Journal of Geochemical Exploration 176 (2017) 100–107

Contents lists available at ScienceDirect

Journal of Geochemical Exploration

journal homepage: www.elsevier.com/locate/gexplo

Multi element exposure risk from soil and dust in a coal industrial area

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ARTICLE INFO

Article history:
Received 28 April 2015
Revised 15 September 2015
Accepted 15 December 2015
Available online 18 December 2015

Keywords:
Mining
Coal
Dust
Potentially toxic elements
Exposure
Risk assessment

ABSTRACT

Coal mining and processing have profound environmental concerns, where large quantities of mine spoil and dust particles are generated. Potentially toxic elements dispersed in the dust and soils in coal mining ecosystem may have adverse health impacts to the nearby inhabitants. Dust and soil samples collected from Jharia coal mining area, India were analysed for As, Cd, Co, Cr, Cu Ni, Pb, V, and Zn. With respect to crustal abundance, As, Cd, and Pb were enriched in the soil, whereas Pb, and As were enriched in the dust. The geo-accumulation index (I_{geo}) was <0 for most of the elements, except for Zn (I_{geo} 1.07), and Pb (I_{geo} 0.9). Pollution load index was higher for soil (1.3) than dust (1.2), and both were categorized as moderately polluted. Exposure risk assessment showed that, ingestion is the main route of exposure to potentially toxic elements present in soil/dust followed by dermal exposure. Exposure risk was higher for child than adult. Though the hazard index (HI) was <1.0 for all the elements, the contents of Cr, As, Pb, and V were close to the permissible exposure limits. The carcinogenic risks associated with As, Cd, Co, Cr, and Ni were also less than the permissible limits.

1. Introduction

Globally, coal is one of the most abundant and important energy resource. It plays an imperative role in defining the economy of a nation. Coal is also used as a reducing material (in the form of coke) in iron and steel industries. It is relatively an inexpensive fuel that enables developing countries to strengthen their economies and improve the standard of living of their citizens. Coal mining involves excavation of the earthly bound coal by removing overburdens using mechanical devices. This process is associated with the release of large quantities of mine spoil and dust particles. Open cast coal mining is associated with large quantities of emissions (dust and gases) that are potentially hazardous to the local community (Masto et al., 2010). Metal pollution from coal is of concern because some of the elements have high enrichment factors. Bi is considered as highly enriched in coal with a factor of 10, whereas As, Cd, B, Sb, Mo, and Hg are less enriched (factor, 2–10) (Masto et al., 2007). Dusts from coal mines contain metal species and organic pollutants that settle down to the nearby soils and other structures. Soil is an important natural resource which supports plant growth and other human needs. But, the presence of pollutants can affect soil quality and impair its life sustaining capacity.

Coal mining is one of the significant causes of environmental pollution, as large quantities of coal dust particles are emitted (León-Mejía et al., 2011). Exposure to coal dust has been associated with different chronic diseases and mortality risk (Guerrero-Castilla and Olivero-Verbel, 2014). Exposure to high levels of heavy metals can result in acute and chronic toxicity, leading to the damage of central and peripheral nervous systems, blood composition, lungs, kidneys, liver, and even death. Local communities in coal mining areas are exposed to heavy metals in dust and soil through exposure routes like ingestion, inhalation, and dermal absorption (Li et al., 2014). In rural communities typical of coal mining areas, the level of exposure is usually higher for children than adults because of pica and other play behaviours.

Elemental composition in dust and soil samples can reflect the characteristics of short- and long-term activities in that area. It can also provide information about the levels of human exposure to heavy metals pollution from coal mining activities. However, systematic studies on heavy metals in dust and soil and their combined impact on human health especially in coal mining areas are very few. Caravanos et al. (2013) emphasized on the need of tools for rapid assessment of exposure risks in mining industries, especially for the Initial Site Screening (ISS), to quickly identify key site criteria including human exposure pathways, estimated populations at risk, sampling information, etc. Exact exposure assessment is important for risk estimation and regulation (Pesch et al., 2004).

In a small mining town (Gaungxi Zhuang Autonomous Region in southern China), Zhang et al. (2009), found that the heavy metals were associated with significant human health effects ranging from reduced intelligent quotients (IQs) in children (from Pb exposure) to

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http://dx.doi.org/10.1016/j.gexplo.2015.12.009
0375-6742/

cancer (Cd and As). In Colombia, León-Mejía et al. (2011) observed genotoxic effect in humans due to coal mining. Continuous input of some toxic metals from coal-mining operations to agricultural lands in the region of Cam Pha (Vietnam), enhanced absorption of metals by rice plant, which may lead to metal accumulation (especially Cd) in human organs (Martinez et al., 2013). Risk assessment studies near the Shuoli coal mine (China), showed that the contents of As, Cu, and Zn in wheat grains were much higher than the exposure limits. The hazard indices of aggregate risk through consumption of wheat grains were 2.3–2.4 for rural inhabitants and 1.4–1.5 for urban inhabitants (Shi et al., 2013). Cr, Mn, Pb, As and Sb exposure risks to children near a large coking plant (China) were 3 to 10 times higher than the acceptable levels (Cao et al., 2014). Arsenic exposure of residents of Changqing (Guizhou, China) was linked to coal burning (Shraim et al., 2003). A systematic review of data from 72 Chinese mining areas revealed that the soils surrounding the mining areas are seriously polluted by heavy metals emitted from mining activities and pose health risks to the public, especially to children (Li et al., 2014).

