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Seasonal and spatial variations in dust deposition rate and concentrations of dust-borne heavy metals, a case study from Isfahan, central Iran

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ABSTRACT

This study reports the seasonal and spatial variations of atmospheric dust deposition rates (DDR) and dust-borne heavy metals concentrations in the city of Isfahan and its surrounding areas in central Iran. Dust samples were collected from 67 different sites on a monthly basis from June 2012 to May 2013 and topsoil samples were taken only once from the same sites. Fall and winter seasons exhibited the lowest DDR due to the higher precipitation while the highest rate was observed in the summer season. The northern and central parts of the desert land in the study area recorded the highest annual DDR with a mean value of 61.24 ton km^{-2} $year^{-1}$. Seasonal distribution of dust-borne heavy metals concentrations showed that almost all the elements followed the trend winter > fall ≥ spring > summer. Spatial distributions of dust-borne Cd, Cu, Ni, Pb, and Zn almost followed the same pattern with highest concentrations in the western stretches of the study area and in the city of Isfahan. The highest concentration of Hg and As were observed in the urban and desert rural areas. Cr recorded its highest concentration in the urban area while dust-borne Co exhibited a fairly uniform distribution over the whole study area. Results of crustal enrichment factor (EFc) analysis showed that anthropogenic sources contribute a substantial amount of all studied elements in dust particles rather than crustal origin. Fossil fuel, vehicle traffic, and industrial activities seem to be the most important anthropogenic factors responsible for dust elemental pollution in the study area.

1. Introduction

Atmospheric dust is one of the most serious environmental hazards in arid and semi-arid areas (Nazir et al., 2011; Al-Harbi, 2015). It has significant influence on ecosystems, atmospheric radiation transfer, global geochemical cycles, environmental pollution, and human health (Yang et al., 2005; Miri et al., 2007, 2009; Lawrence and Neff, 2009; De Longueville et al., 2010; Sing and Sing, 2010; Shi et al., 2011).

Atmospheric dust particles are continuously deposited by dry and/or wet deposition processes (Lawrence and Neff, 2009). Dust deposition rate is affected by factors such as dust concentration in the atmosphere, energy of dust transporting winds, and characteristics of depositional environment (Goossens, 2000; Motelay-Massei et al., 2005). Moreover, type of emission sources, as well as their distance, location of sampling site, and certain meteorological conditions are some of the other factors involved (Lawrence and Neff, 2009). Knowledge of temporal and spatial variability of dust deposition rate provides a useful framework for evaluating dust characteristics in any given area.

Atmospheric dust has a broad range of chemical species, including elemental, organic, and inorganic components (Park and Kim, 2005; Callén et al., 2009). Heavy metals originating from various natural and anthropogenic sources (Nazir et al., 2011; Qiang et al., 2015) are among the major components of dust particles with adverse effects on ecological quality (Batjargal et al., 2010) and

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human health (Pope, 2000; Shi et al., 2011). Heavy metals associated with dust particles might enter the human body through inhalation and ingestion or even through physical contact (Shi et al., 2011) to cause not only respiratory and cardiovascular diseases but damages to other organs as well (Pope, 2000). Moreover, it has been established that toxic metals may affect the central nervous, renal, and reproductive systems (Papanikolaou et al., 2005). Heavy metals are constantly released into the atmosphere from various sources. Natural sources such as local soils, weathered materials, and crustal minerals (El-Fadel and Hashisho, 2001; Zhang et al., 2012) as well as many different anthropogenic activities such as vehicular traffic (Kim et al., 2002; Charlesworth et al., 2003; Kreider et al., 2010; Amato et al., 2011), industrial emissions (Kim et al., 2002; Shah et al., 2006; Shah and Shaheen, 2010), residential fossil fuel burning (Bilos et al., 2001; Schleicher et al., 2011; Zhang et al., 2012), construction operations (Shah et al., 2006; Shah and Shaheen, 2010) and non-ferrous metal production (Bilos et al., 2001) are the principal sources of elements in atmospheric dust. It is, therefore, essential to conduct studies on the composition, distribution, and sources of heavy metals adhered to or absorbed by atmospheric dust in order to evaluate atmospheric pollution and human health.

A number of studies have been carried out to evaluate dust deposition rates and its physical, chemical or mineralogical characteristics in Iran (Zarasvandi et al., 2011; Rashki et al., 2013; Gholampour et al., 2014, 2015) and also in other countries (Ta et al., 2004; Shah and Shaheen, 2008; Lu et al., 2010; Schleicher et al., 2011; Al-Harbi, 2015). However, the seasonal and spatial variability of dust deposition rate and its characteristics have not been well investigated.

