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Source apportionment and spatial–temporal variations in the metal content of surface dust collected from an industrial area adjoining Delhi, India

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HIGHLIGHTS

► Faridabad industrial area adjoining Delhi have high surface dust pollution load for Cd, V, Co, Ba, Ti, Ni, Cu, Cr and Zn.
► Sampling sites are least to highly polluted but specific to metal(s) and sampling season.
► Major metal pollution sources are mixed type industries, crustal, vehicular emissions, oil and battery burnings.
► Compared to large, small and medium scale unorganized industries add more pollution.
► Nature of industries, changes in land use pattern and shifting of small scale industries cause spatio-temporal variations.

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ABSTRACT

Surface dust collected during three different seasons from Faridabad industrial area adjoining Delhi is studied for different metals, their spatial and temporal variations, and sources. Al, Fe, Mn, Ti, Ca and Mg show limited variations and lower abundances compared to Upper Continental Crust (UCC); Fe shows enrichment and seasonal changes. Cd, V, Co, Ba, Ti, Ni, Cu, Cr and Zn show significant spatial and temporal variations, and enrichments compared to UCC indicate their anthropogenic sources. Seasonal variability could be due to: 1) different types of industries, 2) variations in the emissions, 3) very frequent shifting of small scale industry within the region, and 4) changes in the land use pattern.

The sampling sites, according to the geo-accumulation index, are: 1) least polluted for Ca, Mg, Al and Ti except for Ti in winter, 2) least to moderately polluted for Ba, Co and V but season specific, and 3) moderately to extremely polluted for other metals. Average pollution load index of 2.67–2.87 indicates consistently high level of pollution at all sites in all sampling seasons. The sites located in the residential areas near small to medium scale unorganized industry are more polluted compared to sites near large industries suggesting that the small scale unorganized industries causes more pollution. Three dominant sources of metals were identified: 1) mixed industrial, 2) crustal, and 3) vehicular, oil and battery related burnings. The third component related to Ba, Pb, Cd, Zn and Cr, further splits into two components in the pre-monsoon and winter samples. Surface dust, enriched in metals, is likely to cause serious danger to public health. There is an urgent need to make a shift from unorganized to formally organized industry to reduce the metal pollution and protect human health and environment as a whole.

1. Introduction

Emissions from industries, thermal power plants, fossil fuel burning from vehicles and construction activities are major anthropogenic contributors of metals and metalloids in the urban environments (Khlifi and Hamza-Chaffai, 2010). Although soil–crop system is taken as the main path through which humans are affected by the metals present in the environment (Liu et al., 2007; Sharma et al., 2007; Bose et al., 2008; Pandey et al., 2009), urban dust, especially in industrial areas and road sides not used for growing food crops, influences public health to a significant extent (De Miguel et al., 1997; Mielke et al., 1999; Madrid et al., 2002). Dust inhalation and ingestion, and hand mouth interactions are key pathways through which all human beings, particularly children, are exposed to metals and metalloids (Watt et al., 1993; Meyer et al., 1999; Rasmussen et al., 2001). This leads to high metal levels in blood, and affects intelligence and behavior of the affected person as has also been reported by Dietrich et al. (1990) for lead toxicity. The chronic adverse effects of the metals are well established (Khlifi and Hamza-Chaffai, 2010 and more references therein). This phenomenon is more evident in those urban areas, where multiple sources release large amounts of metals into the environment including atmosphere and soil (Nriagu, 1998; Bilos et al., 2001; Li et al., 2001). Liu et al. (2009) have reported high cancer risk ($>1\times10^{-6}$) for Cd, Ni, and Cr

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in workers occupationally exposed to industrial emissions. Therefore, the need for the better understanding of urban dust pollution has been recognized by several researchers (De Kimple and Morel, 2000; Manta et al., 2002) and research has been carried out worldwide (Kelly et al., 1996; Chen et al., 1997; Mielke and Reagan, 1998). The other important aspect of urban dust pollution is that it is not limited in time and space i.e. there is long term influence extended to space with contamination of air, water and soil (Fujiwara et al., 2011 and references therein).

In developing countries like India, there are enormous problems associated with the metal pollution of surface dust due to industrial activities. Faridabad city located adjacent to the national capital city of India, New Delhi, houses many industries like electroplating, metal coating, tire, tractor, power plant, etc. ranging from small to large scale. It is known that metal plating, copper motor burning and rewiring, batteries, metal alloy industries contribute both ferrous and nonferrous metal pollution in the environment, especially in urban dusts (Khlifi and Hamza-Chaffai, 2010). These authors have reviewed the adverse human health effects of ferrous as well as nonferrous metals such as Pb, Ni, Cr, Cd and Zn. The metal pollution in this region has not been looked into, rather there is lack of information on metal pollution in such areas having multiple types and different scales (small to large) of industries. The urban surface dust samples were collected from nearly 20 locations during three seasons i.e. pre-monsoon, post monsoon and winter from Faridabad industrial area and analyzed for different metals. The metal data is interpreted to understand the metal distribution, spatial and temporal variations, and their sources in the surface urban dust samples, and to assess related environmental and health effects in this region.