These direct health problems due to coal mining may be severe (leading to death), widespread (affecting many millions of people), and complex (requiring a multidisciplinary research approach) (Finkelman et al., 2002). Dust and soil are the complex heterogeneous media that may directly affect the health of the inhabitants due to the presence of heavy metals in them. Studies on the combined exposure risk from these two media are limited. Thus, this study was carried out in the Jharia coal mining area (India) to assess the potential human exposure risks due to heavy metals in the soil and dust.

2. Materials and methods

2.1. Site description

The study was conducted in Jharia, Dhanbad district, India. Jharia town located in the eastern part of Jharkhand state of India (Fig. 1), between latitudes 23°44′53″ N and 23°44′02″ N and longitudes 86° 25′13″ E and 86° 24′54″ E, with an average elevation of 202 m. Jharia is actively associated with coal mining activities for more than a century. There are many active opencast and underground mines, abandoned coal mines, natural coal fires, and overburden dumps. The site has congested roads for local commuters and for transportation of coals from the mines.

2.2. Sample collection and analysis

Settleable dust samples were collected from 20 different spots using wooden trays covered with stainless steel plates (60 × 40 cm, height 10 cm). All the sampling spots were located within 1 km from coal mining activity. Dust samples were collected for a 15 days interval during winter season of 2012. Dust particles were wiped off from the bottom of plates with a camel hair brush, and were collected in polyethylene containers. Soil samples were also collected from the places where dust samples were collected. The dust and soil samples were dried to constant weight in a hot air oven at 105 °C and sieved.

The methods described by Tandon (1993) and Baruah and Barthakur (1999) were used to determine the following soil properties: bulk density (BD) (soil core method), maximum water holding capacity (by equilibrating the soil with water), pH and EC in water (1:2.5, soil/water ratio), soil organic carbon (by potassium dichromate oxidation), loss on ignition, and soil N (alkaline permanganate method). Heavy metals from the soil and dusts were extracted using USEPA method 3051A (USEPA, 2007), in a microwave system (Milestone, Italy) and analysed through ICP-OES (ICAP 6300 Duo, Thermo Fisher Scientific, UK). Multi elemental standard solution (CertiPUR) (1000 mg/l) procured from Merck, Germany was used for the development of calibration curves. Yttrium was used as internal standard for consistency in sample measurement. NIST coal fly ash (NIST 2689) and loamy sand soil (CRM024-05, RTC, Laramie, WY) certified reference materials (CRM) were used for quality assurance. The percentage recovery of elements from CRM ranged from 93.8% for Ni to 118% for As. The blank reagent and standard reference material were analysed intermittently, to verify the accuracy and precision of the digestion procedure. After every tenth sample during analysis, the calibration standards were analysed to check the analytical accuracy. The analytical variations of these repeated standard samples were within 5%. All the samples were digested and analysed in triplicate and the coefficient of variations (CV) was within 7%.

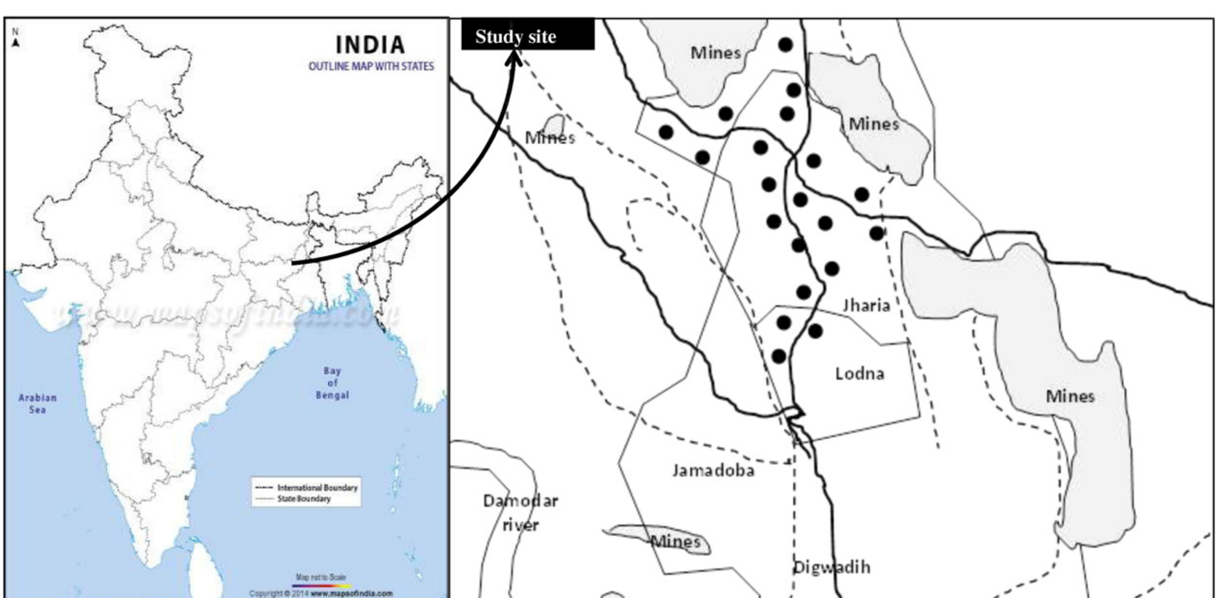

Fig 1. Location of the study area.

