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

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ABSTRACT

Trace element concentrations in PM₁₀ were investigated for their distribution, source apportionment and health impact assessment in Dhanbad, Jharkhand. PM₁₀ 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 PM₁₀ ($216 \pm 82 \mu\text{g}/\text{m}^3$) which is about 3.6 times the NAAQS (CPCB) and 10.8 times the WHO air quality guidelines. The highest concentration of PM₁₀ was found during winter season ($249 \mu\text{g}/\text{m}^3$) followed by summer ($217 \mu\text{g}/\text{m}^3$) and post-monsoon ($183 \mu\text{g}/\text{m}^3$). Among the trace elements Zn ($4753 \text{ ng}/\text{m}^3$) and Fe ($3661 \text{ ng}/\text{m}^3$) 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 PM₁₀ 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).

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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 (PM₁₀) 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 PM₁₀ and PM₁₀ 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 Km² of the total 450 Km² 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 PM₁₀ 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). PM₁₀ samples were collected, using respirable dust sampler (Envirotech APM 460 NL) (flow rate of 1.1 m³ 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 PM₁₀ concentration). The flow rate was recorded four times to insure the variation in flow rate within 0.9–1.1 m³/min and the average flow rate was used for the calculation of PM₁₀ 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 PM₁₀ 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

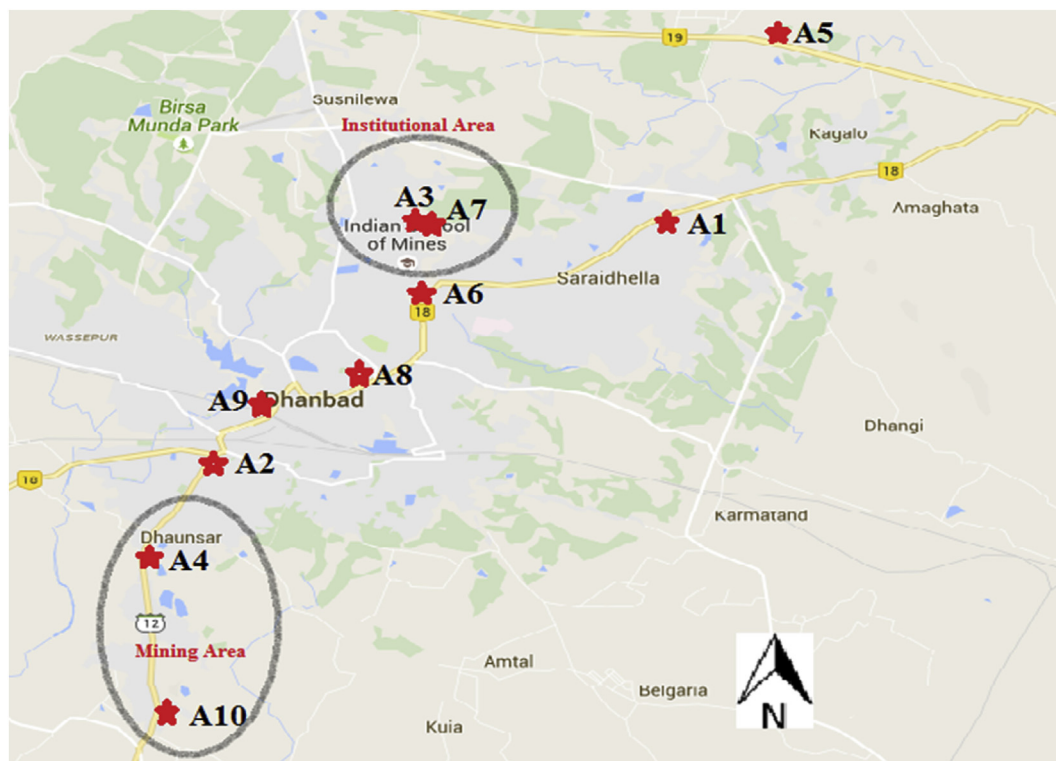


Fig. 1. Map of study area depicting monitoring stations.

Table 1
Details of monitoring stations in the study area.

Station code	Monitoring stations	Geographical location		Dominating activities
		N	E	
A1	Big Bazar	23°49.230'	86°28.192'	Vehicular movement, Commercial activities
A2	Bank More	23°47.302'	86°25.165'	Busy market center, surrounded by residential area. Commercial activities, mining area. High traffic density
A3	IIT (ISM) Canteen	23°48.923'	86°26.511'	Burning activities, very little movement of vehicles
A4	Dhansar P.S.	23°46.540'	86°24.673'	Mining activities (open-cast and underground), road transport (paved and unpaved road)
A5	Govind Pur	23°50.673'	86°28.999'	Industrial area activities, vehicle movement, coke oven plant
A6	IIT (ISM) Gate	23°48.554'	86°26.555'	Main road in Dhanbad city, commercial activities, vehicle movement
A7	IIT (ISM) Petroleum Dept.	23°48.890'	86°26.590'	Relatively clean area
A8	Court More	23°47.892'	86°26.226'	Traffic junction, vehicle movement, commercial activities
A9	Shramik Chowk	23°47.654'	86°25.529'	Heavy vehicle density, road traffic junction,
A10	RSP college	23°45.193'	86°24.740'	Mining activities, mine fires and vehicular movement (paved road and unpaved road)

calibration using ICP-OES standard solution from E-Merck (Germany). The detection limit of the instrument was 3.6, 0.07, 0.25, 0.25, 0.9, 0.2, 0.03, 0.4, 1.4, and 0.2 ppb for As, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb and Zn, respectively.

