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Human health risk assessment of airborne trace elements in Dhanbad, India

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ABSTRACT

Trace element concentrations in PM_{10} were investigated for their distribution, source apportionment and health impact assessment in Dhanbad, Jharkhand. PM_{10} at ten monitoring stations were collected on glass fiber filters during March 2014 to February 2015 and the quantification of the trace elements was done by using ICP-OES. The results revealed relatively high average annual concentration of PM_{10} (216 ± 82 μg/m^3) which is about 3.6 times the NAAQS (CPCB) and 10.8 times the WHO air quality guidelines. The highest concentration of PM_{10} was found during winter season (249 μg/m^3) followed by summer (217 μg/m^3) and post-monsoon (183 μg/m^3). Among the trace elements Zn (4753 ng/m^3) and Fe (3661 ng/m^3) were observed with highest concentration. Enrichment factor analysis revealed very high enrichment of Zn and Cd, indicating their specific anthropogenic origin. From the results of principle component analysis, vehicular emissions (exhaust as well as non-exhaust), road dust resuspension, coal combustion and mine fire were identified as the foremost sources of PM_{10} in the study area. The potential health risks (non-carcinogenic and carcinogenic) associated with different trace elements (for adults and children) were also estimated by using the concentration of concerned elements. Ingestion and inhalation were observed as the primary route of trace element exposure to humans. Multi elemental hazard index indicated integrated impacts of a mixture of elements especially in case of children. The carcinogenic risk assessment illustrated very high probability of cancer risk to the inhabitants in the area, especially in children (10–18 times higher than adults).

1. Introduction

Particulate matter (PM) has become the most crucial parameter of air pollution as many of the epidemiological studies have shown a direct relationship between atmospheric PM and adverse effect on human health (Alessandrini et al., 2012; Dockery and Stone, 2007). These airborne PM are carrier of several trace elements such as As, Cd, Cr, Cu, Zn, Pb, Ni etc (Brunekreef and Holgate, 2002). In terms of mass, trace elements contribute little to PM, but even this minute amount can be considerably hazardous to human health. The trace elements are adsorbed on PM of various size fractions ranging from few nanometers to few micrometers (Alam et al., 2011). Fine PM carries a higher burden of heavy toxic elements than does coarse PM (Fang et al., 2000). Trace elements associated with respirable particles have been observed to increase lung and cardiopulmonary injuries in humans (Lee et al., 2005; Shaheen et al., 2005).

The main routes of exposure of these toxic elements are ingestion, inhalation and dermal absorption (Du et al., 2013; Hu et al., 2012). Trace elements are severely toxic to humans because of their tendency of bio accumulation in the biological system (Du et al., 2013) especially, in the fatty tissues. The effects of these trace elements cover a wide range of health issues. As is a human carcinogen. It can also cause respiratory tract disorders (US EPA, 1984), skin ailments, can interfere with cardiovascular, hematopoietic and nervous system (ATSDR, 1989; Franzblau and Lilis, 1989; US EPA, 1984). Pb and Cd are probable human carcinogens. In addition to the carcinogenic effect, Pb causes kidney disorder, neuropathy and encephalopathy (ATSDR, 1993; US EPA, 1990) and Cd also interferes with the normal functioning of kidney (Goyer, 1991). Cr causes lung cancer (Mancuso, 1975), skin ailments

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(Burrows, 1983; Pedersen, 1982) and shows teratogenic effects (Danielsson et al., 1982; Iijima et al., 1983; Matsumoto et al., 1976) as well as a human carcinogen (Cr(VI)). The well-known toxicity possessed by the elements and its recalcitrant nature, make it of foremost scientific concern (Hall, 2002). Hence, the trace element composition of atmospheric particulates (PM_{10}) has been focused by number of studies worldwide (Abulude et al., 2003; Banerjee, 2003; Bhuyan et al., 2010; Feng et al., 2009; Karar et al., 2006; Leili et al., 2008; Limbeck et al., 2009; López et al., 2005; Senlin et al., 2007). Many studies have used trace elements as tracers to identify source of PM, since trace elements can be associated with specific anthropogenic sources (Birmili et al., 2006; Weckwerth, 2001). Trace elements are used as markers in many of the source apportionment studies in India (Basha et al., 2014; Roy et al., 2012; Gummeneni et al., 2011; Meena et al., 2016; Pathak et al., 2013; Shridhar et al., 2010), but few works (Izhar et al., 2016; Khanna et al., 2015) deal with the application of these concentration in terms of exposure and health.

Dhanbad, located in Jharkhand (India) holds an important position in the economy of India, because it is the largest producer of coking coal in the country. Due to incessant and extensive mining activities, this region has become prone to intense air pollution. This persistent problem of air pollution has led to a large number of studies regarding periodic assessment of ambient air quality. The pollutants of foremost concern in this area are PM and associated trace elements originated from mining and allied activities, vehicular emissions and industrial emissions (Dubey et al., 2012; Pandey et al., 2014). These authors have assessed the PM concentration and trace element composition and source characterization of PM in the area. These studies lack the information about impacts of the pollutants on human health. In order to fill the gap, the present study was designed to assess the health risks associated with the trace elements in the study area.