2.3. Pollution indices

The contamination factor (CF) was calculated to derive the degree of soil contamination and heavy metal accumulation with respect to the earth crust value (Kisku et al., 2000).

$$CF = \frac{Cm_{Sample}}{Cm_{Crust}} \quad (1)$$

where, Cm, concentration of metal 'm' in dust/soil and earth crust respectively. To assess the mutual contamination effects of the elements, pollution load index (PLI) was calculated (Tomlinson et al., 1980):

$$PLI = (CF_1 \times CF_2 \times CF_3 \times \ldots\ldots \quad CF_n)^{1/n} \quad (2)$$

where CF, contamination factor and n is the number of elements involved. PLI close to one indicates heavy metal load near background level, while PLI > 1 indicates soil pollution (Liu et al., 2005).

The geo-accumulation index (I_{geo}) was calculated using the following equation (Muller, 1969):

$$Igeo = Log_2\left(\frac{C_m}{1.5B_m}\right) \quad (3)$$

where C_m, is the concentration of element m in dust/soil, B_m is the geochemical background value (average content in earth crust) for element m (Taylor, 1964), and 1.5 is the background matrix correction factor due to lithogenic effects.

2.4. Exposure risk assessment

The mean value of the heavy metal contents in the dust and soil were used for exposure risk assessment. The potential exposure pathways identified were (1) incidental ingestion of dust/soil particles, (2) dermal absorption, and (3) inhalation of dust and soil particles. The exposure risk was calculated for 6 years old child and 30 years old adult (ICMR, 2009). The average daily dose (ADD) (mg/kg/day) of a pollutant through dust/soil ingestion, dermal contact and inhalation exposure pathways were estimated based on the equations given by the USEPA Exposure Hand book (USEPA, 2011).

$$ADD_{ingestion} = (C \times IngR \times EF \times ED)/(BW \times AT) \quad (4)$$

$$ADD_{dermal} = (C \times SA \times AF \times ABS \times EF \times ED)/(BW \times AT) \quad (5)$$

$$ADD_{inhalation} = (C \times InhR \times EF \times ED)/(PEF \times BW \times AT) \quad (6)$$

where C, concentration of the contaminant in soil/dust (mg/kg); IngR, ingestion rate of soil/dust [0.0001 and 0.0002 kg/day for adult and child respectively, USEPA (2011)]; EF, exposure frequency (365 days/year); ED, exposure duration [6 years for children and 24 years for adults (ICMR, 2009; Xu et al., 2015)], BW, body weight [20 kg for child and 60 kg for adult (ICMR, 2009; Khadilkar et al., 2007)]; AT, the time period over which the dose is averaged [365 × 6 days for child, and 365 × 24 days for adult (USEPA, 2011)]; SA, surface area of the skin that contacts the dust/soil (m^2); AF, skin adherence factor (kg/m^2); ABS, dermal absorption factor [0.001 for all elements (Ferreira-Baptista and De Miguel, 2005; Xu et al., 2015)]; InhR, inhalation rate [10.1 m^3/day for children; 16 m^3/day for adult USEPA (2011)]; PEF particle emission factor [1.36×10^9 m^3/kg (Xu et al., 2015)].

In the present study, the body weight of 20 kg for 6 years old child, and 60 kg for 30 years old adult was chosen to suit the Indian ideal situation (ICMR, 2009; Khadilkar et al., 2007). The corresponding body surface area for 20 kg child would be 1 m^2, and 60 kg adult would be 3.0 m^2 (Verbraecken et al., 2006). For Indian setting about 35% of the body surface is exposed (Harinarayan et al., 2013), and accordingly we used SA of 0.35 and 1.05 m^2 for child and adult, respectively. For a conservative estimate on dust adherence we considered a skin adherence factor of 0.0017 kg/m^2 for children (Holmes et al., 1999), and 0.001595 kg/m^2 for adult (Kissel et al., 1996).

The contribution of soil in dust varies from 8 to > 80%, depending on a wide variety of site-specific factors and methodological approaches (Bierkens et al., 2011). We used a 50% fraction of soil in dust (F_{soil}) while calculating the exposure risk (Cornelis and Swartjes, 2007). Thus the total average daily intake (TADD) was calculated as below.

$$TADD = ADD_{soil} + (1 - F_{soil}) \times ADD_{dust} \quad (7)$$

Potential exposure to trace elements was assessed in terms of daily intake calculated separately for each element and for each exposure pathway. Estimated daily intake dose for each receptor group on a per body weight basis was expressed as mg/kg/day. The intake thus calculated for each element of interest and exposure pathways were subsequently divided by the corresponding reference dose (RfD) to yield a hazard quotient (HQ).

$$HQ = TADD/RfD \quad (8)$$

The RfD values for each elements and exposure routes are presented in Table 1. Hazard index (HI) is equal to the sum of HQ (ingestion, inhalation and dermal absorption).

$$HI = \sum HQ_i \quad (9)$$

If the value of HI is < 1.0, it is believed that there is no significant risk of non-carcinogenic effects; if the value of HI > 1.0, there is a chance that non-carcinogenic effects may occur.