3.3. Contaminant level assessment

Enrichment factor (EF) gives an idea about whether the element is of geogenic nature or its concentration is enriched by some anthropogenic sources. Rahn (1971) first introduced the concept of enrichment factor to estimate the contribution of anthropogenic emissions to the total atmospheric elemental concentration (Feng et al., 2009; Lim et al., 2010; López et al., 2005; Rovira et al., 2011). The enrichment factor is the ratio of concentration of elements in the air sample with that of a selected reference element that is entirely crustal in origin, relative to the average ratio in earth

crust. Fe, Al and Si are mostly used as reference elements for the estimation of EF. For this study Fe was taken as a reference element (Nazir et al., 2011) considering the fact that, the natural concentration of Fe is substantially higher than the concentration of elements of concern from toxicological perspective (Wedepohl, 1995). The enrichment factor was calculated through equation (1):

$$EF_x = \frac{\left(\frac{X}{R}\right)_{\text{Sample}}}{\left(\frac{X}{R}\right)_{\text{Crust}}} \quad (1)$$

where, X is the concentration of target element and R is the concentration of reference element. The mean abundance of target elements and reference element in the earth crust was opted from CRC handbook of chemistry and physics (Lide, 2008). The EF of an element close to unity indicates its crustal origin, while elements with EFs of 1–5 are considered being originated from both

anthropogenic and crustal sources (Hsu et al., 2010). Trace metals with the EF of ≥ 5.0 , are predominantly from anthropogenic emissions (Hsu et al., 2010).

3.4. Health risk assessment model

3.4.1. Exposure dose

This study used the model developed by US Environmental Protection Agency (EPA) to calculate the exposure of humans to atmospheric particle bound trace elements. The exposure levels of each elements via the three main exposure paths: (a) ingestion of atmospheric particulates due to their deposition, (b) inhalation through mouth and nose and (c) dermal absorption of trace elements in atmospheric particulates adhered to exposed skin (Hu et al., 2012; Li et al., 2015) were separately estimated in terms of chemical daily intake (CDI) (mg/kg/day), exposure concentration (EC) ($\mu\text{g}/\text{m}^3$) and dermal absorption dose (DAD) (mg/kg/day). CDI, EC and DAD were calculated according to the Human Health Evaluation Manual (Part A), Supplemental Guidance for Inhalation Risk Assessment (Part F) and Supplemental Guidance for Dermal Risk Assessment (Part E) (US EPA, 1989, 2004a, 2009) using Equations (2)–(4):

$$\text{CDI} = \frac{C * R_{\text{ing}} * \text{CF} * \text{EF} * \text{ED}}{\text{BW} * \text{AT}} \quad (2)$$

$$\text{EC} = \frac{C * \text{ET} * \text{EF} * \text{ED}}{\text{AT}} \quad (3)$$

$$\text{DAD} = \frac{C * \text{SA} * \text{AF} * \text{EV} * \text{ABS} * \text{EF} * \text{ED} * \text{CF}}{\text{BW} * \text{AT}} \quad (4)$$

where, C is the concentration (annual average concentration for this study) of elements in PM_{10} (mg/Kg for CDI and DAD and $\mu\text{g}/\text{m}^3$ for EC). All the factors used in calculation are depicted in Table S1 of the supplementary materials.

3.4.2. Non carcinogenic health risk

Once CDI, EC and DAD for the three exposure pathways is known, a Hazard Quotient (HQ) and Hazard Index can be estimated to measure the non-carcinogenic health risk of the trace elements in airborne particles. HQ via ingestion, inhalation and dermal contact were calculated by Equation (5).

$$\text{HQ} = \frac{\text{CDI}}{\text{RfDo}} = \frac{\text{EC}}{(\text{RfCi} * 1000 \mu\text{g}/\text{m}^3)} \quad (5)$$

$$= \frac{\text{DAD}}{(\text{RfDo} * \text{GIABS})}$$

where, RfDo is oral reference dose (mg/Kg/day), RfCi is inhalation reference concentrations ($\mu\text{g}/\text{m}^3/\text{day}$) and GIABS is the gastrointestinal absorption factor. RfDo and RfCi are an estimate of a daily exposure level for the human population, including sensitive sub-populations, that is likely to be without an appreciable risk of deleterious effects during a lifetime (US EPA, 1989). The values of RfDo, RfCi and GIABS were taken from regional screening level tables provided by the US EPA (2016) (Table S2 of the supplementary materials).

If $\text{HQ} < 1$ (CDI/EC/DAD is less than threshold dose/concentration), there is no adverse effects on health and if $\text{HQ} > 1$ (CDI/EC/DAD is more than threshold dose/concentration) there is likely adverse health effects due to exposure (US EPA, 1989).

Further, the estimation of hazard potential of only one element at a time might significantly underestimate the hazards associated

with the simultaneous exposures to multiple elements. Hence, HQs of individual elements should be added to compute a Hazard Index (HI) to estimate the risk of mix exposures (Equation (6)). HI refers to the sum of more than one HQ for multiple chemical exposure.

$$\text{HI} = \sum_{i=1}^n \text{HQ}_1 + \text{HQ}_2 + \dots + \text{HQ}_i \quad (6)$$

where, HQ_i refers to the hazard quotient for the i th element. $\text{HI} < 1$ indicates no significant risk of non-carcinogenic effects and $\text{HI} > 1$ indicates likely occurrence of non-carcinogenic effects and the probability of which tends to increase with an increase in HI values (Guney et al., 2010; US EPA, 1989; Zheng et al., 2010).

3.4.3. Excess cancer risk

The estimation of excess cancer risks (ECRs) have been carried out in terms of the incremental probability of developing cancer over a lifetime of a person as a consequence of total exposure to the potential carcinogen. ECR is computed by using the given Equation (7) (Hu et al., 2012; US EPA, 2011).

$$\text{ECR} = \frac{C * \text{ET} * \text{EF} * \text{ED} * \text{IUR}}{\text{AT}} \quad (7)$$

where, C is the concentration (annual average concentration for this study) of trace elements ($\mu\text{g}/\text{m}^3$), IUR is the inhalation unit risk ($\mu\text{g}/\text{m}^3$)⁻¹ (Table S2 of the supplementary materials), AT is the average time for carcinogens (70 year \times 365 days/year \times 24 h/day), ET is the Exposure time (24 h/day) and other parameters are earlier mentioned. Carcinogens are non-threshold (zero safe dose), means exposure of any dose of carcinogens will cause likelihood of cancer. The tolerable value of ECR for regulatory purposes is 10^{-6} – 10^{-4} which means that if the value of risk lies under this range then there is no likely threat of cancer due to the contamination (Hu et al., 2012; US EPA, 1989).