The city of Isfahan, located in central Iran with a large population, heavy traffic, and many different industrial plants, is reasonably known as one of the most polluted cities in Iran (Modarres and Khosravi Dehkordi, 2005; Mansourian et al., 2010; Mansouri and Hamidian, 2013). Moreover, the desert areas in the eastern and northern skirts of the city frequently experience dust events during the year (Isfahan Governor's Office, 2013). Despite this, no comprehensive research has yet been carried out on the spatial and temporal variation of dust deposition rates and its characteristics in the area.

Understanding the chemical properties of atmospheric deposits and the sources of dust-borne heavy metals is important not only for controlling atmospheric pollution but also for developing proper pollution mitigation strategies. The objectives of this study are (1) to investigate the spatial and temporal variability of dust deposition rates in the region including the urban, rural, and desert areas; (2) to determine the seasonal and spatial variability of the concentrations of selected dust-borne heavy metals (Cu, Cd, Co, Cr, Ni, Pb, Zn, Hg and As); and (3) to identify the likely natural or anthropogenic sources of heavy metals in atmospheric dust.

2. Materials and methods

2.1. Study area

The study area is located between 51° 30′ 40″ to 52° 26′52″ E and 32° 26′53″ to 32° 54′27″N in Isfahan Province, Iran (Fig. 1a), covering an area of about 4500 km^2 (Fig. 1b). It includes the city of Isfahan, as the provincial capital and the second largest industrial and the third populated city in Iran, as well as the eastern and northern desert regions housing small towns and rural areas (Fig. 1b). The study area is characterized by the flat relief of the Central Iranian Plateau with an average elevation of 1580 m above the sea level and a dry climate with hot summers. The climatic characteristics of the study area during the dust sampling times are reported in Table 1 (Iranian Meteorological Organization, 2012 and 2013).

There are many different kinds of industrial complexes operating in the province such as a steel plant, the biggest across the nation, and a large steel mill, both located in west and southwest of the city of Isfahan (Fig. 1c). Also, an oil refinery and a petrochemical plant and many more major and minor plants are located closer to the city (Fig. 1b) (Isfahan Governor's Isfahan Governor's Office, 2013). The prevailing eastern wind in the summer carries dust from both the desert regions in the northeastern and eastern stretches of the study area and from the large number of construction and industrial sites to mix with traffic emissions; hence, the area receives a large quantity of particulate matter as dust (Karimzadeh, 2002; Isfahan Governor's Isfahan Governor's Office, 2013).

2.2. Dust and soil sampling

For dust and soil sampling, 67 sites distributed well across the study area were selected (Fig. 1b). Following the procedures employed by Menéndez et al. (2007), Hojati et al. (2012), and Norouzi et al. (2015), dust samples were collected using a flat glass with a surface area of 1 m^2 with a PVC net 2-mm mesh opening on top in order to yield a rough area able to trap the saltation particles. At each sampling site, 2 glass trays were placed on the roof of a one-story building 3–4 m above the ground level. Dust samples were collected each month from 19 June, 2012 to 19 May, 2013 using a rubber spatula to scrape the materials adhered on the glass trays over a 30-day interval. All the trays were washed with distilled water after each sampling period.

In order to evaluate the contribution to dust production by local soils and other sources, surface soil samples (0–15 cm) were also collected from the neighboring areas of the dust sampling sites. In the laboratory, dust samples were passed through a 2-mm sieve, weighed accurately using an AND jewelry balance FX-300GD with an accuracy of 0.001 g, packed, and stored in plastic cans until analysis. Soil samples were dried at room temperature, crushed and passed through a 2-mm sieve and kept for analyses.

2.3. Elemental analysis

The total elemental compositions of the dust and soil samples were determined after acid digestion. In this procedure, 1 g of the ground sample was digested using 10 ml HNO_3 and 10 ml $HClO_4$ at 210 °C for 90 min. Upon cooling, 0.1 N HCl was added to fill the 100 ml volumetric flask (Risser and Baker, 1990). The samples thus prepared were then passed through a filter paper and the extract was analysed for Al, Pb, Cu, Zn, Cd, Ni, Cr, Co, Hg, and As concentrations using an Agilent 7500CE Inductively Coupled Plasma Mass Spectrometer (ICP-MS, Agilent Technologies). Certified reference material (BAM-U110) (Federal Institute for Material Research and Testing, 2010) and reagent blanks were used as quality control samples during the analyses.

2.4. Data analyses

For each sampling site, dust deposition rate (DDR) was calculated based on the sample weight, dust trapping area (1 m^2), and the period of dust collection (1 month). The mean value of the DDR of the three months in each season was calculated as the seasonal DDR reported as ton km^{-2}·month^{-1}. For each site, sum of DDRs of all the12 sampling months was calculated and reported as the annual dust deposition rate in ton km^{-2} year^{-1}.

All the statistical analyses including the Duncan's test (test of significance of differences among mean values) and correlation