Exposure assessment of human to carcinogen (As, Cd, Co, Cr, Ni) through different exposure pathways was carried out by considering that adults and children are exposed to carcinogens on all the days in an year (Kumar et al., 2013). Incremental lifetime cancer risk (ILCR) was calculate from the respective TADD data as below.

$$ILCR = TADD \times CSF \quad (10)$$

where CSF is the carcinogenic slope factor (mg/kg/day) of individual elements.

3. Results and discussion

3.1. Basic soil characteristics

The data on soil properties like pH, EC, loss on ignition, soil organic carbon content, and nitrogen are presented in Table 2a. The soils are Entisol and are acidic with a mean soil pH of 5.8. Electrical conductivity varied from 0.325 to 1.14 dS/m. The soil carbon (1.26–2.86%) and loss on ignition (8.5–20.9%) was much higher than the normal agricultural and were black coloured may be due to the significant level of coal contamination (Masto et al., 2011; Masto et al., 2015). The correlation between the different trace elements and these basic soil properties showed that most of the elements were significantly ($P < 0.05$) associated with soil organic carbon and loss on ignition (Table 2b). This correlation supports that coal particles could be the source for these trace elements in the soil.

3.2. Heavy metal content and pollution indices

The content of the potentially toxic elements (Table 3) in dust samples was in the order: Zn > Cu > Cr > Pb > V > Ni > Co > As > Cd, whereas, for soil the sequence was different (Cr > Zn > V > Cu > Ni > Pb > Co > As > Cd) depicting the complex distribution of these elements in these two environmental media. In dust, the contamination factor (Table 3) was higher for Pb and Zn (>4.0) followed by As (2.16). CF was >7 for Cd in soil; As and

Table 1
Toxicity reference dose of elements used in the present study.

	Element	ABS_{GI}	$RfD_{ingestion}$	RfD_{dermal}	$RfD_{inhalation}$
1	As	0.95[a]	3.0E−04[c]	2.85E−04[f]	4.29E−06[g]
2	Cd	0.025[a]	1.0E−03[c]	2.50E−05[f]	5.71E−06[g]
3	Co	0.2[b]	3.0E−02[d]	6.00E−03[f]	2.86E−05[g]
4	Cr	0.013[a]	3.0E−03[b]	3.9E−05[f]	2.86E−05[g]
5	Cu	0.2[b]	4.0E−02[e]	8.00E−03[f]	6.86E−04[g]
6	Ni	0.04[a]	2.0E−02[c]	8.00E−04[f]	2.57E−05[g]
7	Pb	0.2[b]	3.5E−03[e]	7.00E−04[f]	3.52E−03[h]
8	V	0.026[a]	9.0E−03[c]	2.34E−04[f]	7.00E−03[h]
9	Zn	0.2[b]	3.0E−01[c]	6.00E−02[f]	1.00E−02[g]

a: USEPA (2004); b: default value (RAIS, 2013); c: IRIS (2015); d: Finley et al. (2012); e, h: Xu et al. (2015); f: calculated from $RfD_{ingestion}$ and ABS_{GI}; g: RSEI (2013).

Pb has CF > 2.0. Preferential enrichment of Zn and Pb in dust may be due to the contribution from traffic emission. Automobile tyres are considered as the prominent source for Zn (Apeagyei et al., 2011). Zinc is normally added as an additive during the vulcanizing process and the resulting tyre tread contains 0.4–4.3 Zn (Yang et al., 2011). Cadmium is a rare heavy metal that occurs naturally in combination with Zn. In a coal mining area of Jianping China, the Cd content in arable soils (7.1 mg/kg) showed significant enrichment up to 79 times of the reference soil (Liu et al., 2015). The high Cd in this region may be due to geogenic as well as, in part, by mining of Cd rich coals (Liu et al., 2013). Though lead-free petrol is used in vehicles in India, its existence is likely in urban environment due to the low solubility of pre-existing Pb that allows a long residence time in the soil and dust (Yuen et al., 2012). I_{geo} (Table 3) was <0 for all the elements except for Zn (1.07) and Pb (0.90). The relatively higher Igeo for Zn may be due to their contribution from traffic emission. The contribution of Zn from local coal is negligible due to its lower content in coal (13.8–25.0 mg/kg) (Rout et al., 2015). Dust generated from vehicle tyres could be the source for Zn, the wear and tear of tyres due to the poor roads and high traffic density might be the contributing factors. The pollution load index (Table 3) was higher for the soil (1.36) than the dust (1.21).