4. Results and discussion

4.1. PM_{10} concentration

During the period of observation, the average concentration of PM_{10} was found $216 \pm 82 \mu\text{g}/\text{m}^3$ (ranged from 92 to $436 \mu\text{g}/\text{m}^3$) which is about 3.6 times the National Ambient Air Quality Standards (NAAQS) ($60 \mu\text{g}/\text{m}^3$; annual) prescribed by CPCB (2009b) and 10.8 times the World Health Organization (WHO) air quality guidelines ($20 \mu\text{g}/\text{m}^3$; annual) (WHO, 2005). As far as the seasonal variation in PM_{10} concentration is concerned, winter season ($249 \mu\text{g}/\text{m}^3$) experienced the highest concentration of PM_{10} , followed by summer ($217 \mu\text{g}/\text{m}^3$) and post-monsoon ($183 \mu\text{g}/\text{m}^3$). Similar findings were also obtained by Banerjee and Hussain (1989), Chaulya et al. (2002), Dubey et al. (2012), Pandey et al. (2014) Sinha (1995) and Soni and Agarwal (1997) around mining areas in Jharia Coalfield. The highest concentration of PM_{10} observed during the winter season might be attributed to stable meteorological condition (low wind speed, strong inversion, shallow mixing depth and very low turbulence) (Chaulya, 2004) coupled with increased anthropogenic activities such as biomass burning and space heating (Chakraborty and Gupta, 2010; Karar et al., 2006; Ni et al., 2013; Pakbin et al., 2010). High particulate concentration events synergistically act along with fog to reduce the visibility (Javed et al., 2015) in Dhanbad and its surrounding area during the winter season. Higher concentrations of PM_{10} during the summer was likely due to enhanced re-suspension of road dust and crustal dust triggered by high temperature and wind speed, coupled with low rainfall and relative humidity (Pakbin

Table 2Spatial distribution of PM₁₀ concentration levels (µg/m³) during summer, post-monsoon and winter seasons.

Sampling Stations		Code	Summer (N = 12)	Post-monsoon (N = 12)	Winter (N = 12)	Year (N = 36)
Mining area	Dhansar P. S.	A4	286 ± 16	231 ± 23	296 ± 18	205 ± 11
	RSP College	A10	406 ± 31	352 ± 46	436 ± 16	398 ± 20
Traffic routes	Big Bazaar	A1	220 ± 14	188 ± 50	249 ± 25	218 ± 22
	Bank More	A2	250 ± 16	203 ± 46	295 ± 31	249 ± 23
	Govind Pur	A5	218 ± 14	185 ± 28	211 ± 17	271 ± 12
	IIT (ISM) Gate	A6	198 ± 59	106 ± 15	288 ± 41	175 ± 17
	Court More	A8	148 ± 19	131 ± 9	172 ± 21	150 ± 8
	Shramic Chowk	A9	247 ± 15	220 ± 16	284 ± 16	250 ± 10
	IIT (ISM) Canteen	A3	116 ± 9	112 ± 12	125 ± 7	118 ± 7
Institutional area	IIT (ISM) Petroleum Dept.	A7	94 ± 8	92 ± 7	98 ± 9	95 ± 6
NAAQS, 2009 (CPCB, 2009b)			60 (Annual average)			
			100 (24 h average)			

N = Number of samples per station.

et al., 2010; Shah and Shaheen, 2010). The seasonal variation in PM₁₀ concentration levels at 10 selected monitoring locations across the study area is presented in Table 2.

From the observations, a substantial spatial variation in PM₁₀ concentration was also observed, which depend strongly upon the prevailing meteorological conditions (Gao et al., 2011; Li et al., 2011; Wang and Gao, 2008) and proximity of specific sources. In mining area, transportation routes and institutional area the annual average PM₁₀ concentration was observed 302 µg/m³ (231–436 µg/m³), 212 µg/m³ (131–295 µg/m³) and 107 µg/m³ (92–125 µg/m³), respectively. RSP College, Jharia (A10) (mining area) experienced highest load of PM₁₀ concentration 398 µg/m³ (436 µg/m³ during winter, 406 µg/m³ during summer and 352 µg/m³ during post-monsoon season). It may be accounted to a wide array of open-cast coal mines surrounding the monitoring station. The other important factor which governs strongly the particulate matter concentration is substantial influence of the heavy load of mining and non-mining vehicles plying on the road, crossing close to the college boundary. Whereas, the lowest concentration (95 µg/m³ (98 µg/m³, 94 µg/m³ and 92 µg/m³ during winter, summer and post monsoon seasons, respectively)) was observed at IIT (ISM) Petroleum Department (A7), which is observed slightly lower than 24 hourly NAAQS (100 µg/m³). This site is comparatively clean because of absence of sources of pollution as well as maintenance of greenbelt in the IIT (ISM) Campus. The main source of PM₁₀ at this station is dispersed particulates from distant sources.

4.2. Trace elements concentration

The annual average concentration of all elements under consideration (Zn, Fe, Cu, Mn, Pb, Ni, Cr, As, Cd and Co) in the entire study area were observed as 4754 ng/m³, 4164 ng/m³, 319 ng/m³, 164 ng/m³, 89 ng/m³, 29 ng/m³, 22 ng/m³, 9 ng/m³, 7 ng/m³ and 6 ng/m³, respectively (Table S3 of supplementary materials). Zn was found to be present in highest concentration (except at IIT (ISM) Canteen (A3) and IIT (ISM) Petroleum Department (A7)) as compared to other elements. The dominance of Zn (50% of the total trace elements under consideration) and Cu (4% of the total trace elements under consideration) in PM₁₀ clearly demarcate its anthropogenic origin (from lubricant oil, brake wear, tyre wear and resuspension of road dust) (Alolayan et al., 2013; Shah et al., 2012), whereas, second highest contribution of Fe (43%) is associated with crustal emission. Thus, it can be hypothesized that the major contributor of PM₁₀ in the study area is resuspension of road dust.

The annual average concentration of total trace elements were observed to be 4270 ng/m³ in institutional area, 11,580 ng/m³ (2.7 times that of the institutional area) along transportation routes and 13,710 ng/m³ (3.2 times that of the institutional area) in mining

area, accounting for about 4%, 5.5% and 4.5% of the total PM₁₀ concentrations, respectively. In addition, the concentrations of individual elements, Zn, Mn, As, Pb, Co, Fe, Cr and Cu were observed highest in mining area which is 11.1, 5.2, 2.9, 2.6, 1.9, 1.7, 1.6 and 1.2 times, respectively than the institutional area. Cu and Co were observed highest along the transportation routes (441 ng/m³ and 8 ng/m³, respectively), which is 2 and 1.8 times, respectively higher than the mining areas and 2.4 and 4 times, respectively than institutional area.