2. Study area

Study area for the present work includes Faridabad, an industrial township of Haryana state (known as the “Manchester of India”) located around 25 km from the central part of the National Capital city of India, New Delhi (see Supplementary material: Fig. AF 1). The geographical location of Faridabad town is 28° 25′ 16″ North Latitude and 77° 18′ 28″ East Longitude covering nearly 2151.00 km^2 (http://faridabad.nic.in/socio-ec.htm). This township shares the common boundary on its north with Delhi, and the river Yamuna on the eastern side separates it from the state of Uttar Pradesh. From barely housing 4 to 5 industries in 1950, this area has grown phenomenally into big industrial city beyond the expectations, particularly in last decade after the Honorable Supreme Court of India order to shift very large numbers of industries from Delhi, making it the ninth largest industrial estate in Asia. The total land occupied by the industries is about 6948 ha. At present about 15,000 small, medium and large scale industrial units are situated in Faridabad employing half a million people. The detailed description of the product and related industrial units are given in Supplementary material Table AT 1.

Faridabad is the most densely populated district of Haryana having population density of 1020 persons/km^2 against the average of 372 for the whole state. (http://faridabad.nic.in/socio-ec.htm). Faridabad with 2151.00 km^2 of land accommodates 2,193,276 people (2001 Population census). This district covers only 4.86% of the total land area of the state but it accommodates 10.40% of the total state population. In addition, a large number of migratory workers are residing in the area making it further dense. Thus, a large population is expected to be affected by the environmental pollution in this area. Major and large scale industrial units are situated in the industry specific areas, but apart from these, several areas have interwoven web of industrial and residential units. The small scale industries which includes motor winding, metal alloy, electroplating and many more are unorganized and operating in the residential areas. The combined turnover is estimated to be about Rs. 1500 billion per year.

Thus, Faridabad is among one of the most important industrial towns of northern India having a mixed pattern of industries. Dumping of solid industrial discard on any empty and open places including roadside is the most prevalent practice and can be easily felt and seen there. The discharge of liquid effluent is also not done in environmental friendly manner rather drained directly into small *nalas* which finally enter into the nearby flowing river Yamuna. The large number of industries of various types and scales emitting solid, liquid and gaseous pollutants in this area made it a suitable study area to note the impact of such complex industrial setup interwoven within residential pattern on human health and the environment as a whole. Therefore, we choose this area to study the surface dust for metal pollution.

Part of Faridabad region is a plateau of 250–300 meter height rising about 1000 m above the surrounding area known as Delhi ridge (Yamuna river flood plain is in the east) which extends up to Wazirabad in Delhi. Sand dunes of Thar Desert are situated in the west of the Delhi ridge and are potential source of dust during summer season. This district experiences semi-arid climate with average annual rainfall of 350.4 mm. Maximum rainfall takes place during the summer monsoon (July–August) period only. The district has almost flat plains made by the river Yamuna and soil varies from sandy to sandy loam. The region also experience strong south–southwest winds during the summer periods creating dusty situation in the area. This helps in transport and distribution of polluted surface dust in the nearby agricultural areas, affecting the crop productivity and quality. The leaching of pollutant is affecting the ground water as the water table is very high due to the river Yamuna. The surface waters are also contaminated due to direct draining of pollutants as well as through atmospheric deposition of polluted surface dust.

3. Sampling and analysis

Three sampling campaigns during winter, pre-monsoon and post monsoon seasons were performed for the collection of surface dust from the pre-determined sampling points in the study area to assess the nature and level of pollution caused by mixed type of industries. The whole area was divided in 500 m × 500 m size grid to get representative samples from all parts of the Faridabad industrial area. Out of the total collected samples, we selected only 21 samples as representative of different industrial patterns covering a wide range from small scale unorganized to medium and large industries (see Supplementary material: Fig. AF 1). The nature and scale (small to large) of industries were seriously taken into consideration before selecting the sampling points. A general description of the nature of industry around each sampling site is provided in Table 1.

Sufficient amount of sample was collected on laboratory grade butter paper by slow and careful scraping of surface dust by fine size brush. Both, butter paper and brush were nonsticky in nature. Appropriate care was taken to avoid the collection of any obvious contaminants like plant leaf, pebbles, etc. Samples were collected in pre-labeled good quality polythene zip bags to avoid any further contamination and brought back to the laboratory. All samples were sun-dried for 4–5 days in plastic trays to drive out the moisture. After sun-drying, dust samples were passed through 2 mm sieve to remove plant material, small pebbles, etc., if any. Nearly 20–30 g of each sample was taken from the homogenized bulk sun-dried samples by following coning and quartering method. All such samples were grounded to −200 mesh size (<63 μm) using agate mortar and pestle, and stored in pre-labeled plastic vials for further analysis.

3.1. Total organic carbon (TOC) estimation

TOC was estimated by following Walkely (1947) method modified by Okalebo et al. (2002) and later modified in our laboratory. 0.1 to 0.5 g of each processed sample was taken in a 250 ml conical flask and 5 ml of 1 M $K_2Cr_2O_7$ solution was added. 10 ml conc. H_2SO_4