3.3. Risk assessment

To characterize the potential health risks, the total elemental intake from all exposure pathways were compared with the RfD. The mean elemental concentration was used for calculation of exposure risk. Estimated daily intake values for each receptor group on a per body weight basis are expressed as mg/kg/day. The intakes thus calculated for each element of interest through different exposure pathways were subsequently divided by the corresponding reference dose to yield a hazard quotient (HQ). Ingestion of soil/dust particles appears to be the route of exposure that results in higher risks for all the elements, followed by dermal contact (Table 4a, Fig. 2). Dust/soil ingestion through hand-to-mouth activity is an exposure pathway for humans, especially for children who may exhibit pica behaviour (Csavina et al., 2012). In an exposure assessment study of a mining district, it was observed that children who played with dirt had higher exposure relations for Pb, Sb, and Cu; and children who put hands or toys in their mouths had higher correlations of Cd (Barbieri et al., 2014). For another mining site of Congo, Cheyns et al. (2014) found that consumption of legumes, cereals, and fish were the largest contributors to Co intake in adults, whereas dust ingestion appeared to contribute substantially in children.

Table 2a
Basic soil properties of Jharia coal mining area.

Soil parameters	Mean	Maximum	Minimum	Standard deviation
pH	5.8	7.8	4.6	0.7
EC (dS/m)	0.596	1.14	0.325	0.19
BD (Mg/m^3)	1.24	1.37	1.11	0.08
WHC (%)	30.1	39.3	11.4	5.70
N (mg/kg)	17.0	28.3	6.3	2.5
SOC (%)	2.13	2.86	1.26	0.47
LOI (%)	15.1	20.9	8.5	4.00

Table 2b
Correlations between soil parameters and trace elements.

Elements	pH	EC	BD	WHC	N	SOC	LOI
As	−0.293	−0.742**	−0.492*	0.283	−0.132	0.540**	0.490*
Cd	−0.514*	−0.463*	−0.606**	0.346	−0.136	0.673**	0.679**
Co	−0.013	0.052	−0.433*	−0.095	−0.319	0.256	0.261
Cr	−0.059	−0.304	−0.190	0.363	−0.149	0.447*	0.361
Cu	−0.423*	−0.300	−0.555**	0.222	−0.274	0.557**	0.543**
Ni	−0.115	−0.122	−0.528**	0.314	−0.202	0.690**	0.699**
Pb	−0.335	−0.551**	−0.398	0.242	−0.084	0.430*	0.365
Zn	−0.329	−0.431*	−0.446*	0.147	−0.203	0.513*	0.507*
V	0.007	−0.031	−0.487*	0.199	−0.298	0.495*	0.446*

HQ due to inhalation of dust particles is much lower than the other two exposure pathways. It is unlikely that this exposure route would pose a higher risk than ingestion. Similar result was reported by Zheng et al. (2010), they inferred that heavy metal exposure risk through inhalation is almost negligible compared with the other routes of exposure. In another mining site while studying the exposure risk for Pb, Zheng et al. (2013) found that dermal exposure was negligible, diet and ingestion of soil and dust are the dominant parameters of exposure to children.

The exposure risk was higher for child than adult (Fig. 2). The higher ADD for child is due to their hand-to-mouth activity, the behaviour of mouthing non-food objects and repetitive hand/finger sucking during outdoor activities, through which dust can be readily ingested (Meza-Figueroa et al., 2007; Mielke et al., 1999). Similarly, children residing in the mining area of Taxco (South Mexico) were environmentally exposed to several metals and these children had levels of Ni, Ba, Mn, Cr, Co, Cd, As, Hg, and Pb above reference values (Moreno et al., 2010). The exposure profiles of individual elements are discussed below.

3.3.1. Arsenic exposure

Mean As content was comparable between soil and dust (3.89 vs 3.81 mg/kg) and was higher than the earth crust value with a contamination factor >2.0 (Table 3). The mean arsenic intake was higher for ingestion pathway which is about 10^2 and 10^4 times higher than dermal and inhalation exposure routes, respectively. The maximum intake recorded for child (5.75E-05 mg/kg/day) is less than the RfD, with an HI 0.192 (Table 4a, Fig. 2). This exposure risk is lesser than that reported for Baoji city of China (Wang et al., 2014), where the HI value for As was 0.73. Liao et al. (2012) studied As contamination on the surface of buildings and facilities at a coking plant and found that almost 20% of samples exceeded the As health risk limit. In a similar study, Ferreira-Baptista and De Miguel (2005) reported that the HQ for As was >0.1 indicating that this element was the most concern to the potential occurrence of health effects. Though many past studies concluded that

Table 3
Summary (n-20) of potentially toxic elements in soil and dust of Jharia coal mining area (SD, standard deviation; CF, contamination factor; I_{geo}, geoaccumulation index).

Elements	Dust (mg/kg)				Soil (mg/kg)			
	Mean	SD	CF	I_{geo}	Mean	SD	CF	I_{geo}
As	3.89	0.551	2.16	−2.33	3.81	0.460	2.11	−2.33
Cd	0.37	0.203	1.87	−0.26	1.43	0.222	7.15	−0.26
Co	17.2	2.43	0.69	−0.73	23.7	2.20	0.95	−0.73
Cr	63.7	11.8	0.64	−1.08	124	14.3	1.24	−1.08
Cu	65.3	12.8	1.19	−0.05	48.2	7.41	0.88	−0.05
Ni	32.1	7.56	0.43	−1.22	36.3	6.35	0.48	−1.22
Pb	55.9	16.9	4.47	0.90	27.0	4.19	2.16	0.90
V	43.1	8.74	0.32	−2.18	86.3	14.8	0.64	−2.18
Zn	299	52.1	4.28	1.07	110	9.20	1.58	1.07
Pollution load index		1.21				1.36		

Table 4a
Total average daily intake (TADD) of elements to children and adults through three exposure routes.