In the institutional area, Fe was found in highest concentration (accounting for 69% of the total trace element concentration) followed by Zn, Cu etc. Whereas, in the mining area and traffic routes, the concentration of Zn was observed highest accounting for 48% of the total trace element concentration in both group of monitoring stations. The dominance of Fe (crustal element) in institutional area is accounted to the contribution of PM₁₀ from natural sources (windblown dust) and resuspension of road dust, while, the dominance of Zn in mining area and traffic routes is attributed to the contribution of PM₁₀ from anthropogenic activities (tyre wear, oil burning and resuspension of road dust).

The seasonal trends of trace elements concentration under consideration is depicted in Fig. 2. Seasonally, the mean concentrations of trace elements in PM₁₀ were found higher in winter than those of summer and post monsoon (Malandrino et al., 2013a, 2013b; Marcazzan et al., 2001; Prodi et al., 2009), except, Zn and Ni, which were observed with highest concentration during summer and post monsoon seasons, respectively. The significant increase in concentration of elements during the winter could be attributed to more domestic heating and other combustion sources in the area (Khare and Baruah, 2010) and thermal inversion as well as ground level fog, which cause stagnation of air and consequently, the buildup of pollutants concentration (Padoan et al., 2016). Whereas, the lower concentration of Zn and Ni during the winter might suggest the influence of transportation and industrial sources, which have lower strength during the winter season. Lower concentration of Ni and Zn during the winter season was also recorded in Hisar city (India) (Haritash and Kaushik, 2007) and Bohai Rim (China) (Zhang et al., 2014a), respectively.

The trace elements concentration observed during the present study were compared with those reported from other parts of the world (Table 3). Table 3 illustrates relatively higher concentration of PM₁₀ and trace elements in the study area in comparison to the other coal mining and industrial areas.

4.3. Correlation analysis

Pearson's correlation analysis was performed to investigate the correlation between all the trace elements under consideration in

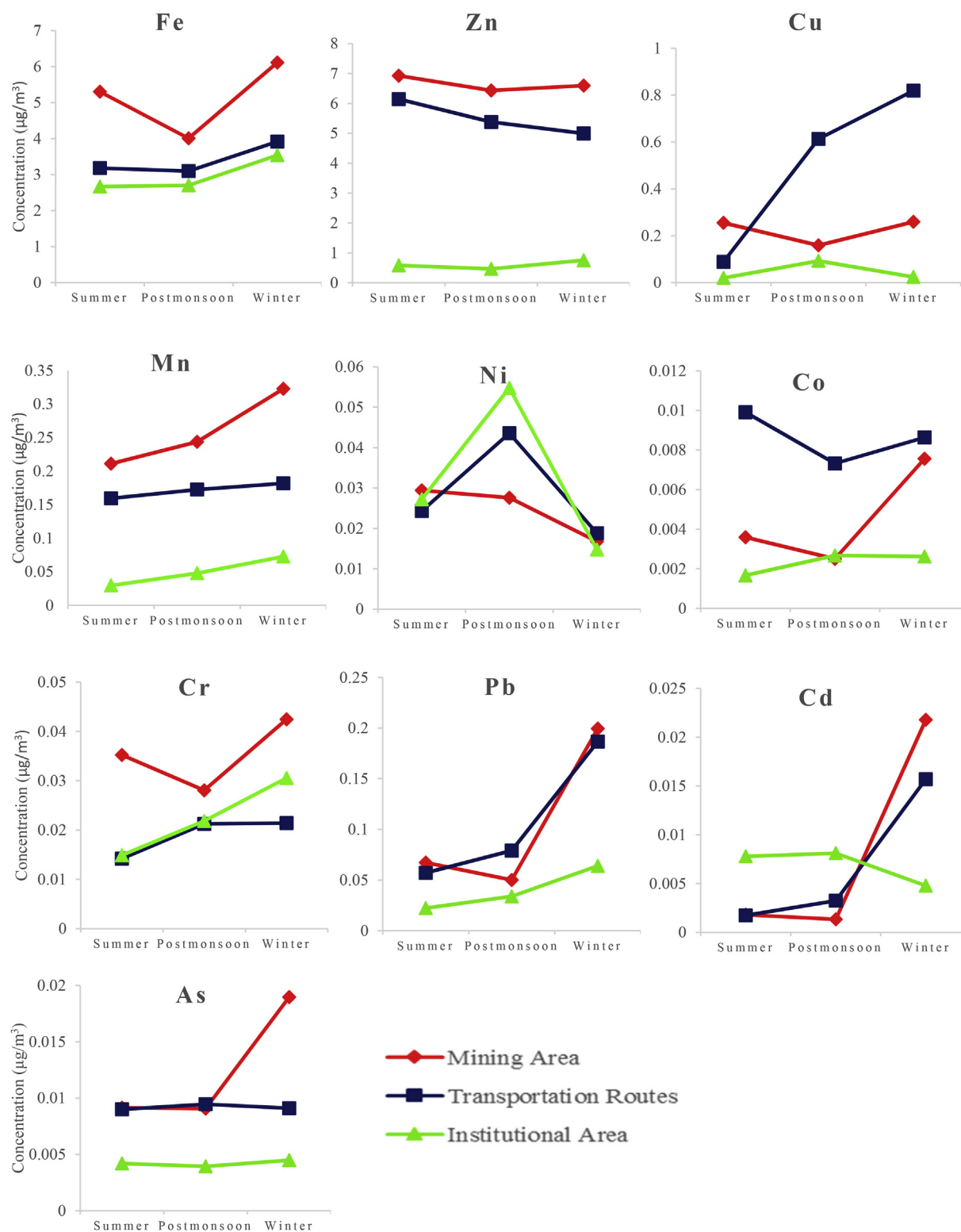


Fig. 2. Seasonal Trends of elemental concentrations in PM_{10} samples in different groups of monitoring stations.

terms of its concentrations and to obtain a general profile of the sources contributing to PM_{10} . Because, it is apparent that elements that are strongly correlated indicate some common sources (Basha et al., 2014; Javed et al., 2015; Shah and Shaheen, 2010; Zhou et al., 2014). The average of three season's concentration (summer, post monsoon and winter) was used for correlation analysis. The values

of correlation coefficient (r) significant at $P < 0.01$ pertaining to trace elements are depicted in Table 4. Fe, Mn and Cr were observed correlated well with each other (Fe-Mn; $r = 0.64$, Mn-Cr; $r = 0.50$ and Fe-Cr; $r = 0.53$). Fe, Mn and Cr are Lithophile (concentrated more in Earth's crust) (Nordberg et al., 2005; White, 2013), hence these elements are likely to be contributed from windblown dust

Table 3PM₁₀ bound trace elements concentration (ng/m³) in different mining and industrial areas.

