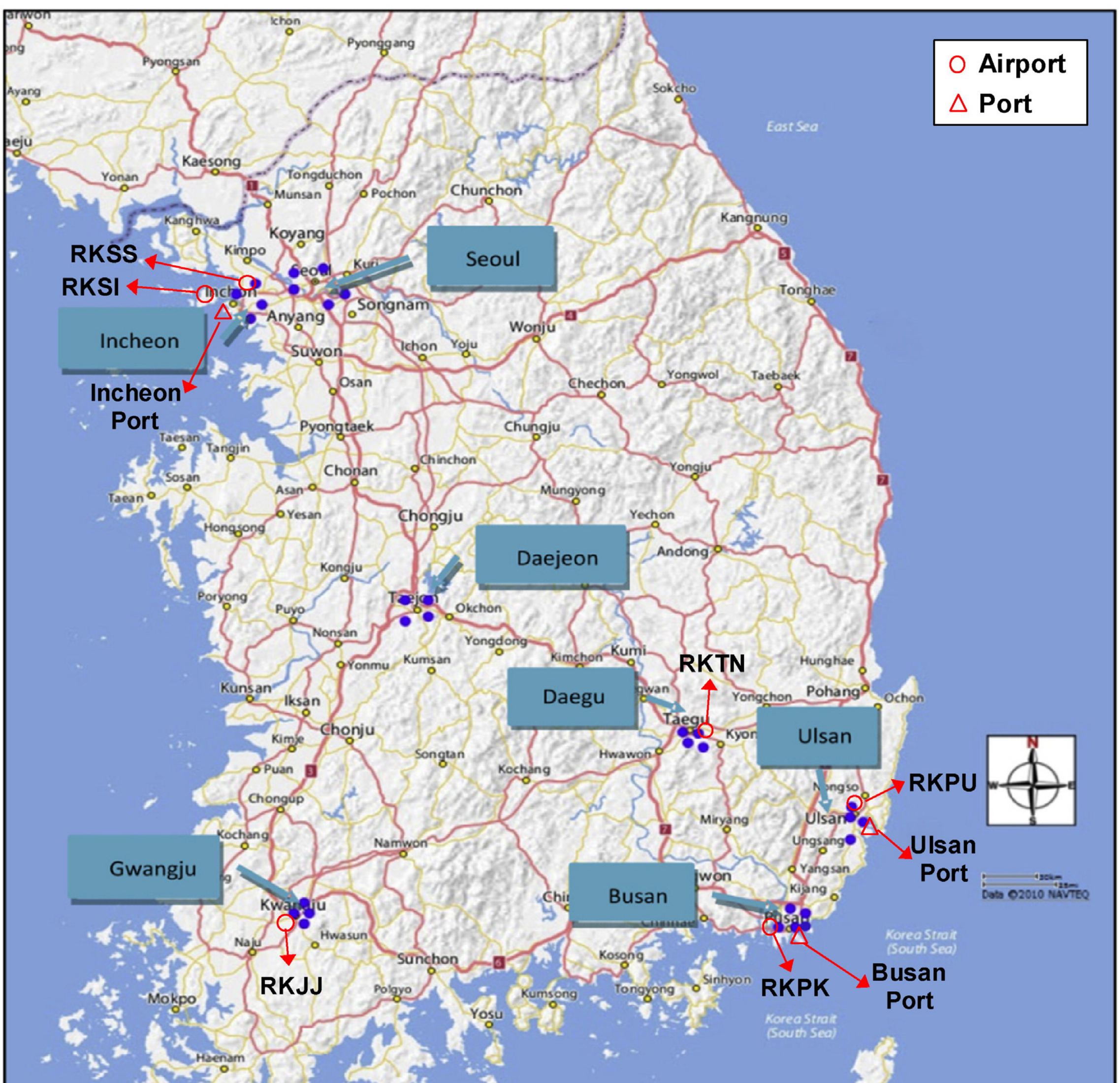

Fig. 1. Map showing the seven major Korean cities where airborne Fe concentration levels were monitored (Source: Ray and Kim, 2014).