Element	Child (mg/kg/day)			Adult (mg/kg/day)		
	Ingestion	Dermal	Inhalation	Ingestion	Dermal	Inhalation
As	5.75E−05	1.71E−07	2.23E−09	9.77E−06	1.60E−07	1.18E−09
Cd	1.62E−05	4.81E−08	6.28E−10	2.75E−06	4.51E−08	3.32E−10
Co	3.23E−04	9.61E−07	1.25E−08	5.49E−05	9.01E−07	6.62E−09
Cr	1.56E−03	4.64E−06	6.05E−08	2.65E−04	4.35E−06	3.20E−08
Cu	8.08E−04	2.41E−06	3.14E−08	1.37E−04	2.26E−06	1.66E−08
Ni	5.23E−04	1.56E−06	2.03E−08	8.90E−05	1.46E−06	1.07E−08
Pb	5.49E−04	1.63E−06	2.13E−08	9.34E−05	1.53E−06	1.13E−08
V	1.08E−03	3.21E−06	4.19E−08	1.83E−04	3.01E−06	2.21E−08
Zn	2.60E−03	7.74E−06	1.01E−07	4.42E−04	7.26E−06	5.34E−08

the As concentration in mining areas is above the exposure thresholds (Kim et al., 2014; Taylor et al., 2014; Yáñez et al., 2003), in the present study, As concentration in the soil and dust samples is below the exposure risk level and potential health effects due to As is unlikely for the Jharia coal mining area. The level of cancer risk (Table 4b) associated with the exposure of As by ingestion of dust and soil particles (8.6E-05, child; 1.5E-05, adult) falls within the range of threshold values (10^{-4} to 10^{-6}) above which environmental interventions are needed (Ferreira-Baptista and De Miguel, 2005). The ILCR for other exposure routes (10^{-7} to 10^{-9}) were well within the prescribed limits.

3.3.2. Cadmium exposure

Mean Cd content was about 3.8 times higher in soil (1.43 mg/kg) than the dust (0.37 mg/kg), and the respective contamination factors were 7.15 and 2.16. Igeo was <0, indicating no pollution due to Cd (Table 3). The mean daily intake of Cd for children was in the order of 10^{-5} mg/kg/day (Table 4a), which is about 100 times lesser than the Rfd (10^{-3} mg/kg) (Fig. 2). The HQ for both the child and adult was <1.0. Cd exposure from indoor dust near a mining area was studied by Meyer et al. (1999). They found that in contaminated areas, the Cd transport into the home from external sources and their subsequent re-suspension were the causative factors in the exposure to Cd, whereas in unpolluted areas indoor sources played the major role. Soils near mining activities (Chenzhou City, Southern China) were enriched in Cd and possessed risk to the local residents (Zhai et al., 2008). Overall, in Jharia coal mining area the Cd exposure is well below the threshold limit. The cancer risk due to inhalation of Cd (10^{-9}) is much lower than the regulatory limits (10^{-4} to 10^{-6}) (Table 4b).

3.3.3. Cobalt exposure

The Co content of both the soil and dust was below the earth crust vale (25 mg/kg). Igeo was also <0 (Table 3). Regarding health risk, Co is mainly absorbed from the pulmonary and the gastrointestinal tracts. Absorption through the skin is low (Lauwerys and Lison, 1994). Thus ingestion and inhalation could be the potential exposure pathways. The maximum Co intake observed for child is 100 times lower than the acceptable Rfd (Tables 3, 4a), with HQ 0.02 and 0.01 for child and adult, respectively (Fig. 2). In a Co exposure study around a mining