Pollutants	Present study	USA	Taiwan	China	Spain
PM ₁₀	216,000	57,598	52,400	108,400	41,967.692
Fe	4164.0	—	572	1129.2	—
Zn	4754.2	—	131	263.8	89.2
Cu	318.9	—	15.7	130.48	262.31
Mn	164.0	26.75	20.1	35.3	23.52
Ni	29.2	8.67	9.84	9.56	2.29
Co	6.3	0.804	0.53	—	0.29
Cr	22.5	3.17	30.7	9.6	10.98
Pb	85.2	3.61	21.2	46.72	13.14
Cd	6.6	0.1765	0.7	0.52	0.32
As	8.9	0.839	3.39	—	1.566
Sources	Mining and transportation	Surface coal mining	Coal fired power plant	Coal fired power plant	Traffic emission and coal burning
References		Aneja et al. (2012)	Hsu et al. (2016)	Wu et al. (2013)	Moreno et al. (2013)

Table 4Pearson correlation coefficient matrix for PM₁₀ bound trace elements.

	Fe	Zn	Cu	Mn	Ni	Co	Cr	Pb	Cd	As
Fe	1.00									
Zn	0.49	1.00								
Cu	0.11	0.56	1.00							
Mn	0.64	0.85	0.39	1.00						
Ni	−0.15	−0.08	0.52	0.04	1.00					
Co	−0.26	0.14	0.20	0.18	0.18	1.00				
Cr	0.53	0.12	−0.15	0.50	−0.08	−0.09	1.00			
Pb	0.06	0.37	0.28	0.56	0.24	0.85	0.33	1.00		
Cd	−0.40	−0.04	−0.39	−0.02	−0.43	0.18	0.28	0.28	1.00	
As	0.64	0.72	0.25	0.83	0.13	0.28	0.49	0.56	−0.06	1.00

Bold numerics represent the significant correlation.

(Basha et al., 2014). Fe was also observed significantly correlated with As (0.64). As is originated from automobile emissions, industrial emissions (Karar et al., 2006; Senlin et al., 2007) and coal burning (Pacyna et al., 2007; Tian et al., 2010; Xie et al., 2006; Zhang et al., 2009). Significant correlation were also observed between Zn–Cu (0.56), Zn–Mn (0.85), Zn–As (0.72), Cu–Ni (0.52), Cr–Mn (0.5), Pb–Mn (0.56), As–Mn (0.83), Co–Pb (0.85), As–Pb (0.56). The metals are generally contributed by anthropogenic activities such as vehicular emission and metal corrosion (Cu, Zn, Cd) (Basha et al., 2014), coal burning (As, Cr, Pb) (Pacyna et al., 2007; Tian et al., 2010; Zhang et al., 2009). Zn was witnessed highly correlated with Mn and As. Zn is emitted utterly from vehicular sources like, wear and tear of vulcanized tyres, and oil combustion (Alolayan et al., 2013; Banerjee, 2003; Borbely-Kiss et al., 1999; Karar et al., 2006; Khillare et al., 2004; Kulshrestha et al., 2009; Manoli et al., 2002; Shah et al., 2012; Thorpe and Harrison, 2008). Hence, the most prominent sources of trace elements in the study area are resuspension of road dust due to traffic induced turbulence, vehicular emission (exhaust and non-exhaust) and coal burning.

4.4. PCA (principal component analysis)

To obtain a reliable estimation of possible sources contributing to PM₁₀ in study area, principal component analysis (PCA) with Varimax rotation and Kaiser Normalization was performed (SPSS 16.0) and principal components having eigen values > 1 have been extracted (Winner and Cass, 2001) using the trace elements concentration of all samples 36 (12 per season) samples per station for each groups of monitoring stations separately. Table 5 presents the factor loadings of selected trace elements in different principal components in the entire study area.

In mining area five components (principal components) having eigen values > 1 were extracted accounting about 76% of the total variance in the entire data set. Factor 1 (PC1) is represented by Cd,

As and Pb which is associated with mining activities (Chen et al., 2015). Pb is derived from mining and allied activities (Tian et al., 2010) in addition to vehicular emission (Ambade, 2014; Banerjee, 2003; Kulshrestha et al., 2009). As emission is associated with coal combustion (Pacyna et al., 2007; Tian et al., 2010). While, Cd originates from coal combustion (Ambade, 2014) and resuspension of road dust (Sternbeck et al., 2002). PC2 represented by Cu and Cr is mainly related to coal combustion (Zhang et al., 2014b). The third factor (PC3) with greatest loadings of Co and Ni indicates its origin from vehicular emission (Chen et al., 2015). While, PC4 and PC5 explaining 12% and 11% variance, represented by Fe and Zn, and Mn, respectively. These factors marked by higher loadings of Fe, Zn and Mn may associated with resuspended crustal dust and road dust.

In the traffic routes, four principal components having eigen values > 1 were extracted accounting about 58% of the total variance in the entire data set. PC1 represented by Cd and Pb with 19% variance. This suggested that the road dust contributed by vehicular movement was the major source (Sternbeck et al., 2002). PC2 explains 15% variance with higher loading of Fe, Mn and Zn. Which is attributed to resuspended road dust and crustal sources. The third component (PC3) with 13% variance (Ni and Co) indicates its source from vehicular emission (Chen et al., 2015). While PC4, having high loading of Cr and As with 10% variance is contributed by coal burning (Tian et al., 2010) and vehicular emission (Pacyna et al., 2007).