The key objectives of the study were: 1) to assess the status of ambient air quality with respect to the PM_{10} and PM_{10} bound trace elements (As, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb and Zn), 2) source characterization of the trace elements and 3) to estimate the potential non-carcinogenic and carcinogenic health risks possessed by the trace elements under consideration in the mining, traffic and institutional areas of Dhanbad.

2. Study area

Dhanbad is known as the coal capital of India and is the third largest city in Jharkhand State. It lies between 23°37′3″ N and 24°4′ N latitude and between 86°6′30″ E to 86°50′ E longitude and having a mean elevation of 222 m. The history of coal mining in Dhanbad is not new. It has been vigorously associated with coal mining (open-cast as well as underground) activities for more than a century and it abounds the most important coal fields of India (Jharia coal field) which is the only source of coking coal in India (Singh et al., 2015). This coal field has been badly affected due to underground mine fire (about 7 Km^2 of the total 450 Km^2 area), which spreads from west to south of Dhanbad city (Singh et al., 2015). Widespread mine fire resulting into the generation of huge amount of aerosols over this region (Stracher and Taylor, 2004). Apart from coal mine fire, the major sources of air pollution in this mining and industry dominated area includes open-cast coal mines, coal washeries, coke oven plants as well as transportation (mining and non-mining) activities. Central Pollution Control Board (CPCB) in consultation with the Ministry of Environment and Forests, Government of India, has declared Dhanbad as critically polluted area and ranked 13th among 88 industrial areas, with a score of 78.60 out of 100 (CPCB, 2009a).

Dhanbad being situated in the sub-tropical climatic zone, experiences cool winter as well as an extremely hot and humid summer season. The winter season extends from December to February having the mean temperature range of 11 °C to 22 °C, whereas, the summer season extends from March to mid-June having a mean temperature range of 25 °C to 45 °C. Apart from the extreme hot and cold weather conditions, this region also receives heavy rainfall (approximately 1300 mm) annually and the monsoon season extends from mid-June to mid-September.

3. Methods

3.1. Sample collection and gravimetric analysis

For the present study, the spatial and temporal variation in PM_{10} concentrations and associated trace elements in Dhanbad city were estimated using 10 monitoring stations sited as per selection criteria provided by IS: 5182 Part XIV (BIS, 2000), with special consideration of meteorological conditions and sources of pollution. The details of monitoring stations are presented in Fig. 1 and Table 1. The monitoring stations were grouped into "mining areas, traffic routes and institutional area" for the ease of investigation of the impact of different sources on ambient air quality and its impact on various receptors. For the investigation of seasonal variation the study period was divided into three seasons; summer (March to May 2014), post monsoon (September to November 2014) and winter (December 2014 to February 2015). 24 hourly ambient air samples were collected on once a week basis for three seasons (total 36 samples from each monitoring station). PM_{10} samples were collected, using respirable dust sampler (Envirotech APM 460 NL) (flow rate of 1.1 $m^3\ min^{-1}$) on 20.4 × 25.5 cm Whatman glass fiber filters. The differences in the weight of the filters before and after sampling (using an electronic microbalance (AND HR-200) were used to calculate PM_{10} concentration). The flow rate was recorded four times to insure the variation in flow rate within 0.9–1.1 m^3/min and the average flow rate was used for the calculation of PM_{10} mass concentration. For the proper measurement of air pollutants, the instruments respirable dust samplers were calibrated before every sampling season by orifice transfer standard in accordance with the CPCB guidelines (CPCB, 2009b). Balance calibrations were also performed before and after each weighing session as per the manufacturer's specifications. Filters were inspected for pin holes prior to use and were conditioned in desiccators for 24 h before and after sampling. Field blank filters (one in every 10 samples) and lab blanks (one in every 50) were also collected to reduce the gravimetric bias due to filter handling during and after sampling.

3.2. Chemical analysis

The characterization of trace elements present in the collected PM_{10} samples, was performed by chemical method. After gravimetric analysis the glass fiber filter papers were cut into four pieces. One fourth part was used for determining the trace element after digestion in a mixture of nitric acid (65% GR grade, Merck) and perchloric acid (70% GR grade, Merck) (20:2, v/v) facilitated by heating on hot plate at a temperature of about 150 °C to evaporate the nitric acid solution to 5 ml (method IO-3.1, US EPA, 1999). The digested solution was filtered through a Whatman 42 filter paper and diluted to 50 ml with double distilled water and stored in refrigeration in a cleaned polypropylene bottle until analyzed. The same procedure was repeated for reagent blank filter paper. The concentrations of selected trace elements were determined by using inductive coupled optical emission spectrophotometry (ICP-OES) (PerkinElmer Optima 2100 DV). The instrument was

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