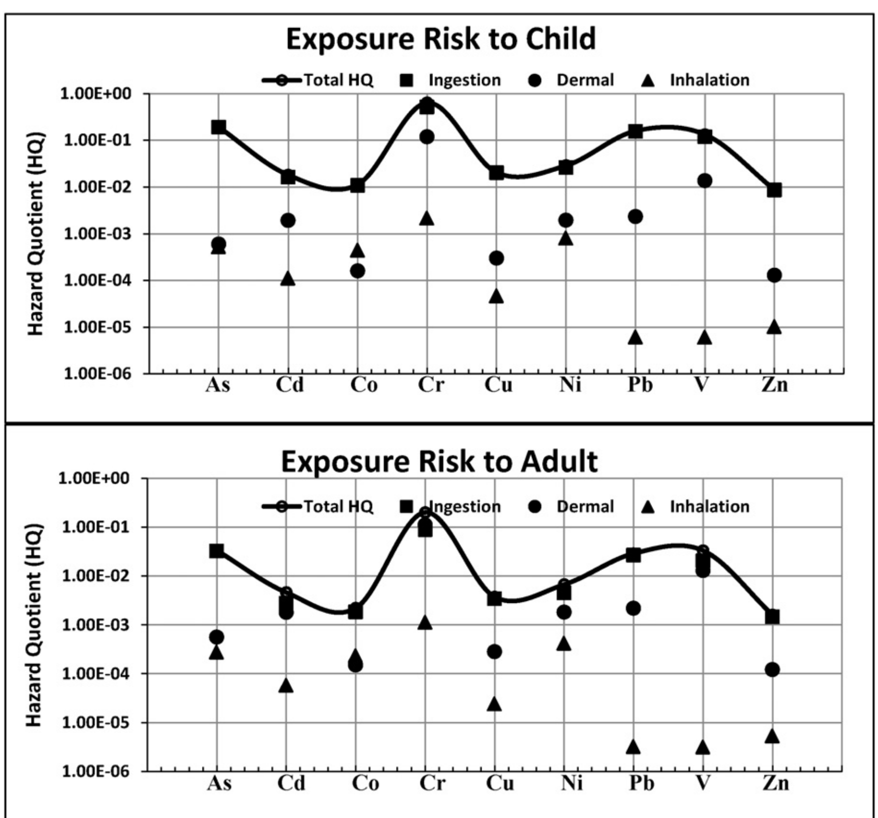

Fig. 2. Hazard quotients of potentially toxic elements.

Table 4b
Incremental life time cancer risk.

Element	Exposure route	TADD (mg/kg/day) Child	TADD (mg/kg/day) Adult	CSF(mg/kg/day)$^{-1}$	ILCR Child	ILCR Adult
As	Ingestion	5.8E−05	9.8E−06	1.5E+00	8.6E−05	1.5E−05
	Dermal	1.7E−07	1.6E−07	3.7E+00	6.3E−07	5.9E−07
	Inhalation	2.2E−09	1.2E−09	1.5E+01	3.3E−08	1.8E−08
Cd	Inhalation	6.3E−10	3.3E−10	6.3E+00	4.0E−09	2.1E−09
Co	Inhalation	1.3E−08	6.6E−09	9.8E+00	1.2E−07	6.5E−08
Cr	Inhalation	6.1E−08	3.2E−08	4.2E+00	2.5E−07	1.3E−07
Ni	Inhalation	2.0E−08	1.1E−08	8.4E+00	1.7E−07	9.0E−08

Likewise the cancer risk for Cd, Co, Cr, and Ni are well within the prescribed limits.

region in Congo, the estimated average total Co intake for adults was 570 (±42) μg/day (Cheyns et al., 2014). The exposure risk to Co for the general population in Jharia coal mining is unlikely. The cancer risk due to inhalation of Co (10^{-7} to 10^{-8}) is much lower than the regulatory limits (10^{-4} to 10^{-6}) (Table 4b).

3.3.4. Chromium exposure

Cr content was about 2 times higher in soil (124 mg/kg) than the dust (63.7 mg/kg). Contamination factor was >1.0 for soil, but the Igeo was <0 (Table 3). The daily intake (Table 4a) of Cr calculated for child (1.5×10^{-3} mg/kg/day) was half of the permissible limit of 3.0×10^{-3} mg/kg/day (HQ 0.52). In a similar study in Baoji city of NW China, Wang et al. (2014) reported higher HI value for Cr (5.71). Kurt-Karakus (2012) while studying the indoor house dust from Istanbul, Turkey, found that the carcinogenic risk level of Cr for adults and children (3.7×10^{-5} and 2.7×10^{-5}) was within the range of EPA's safe limits (1×10^{-6} and 1×10^{-4}). In the present study, a conservative estimate using the Rfd for Cr (VI) revealed that the Cr content in the Jharia coal mining area is within the human exposure limits. Generally, people who live in the vicinity of chromium waste disposal sites or chromium manufacturing and processing plants have a greater probability of elevated chromium exposure than the general population (ATSDR, 1998). Historically coal combustion has been one of the main sources of Cr, but its exact emission profile depends on the type of coal burnt (Charlesworth et al., 2011). The cancer risk due to inhalation of Cr (10^{-7}) is much lower than the regulatory limits (10^{-4} to 10^{-6}) (Table 4b).

3.3.5. Copper exposure

The Cu content in the soils and dust are below the exposure limits (Tables 3, 4a, Fig. 2). As such, there is no copper exposure risk in this coal mining site, copper exposure risks are generally significant around copper mining areas (Wilson and Pyatt, 2007). The content of Cu was slightly higher for dust (65.3 mg/kg) than soil (48.2 mg/kg). The Cu content in the air borne dust particle of Seoul, Korea was 100 times enriched than the earth crust content (Kim and Kazonich, 2004).

3.3.6. Nickel exposure

The adverse health effects of nickel depend on the route of exposure and the most common harmful health effect of nickel on humans is an allergic skin reaction particularly for them who are sensitive to nickel (Das et al., 2008). These data are comparable with the non-carcinogenic hazards index of Ni (1.62E−03) reported by Wang et al. (2014). Mean Ni content of soil (36 mg/kg) and dust (32 mg/kg) were almost the same, and non-polluted in view of PLI and Igeo (Table 3). Nickel compounds are considered as carcinogenic to humans and water-soluble nickel species has an important role in nickel-related cancer (Grimsrud et al., 2002). In our study, the maximum daily intake calculated for child is about 100 times lower than the RfD, indicating no risk (Fig. 2). Similarly, in the road dust of Shanghai, the Ni levels was below the exposure thresholds (Jing et al., 2009). The cancer risk due to inhalation of Ni (10^{-7} to 10^{-8}) is much lower than the regulatory limits (10^{-4} to 10^{-6}) (Table 4b).