In institution area, four principal components having eigen values > 1 were extracted accounting about 58% of the total variance in the entire data set. The first component (PC1) is represented by Ni, Cu and Cr, indicated its origin from coal burning and resuspension (Pandey et al., 2014). While PC2 was loaded by As, Mn, and Co. It is mainly attributed to coal combustion and crustal sources. PC3 explains 12% variance with higher loadings of Fe, Pb and Zn, is contributed by traffic related resuspended dust. Whereas, PC4 loaded by Cd and Co indicates its origin from coal burning.

Table 5
Component loadings for trace element concentrations.

Elements	Mining area					Traffic routes					Institutional area			
	PC1	PC2	PC3	PC4	PC5	PC1	PC2	PC3	PC4	PC5	PC1	PC2	PC3	PC4
Cd	0.956					0.818								0.773
As	0.917													
Pb	0.559					0.698								
Cu		0.844				0.492								
Cr		0.72						0.457			0.775		0.724	
Co			0.848					0.744			0.75			
Ni			0.748					0.75			0.82			0.529
Fe		0.444					0.629							
Zn				0.74			0.521						0.885	
Mn				0.65	0.943		0.577					0.698	0.566	
Eigen Value	2.40	1.70	1.30	1.20	1.10	1.90	1.50	1.30	1.00		2.7	1.7	1.2	1.1
Variance (%)	24.00	17.00	13.00	12.00	11.00	19.1	14.8	13.3	10.3		26.7	16.6	11.6	11
Cumulative Variance (%)	24.00	41.00	54.00	65.00	76.00	19.10	34.00	47.40	57.70		26.7	43.3	55	67
Possible Sources	Coal combustion	Coal combustion	Vehicular emission	Resuspended dust and road dust	Crustal dust	Road dust	Crustal/resuspended road dust	Vehicular emission	Coal burning and vehicular emission		Coal combustion	Coal combustion and crustal	Resuspended road dust	Coal combustion

4.5. Enrichment factor

The EFs of the elements under consideration in the study area is depicted as logarithmic plot in Fig. 3. The elements in terms of its EFs were observed in three distinct groups such as, highly enriched, moderately enriched and slightly enriched. Zn and Cd with the EF values of 918 and 597 were found highly enriched, whereas, Pb (82), Cu (72) and AS (66) fell under moderately enriched category, illustrating its exclusive anthropogenic origin. The EFs of Ni (5), Co (3), Cr (3) and Mn (2) observed < 5 reveals its origin from both crustal and anthropogenic sources. The overall result suggests the predominance of anthropogenic sources like fossil fuel combustion, vehicular emission (exhaust as well as tyre wear and brake wear), coal combustion, mining activities, mine fire and road dust resuspension etc. in the study area contributing to atmospheric PM₁₀.

4.6. Health risk assessment

4.6.1. Non carcinogenic health risk of trace elements via inhalation exposure

Inhalation exposure is typically the primary route of direct exposure to particulate bound trace elements (US EPA, 1989). HQ of all PM₁₀ bound trace elements under consideration in for inhalation pathway for both adults and children according to the supplementary guidance for inhalation risk assessment (US EPA, 2009) for the respective groups of monitoring stations (mining, traffic routes and institutional area) is presented in Table 6. The HQ and HI values for Fe and Mn could not be calculated in this study as their threshold values (RfDo/RfCi) for different exposure routes are not established by US EPA and also is not reported in other studies. This is probably due to the fact that, these are the essential elements for humans and references doses of it may be higher as compared to elements concentration obtained (Izhar et al., 2016).

Table 7 represents that the HQ values for only Cr is higher than the safe limit (=1) in mining area for both adult (1.19) and children (1.19), indicating that Cr might pose non-carcinogenic risk to adults and children. The HQ for other elements were lower than the safe level (=1), indicating no non-carcinogenic health risk from the inhalation exposure of each single elements. The HI (sum of HQ of all the element under consideration) value intensified to 1.3 (higher than the safe level (=1)), indicating the accumulative non-carcinogenic health risk due to inhalation exposure of the mixture of elements. But in traffic routes and institutional area the HQ values for every elements under consideration as well as HI values were observed lower than the safe limit (=1) for both adult and children, indicating no non-carcinogenic effects from the

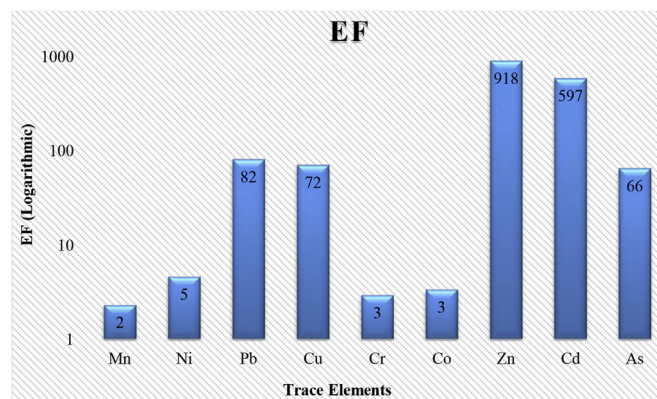


Fig. 3. Enrichment factor for trace elements in PM₁₀ computed with respect to the earth's crustal composition (ECC).

Table 6
Hazard Quotient and Hazard Index for inhalation exposure.

Elements	Mining area		Traffic routes		Institutional area	
	Adult	Children	Adult	Children	Adult	Children
Zn	2.12E–02	2.12E–02	1.75E–02	1.75E–02	1.90E–03	1.90E–03
Cu	5.36E–03	5.36E–03	1.05E–02	1.05E–02	1.06E–03	1.06E–03
Ni	6.81E–03	6.81E–03	8.13E–03	8.13E–03	8.72E–03	8.72E–03
Co	7.19E–04	7.19E–04	1.31E–03	1.31E–03	3.20E–04	3.20E–04
Cr	1.19E+00	1.19E+00	6.15E–01	6.15E–01	7.54E–01	7.54E–01
Pb	2.87E–02	2.87E–02	2.54E–02	2.54E–02	1.09E–02	1.09E–02
Cd	8.15E–03	8.15E–03	5.75E–03	5.75E–03	6.71E–03	6.71E–03
As	3.84E–02	3.84E–02	2.93E–02	2.93E–02	1.28E–02	1.28E–02
Health Index	1.30E+00	1.30E+00	7.13E–01	7.13E–01	7.97E–01	7.97E–01

Table 7
Hazard Quotient and Hazard Index for ingestion exposure.

Elements	Mining area		Traffic routes		Institutional area	
	Adult	Children	Adult	Children	Adult	Children
Zn	6.81E–01	1.59E+00	8.94E–01	2.09E+00	1.79E–01	4.19E–01
Cu	1.62E–01	3.79E–01	5.27E–01	1.23E+00	9.99E–02	2.33E–01
Ni	3.53E–02	8.23E–02	7.30E–02	1.70E–01	1.43E–01	3.34E–01
Co	4.53E–01	1.06E+00	1.34E+00	3.12E+00	7.01E–01	1.63E+00
Cr	3.62E–01	8.44E–01	2.95E–01	6.89E–01	7.05E–01	1.65E+00
Pb	8.89E–01	2.07E+00	1.33E+00	3.09E+00	1.04E+00	2.44E+00
Cd	2.57E–01	6.00E–01	3.01E–01	7.03E–01	6.53E–01	1.52E+00
As	1.28E+00	2.99E+00	1.49E+00	3.49E+00	1.20E+00	2.81E+00
Health Index	4.12E+00	9.61E+00	6.25E+00	1.46E+01	4.73E+00	1.10E+01

inhalation exposure.

4.6.2. Non carcinogenic health risk of trace elements via ingestion exposure

The exposure of atmospheric particulates via ingestion may be through the deposition on food, drinks and hand to mouth or object to mouth transfer of particles deposited on the surfaces of outdoor and indoor appliances (Hu et al., 2012). The exposure due to ingestion of soil and dust may be from the ingestion of indoor and outdoor dusts due to the atmospheric deposition and the mucociliary escalator mechanism (Hu et al., 2012). Therefore, the ingestion exposure to PM₁₀ was investigated as soil and dust exposure via ingestion. HQ of all PM₁₀ bound trace elements under consideration for ingestion pathway for both adults and children according to the Human Health Evaluation Manual (Part A) (US EPA, 1989) for the respective groups of monitoring stations (mining, traffic routes and institutional area) is presented in Table 7. It is evident that, the adverse non-carcinogenic impacts due to ingestion were higher for children than adults. This implies that children are more prone to adverse health impacts than adults. In mining area the HQ values were observed higher than the safe level (=1) for As (1.28) and lower than the safe limit for other elements, but the HI was observed higher (4.12) than the safe limit (=1), indicating the intensification of adverse health impacts by the exposure of mixture of elements for adults. In case of children, in mining area the adverse non-carcinogenic impact was observed for exposure to As, Pb, Co and Zn and no non-carcinogenic health impact was found for Cu, Ni, Cr and Cd, but the accumulative HI (9.61) was observed far greater than the safe level (=1). This illustrates the integrated effect of multi elemental exposure. In the traffic routes the ingestion associated non-carcinogenic risk was observed higher than the mining area. In traffic routes the HQ values for As, Co and Pb in case of adults and As, Co, Pb, Zn and Cu were observed higher than the safe limit (=1). HI values observed for both adult (6.25) and children (14.6) illustrates profound impact of ingestion of the particulate

bound elements in traffic routes. In institutional area the non-carcinogenic health risk was found due for As and Pb in case of adults and for As, Pb, Cr, Co and Cd in case of children. The HI values in the institutional area were also found higher than the safe level (=1) for both adult (4.73) and children (11).

4.6.3. Non carcinogenic health risk of trace elements via dermal exposure

HQ of trace elements under consideration for dermal contact pathway for both adults and children according to the Supplemental Guidance for Dermal Risk Assessment (Part E) (US EPA, 2004a) for the respective groups of monitoring stations (mining, traffic routes and institutional area) is presented in Table 8. From the results, it is evident that the dermal contact of elements exhibit the lowest HQ values than ingestion and inhalation exposure. The HQ values for dermal exposure in case of both adults and children in each of the three group of monitoring stations were observed lower than the safe limit (=1) except for Cd (children; HQ = 1.42). However, in case of children, the HI values were observed above the safe limit (=1) in each of the three group of monitoring stations (1.25 in mining area, 1.42 in traffic routes and 2.46 in institutional area). This indicates that, the integrated impacts of the multi-elemental exposure may cause non-carcinogenic health risk to children and the non-carcinogenic risk via dermal contact mainly resulted from Cd.

4.6.4. Carcinogenic health risk assessment

For the investigation of carcinogenic risks in PM₁₀ six trace element (As, Cr(VI), Cd, Co, Ni and Pb) were taken into consideration, because these are classified as carcinogenic/probably carcinogenic/possibly carcinogenic to humans by IARC (International Agency for Research on Cancer). Arsenic and inorganic arsenic compounds, nickel compounds, cadmium and cadmium compounds and chromium VI compounds are class 1, while, lead compounds (inorganic) are class 2A, and cobalt and cobalt

Table 8
Hazard quotient and hazard index for dermal exposure.

Elements	Mining area		Traffic routes		Institution area	
	Adult	Children	Adult	Children	Adult	Children
Zn	4.53E–03	7.41E–02	5.95E–03	9.74E–02	1.19E–03	1.95E–02
Cu	7.20E–04	1.18E–02	2.34E–03	3.83E–02	4.43E–04	7.25E–03
Ni	1.74E–04	2.84E–03	3.59E–04	5.89E–03	7.05E–04	1.15E–02
Co	6.02E–04	9.86E–03	1.78E–03	2.91E–02	9.32E–04	1.53E–02
Cr	2.41E–02	3.94E–01	1.96E–02	3.22E–01	4.69E–02	7.68E–01
Pb	7.88E–03	1.29E–01	1.18E–02	1.92E–01	9.25E–03	1.52E–01
Cd	3.42E–02	5.60E–01	4.01E–02	6.57E–01	8.68E–02	1.42E+00
As	4.16E–03	6.81E–02	4.85E–03	7.94E–02	3.91E–03	6.40E–02
Health Index	7.63E–02	1.25E+00	8.68E–02	1.42E+00	1.50E–01	2.46E+00