3.3.7. Lead exposure

Pb content was almost double in dust (56 mg/kg) than the soil (27 mg/kg), and enriched by 2–4 times than the crustal abundance (Table 3). The I_{geo} was 0.90 indicating moderate pollution. The exposure risk assessment showed that the HQ value is approaching 1.0 (Fig. 2) thereby insisting on potential exposure risks, especially to children. In a similar study, Ferreira-Baptista and De Miguel (2005) reported HQ > 0.1, for Pb from street dusts of Luanda, Angola, indicating Pb as the element of most concern as regards to the potential occurrence of health effects. Wang et al. (2014) reported a HI value of 4.7 for Pb, which can trigger neurological and developmental disorders. Exposure risk assessment of Pb in dust from class rooms of a Malaysian School showed no adverse effect (HQ < 1.0) (Praveena et al., 2014).

3.3.8. Vanadium exposure

Vanadium content was significantly higher in the soil (86 mg/kg) than the dust (43 mg/kg). Igeo and CF showed that these dusts and soils are not polluted by vanadium (Table 3). Exposure risk (Fig. 2) was also less (HI < 1.0). Pollution indices showed that V is not enriched and supports the geogenic sources, similar results were reported for atmospheric particles of Dongying city, China (Kong et al., 2012). Global vanadium emissions into the atmosphere from coal combustion were estimated to range from 1730 to 3760 tonnes per year (WHO, 2000). In Hong Kong, the dietary exposure of V (0.13 μg/kg/day) was well below the health-based guidance values (Chen et al., 2014). However, in Yaoundé, Cameroon, the dietary V intake has exceeded the regulatory limits, consumption of fish was found to be the major source for V (Gimou et al., 2014).

3.3.9. Zinc exposure

Among all the elements studied, Zn content (Table 3) was much higher in both the soil (110 mg/kg) and dust (299 mg/kg) samples. Igeo was 1.07 which indicated moderate pollution. Zn was enriched in the road and soil dusts of Dongying city, China and the major sources for Zn was attributed to vehicle emission, industrial activities, coal combustion, agricultural activities and crustal materials (Kong et al., 2012). Though the estimated daily intake was higher for Zn, the exposure risk was <1.0. Zn being a micro nutrient, the Rfd (0.3 mg/kg/day) is comparatively higher than other elements.

For all the elements, the HQ value <1.00 indicates that the overall risks through all three exposure pathways are within safe level (Fig. 2). Singh (2011) concluded that in Jharia area, the calculated geo-accumulation index of all the measured elements (except Mn) lies below grade zero, suggesting no pollution threat with respect to these potentially toxic metals.

Overall, child has higher HI than adult, and accordingly the elements could be grouped as (i) HI(>0.1): Cr > As > Pb > V; (ii) HI (0.01 to 0.09): Ni > Cu > Cd; and (iii) HI (<0.01): Zn. HIs for Cr, As, Pb, and V are close to 1.0. Though the HI is <1.0, the potential health risk for children due to the exposure to the street dusts cannot be ruled out (Hu et al., 2011), especially for the cases of pica behaviour. Increased ingestion rate of dust and soil is quiet possible in mining environment. In a similar study on risk assessment from street dust, Ferreira-Baptista and De Miguel (2005) found that Pb and As exhibit HQ > 0.1 and concluded that these elements are of most concern for potential occurrence of health effects. Though the heavy metals in the dust and soils are within the exposure risk limits, suspended dust particle of this region is quiet high and above the permissible limits (Jain and Saxena, 2002; Mishra et al., 2013). Inhalation of direct dust may have many health implications.

4. Conclusion

Dust and soil samples of Jharia coal mining area, India were analysed for potentially toxic elements (As, Cd, Co, Cr, Cu Ni, Pb, V, and Zn). The contamination factor with reference to crustal content was higher for Pb, Zn (>4.0) and As (2.16) in dust; Cd (>7), and Pb, As (>2.0) in soil. All the elements, except Zn (I_{geo} 1.07) and Pb (I_{geo} 0.9) are in non-polluted category ($I_{geo} < 0$) based on geo-accumulation index. Pollution load index was higher for soil than dust. Chronic daily intake showed that ingestion is the main route of exposure to potentially toxic elements present in soil/dust followed by dermal exposure. Exposure risk expressed as HI was <1.0 for all the elements indicating that the levels of these elements in dusts and soil samples are within safe limits. The chronic daily intake was higher for child than adult. Based on child exposure data it was found that the contents of Cr, As, Pb, and V were higher with HI > 0.1, and were close to the permissible exposure limits. The carcinogenic risks associated with As, Cd, Co, Cr, and Ni were within the regulatory limits of 10^{-4} to 10^{-6}.

Acknowledgements

Authors express thanks to Director, Central Institute of Mining and Fuel research, Dhanbad, India, for providing support in publishing this study. The funding of this study provided through the Network Project NWP-0017 (11th Five Year Plan), Council of scientific and Industrial Research (CSIR), Ministry of Science and Technology, Government of India, is greatly acknowledged.

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