compounds are class 2B carcinogenic elements (IARC, 2013). Among the two forms of chromium persisting in the atmosphere Cr(III) and Cr(VI), only the latter has been reported to be carcinogenic. The concentration ratio of Cr(VI) to Cr(III) is about 1:6. Hence, for the estimation of carcinogenic health risk, the concentration of Cr(VI) was taken as 1/7 of the total concentration of PM₁₀ bound chromium (Massey et al., 2013; US EPA, 2004b). The information on the carcinogenic types and the IUR of the elements (As, Cr(VI), Cd, Co, Ni and Pb) was taken from the regional screening level tables provided by the US EPA (2016). The carcinogenic risk assessment only through inhalation pathway has been considered due to unavailability of reference values of carcinogenic risk through dermal exposure and ingestion pathway.

The estimated ECR of PM₁₀ bound carcinogenic elements for the annual average values of As, Cd, Cr, Co, Ni and Pb using Eq. (7) for the respective groups of monitoring stations (mining, traffic routes and institutional area) is presented in Table 9. The carcinogenic risk from Pb, Ni, As, Cd, Cr(VI) and Co in each of the three group of monitoring stations were higher than the acceptable limit (1×10^{-6}) for both adult (9.67×10^{-5} – 1.36×10^{-3}) and children (5.3×10^{-3} – 1.08×10^{-2}). The total cancer risk for adult and children was observed 2.97×10^{-3} and 2.91×10^{-2} in mining area, 2.78×10^{-3} and 2.91×10^{-2} in traffic routes and 3.79×10^{-3} and 6.74×10^{-2} in institutional area. The observed ECR values far exceeds the acceptable level that often leads to regulatory action in the developed countries; that is, 10^{-4} – 10^{-6} , indicating very high risk of cancer to the inhabitants (both adults and children) in the study area. An increased lung cancer mortality may happen in this community primarily because of exposure through inhalation of particulate bound trace elements. Similar result was reported by Zhang et al. (2008) in a typical mining town in South China.

5. Conclusions

This study presents the basic idea of particulate bound trace elements in institutional, traffic and mining areas of Dhanbad city.

The result showed high contamination of Zn (918) and Cd (597) whereas moderate contamination of Pb (82), Cu (72) and As (66). From the results, it is evident that, although there were differences in the concentration of trace elements at the three groups of monitoring stations (mining area, traffic routes and institutional area), the concentration of Zn and Fe as highest contributing trace elements were prevalent everywhere. While Fe is of crustal origin, Zn is contributed by anthropogenic activities in term of vehicular pollution. The major role of vehicular pollution was also supported by statistical analysis (PCA), as the elements extracted in principal components had major contribution by elements of vehicular origin (either exhaust or non-exhaust or both). The seasonal variation in PM₁₀ concentration was quite distinguishable with the highest concentration during the winter season, followed by summer and post-monsoon.

Health hazard assessment identified ingestion and inhalation as the leading route of particle bound trace element exposure to humans followed by dermal absorption. The multi elemental hazard index (HI) showed the intensification of health hazard when exposure to a mixture of elements were considered. The potential carcinogenic risk via inhalation route observed for each elements (Pb, Ni, As, Cd, Cr(VI) and Co) far exceeds the carcinogen acceptable level, indicating very high risk of cancer to the inhabitants (both adults and children) in the study area. This suggest that although these elements were found in low concentration and enrichment factor for some of the elements like Co and Cr were very low, yet they have high carcinogenic effects. This study also found that children are more prone to both non-carcinogenic and carcinogenic effects than adults in the study area. This shows requirement of abatement and control policies for the sources releasing these elements in the environment. Carcinogenic impacts through ingestion and dermal exposure should be of special concern. Further epidemiological studies should be conducted to understand these exposure routes and levels in detail.

It should also be mentioned here that, this is a preliminary study of health risk assessment based on the observed concentration of

Table 9
Excess Cancer Risks (ECR) of carcinogenic elements in PM₁₀.

Elements	IUR ($\mu\text{g}/\text{m}^3$) ⁻¹	Mining area			Traffic routes			Institutional area		
		Concentration ($\mu\text{g}/\text{m}^3$)	ECR		Concentration ($\mu\text{g}/\text{m}^3$)	ECR		Concentration ($\mu\text{g}/\text{m}^3$)	ECR	
			Adult	Children		Adult	Children		Adult	Children
Pb	0.000012	0.1055	1.90E–03	4.39E–03	0.0933	1.67E–03	4.40E–03	0.0400	1.70E–03	1.08E–02
Ni	0.00024	0.0250	4.78E–04	4.57E–03	0.0298	6.00E–04	4.56E–03	0.0320	1.36E–03	1.10E–02
As	0.0043	0.0120	2.26E–04	4.75E–03	0.0092	1.77E–04	4.77E–03	0.0040	1.71E–04	1.11E–02
Cd	0.0018	0.0085	1.67E–04	4.94E–03	0.0060	1.20E–04	4.88E–03	0.0070	3.20E–04	1.13E–02
Cr (VI)	0.012	0.0355	1.03E–04	5.12E–03	0.0183	5.76E–05	5.18E–03	0.0225	1.49E–04	1.15E–02
Co	0.009	0.0045	9.67E–05	5.30E–03	0.0082	1.57E–04	5.29E–03	0.0020	9.10E–05	1.17E–02
Total	–	–	2.97E–03	2.91E–02	–	2.78E–03	2.91E–02	–	3.79E–03	6.74E–02

various elements and various health risk assessment models using certain assumptions. Hence, the obtained health risks are only the estimation of probable impacts. We also assumed that all of the elements in the ambient particulates were biologically available, which is not possible in real scenario. A number of elements, exposure pathways, synergistic and antagonistic impacts of trace elements, and development of human tolerance were also not considered. However, despite of some uncertainties in the health risk estimation, this exposure assessment model is effective means for the assessment of human health risk due to the exposure to airborne trace elements in the atmosphere.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at <http://dx.doi.org/10.1016/j.apr.2016.12.003>.

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