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Ecological and human health risks from pseudo-total and bio-accessible metals in street dusts

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Abstract Street dust samples were collected from industrial and commercial cities (Jamshedpur and Ranchi during monsoon and post-monsoon seasons) for detecting the levels of Cr, Cd, Cu, Ni, Pb, Zn, As, Co, Al, and Mn. The industrial city recorded higher metal concentrations compared to commercial. Similar trend of pseudo-total metal concentrations was observed in both the seasons at industrial city (Al > Mn > Zn > Cr > Pb > Cu > Ni > Cd) and only monsoon season at commercial city (Al > Mn > Zn > Cu > Cr > Pb > Ni > Cd). Zn > Cd was the most bioaccessible metal throughout the cities (monsoon and post-monsoon). The geochemical parameters (Igeo, EF, CF) were highest for Cd and lowest for Ni (both cities for the two seasons). Pollution Load Indices (PLI zone) were highest during the post-monsoon season in the industrial city. The highest carcinogenic risk was posed by Cr ranging from 1.87E-05 to 4.80E-05, in both the cities through ingestion and inhalation pathways. Children were found at higher risks, while the bioaccessible fractions posed neither carcinogenic nor non-carcinogenic threats to the population. Principal component analysis and correlation analysis indicated the influence of vehicular and industrial emissions, especially steel industry and coal-based thermal power plants as the major source of metals in street-dust. The outcomes of this work will be useful in providing baseline information of pollution along with their consequent environmental and human health risks of Jharkhand state.

Highlights
- Igeo, EF and CF followed the trend of Cd > Pb > Zn > Cr > Cu > Mn > Ni in industrial and commercial cities for monsoon and post-monsoon seasons.
- PLIzone was highest at industrial and lowest at commercial cities during post-monsoon season.
- Cd and Zn concentrations in street-dust surpassed WHO permissible limits for soil.
- The non-carcinogenic risks from total metals: HI > 1 through ingestion route in children at industrial city, and through inhalation route in children at commercial city.
- HI 1 for bio-accessible metals at both the cities.
- Carcinogenic risks from total metals: Cr > Cd > Ni. No carcinogenic risks were posed by bio-accessible portions.

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Introduction

Rapid urbanization has led to an increase of pollutants in the environment that brings a serious threat to both human and ecological systems. Metals are omnipresent and have both natural (weathering) and anthropogenic sources like emissions, combustion, and heating processes (Kumar & Bhattacharya, 2020, 2021; Lu et al., 2014a, b; Roy & Bhattacharya, 2020). Lead (Pb) majorly originates from leaded gasoline and paints while Zn, Cd, and Cu from incinerators, industries, tire wear off, and grease (Thornton, 2009). Further, their transformation to organometallic forms by methylation causes a severe threat to humans (Madrid et al., 2002). For instance, an overdose of Pb can damage the circulatory, skeletal or immune systems (Lu et al., 2014). Even, blood lead levels in childhood have been associated with cognitive function, IQ change, mental retardation, cardiovascular diseases and socioeconomic mobility through chronic exposures (Fewtrell & Pru, 2004; Mielke et al., 2017; Reuben et al., 2020). Cd overdose may lead to bone fractures, pulmonary lesions, and kidney dysfunction, and As may cause skin cancers or peripheral neuropathy (Zukowska & Biziuk, 2008). Hence, the quantification of metals in the dust is essential to understand the alterations in urban environmental quality caused due to anthropogenic activities (Kumar et al., 2020; Shaikh et al., 2021). The United States Environmental Protection Agency has listed Cd, Cr, Pb, As, Ni, Zn, and Cu as priority control pollutants, due to their persistent and toxic nature (Jin et al., 2019; Men et al., 2020).

Ingestion, inhalation, and dermal contact are the major pathways for human exposure (Acosta et al., 2014; Kumar et al., 2021a). Contaminated dust can be ingested directly by playing children, and grazing animals. Once ingested, they are mostly retained in the body and excreted in small proportions (Zhang et al., 2020). The accumulation of heavy metals in different tissues and organs (Zheng et al., 2010) leads to the development of many diseases (Faiz et al., 2009). Both the frequency and time duration of intake of these metals determine the severity of its health risks. Specially, children below 8 years are more vulnerable to the risks caused by metal exposure, due to their increased hand-to-mouth activity.

All forms of metallic contaminants are not available for topical absorption, inhalation, or ingestion (Pelfrêne et al., 2013). The availability of potentially toxic elements (PTEs) mainly depends on physicochemical processes like binding to dust reactive surfaces through sorption, complexation, and redox processes (Rodrigues et al., 2010). These processes are controlled by parameters like pH, organic matter, clay content, and amorphous metal oxides (Rodrigues et al., 2010). Bio accessibility test replicates the stomach pH which gives an idea about the release of metals in the stomach. This data can give an idea about the actual toxicity threat of metals in the human body.

To estimate the presence of metals in the human stomach, "in vitro" extractions were carried out in simulated gastric fluids (Madrid et al., 2008). It assumes that the solubility of a metallic contaminant also controls its availability in the human body (Pelfrêne et al., 2012). The bioaccessible fractions of metals are detrimental to the ecosystem (Gope et al., 2017, 2018a). The health risk from Pb, Cr, and Cu was elevated in street dust of Nanjing (Li et al., 2013) and Cd of Xiandao district (Huang et al., 2016) in China. The health risks from pseudo-total heavy metal concentrations of street dust have been studied at several places. Even at higher metal concentrations, if it is not bioaccessible, there might be lesser health risks. In contrast, if the bioaccessible fraction of metal is higher, it may pose significant risks even at lower metal concentrations. In this study, we have reported health risks from both pseudo-total metal and their bioaccessible fractions.

Although studies on metals, distributions, source identifications, and their subsequent risks (Atiemo et al., 2011; Nazzal et al., 2013; Tang et al., 2013) are abundant, similar studies in small rapidly developing cities are sparse (Lu et al. 2014). Jharkhand is a minerally enriched state, where Ranchi and Jamshedpur have high vehicular density and industries respectively (Roy et al., 2020). The total number of registered vehicles was 123,789 from 2017–2018 (buses = 249, light motor vehicles = 1412, goods carrier vehicle = 3459, two wheeler = 90,692, four wheeler = 21,741, miscellaneous = 6236) (Rajesh Kumar, 2019), while number of registered vehicles in Jamshedpur city is 573,329 (two-wheelers, 456,479; cars, 66,817; auto rickshaws, 22,806; commercial taxi/SUVs, 17,683, and truck, 9544) from period of 2003–2017 (Kumari & Kumar, 2019). Hence, it is highly expected that the street dust will be contaminated with heavy metals. In this part of the world, street-side food stalls are popular and there is always a risk of ingestion of metals through the deposited street dust on the food items. Moreover, the growing number of vehicles and consequently degrading air quality is a major concern, so inhalation of metals can also be a potential threat to public health (Kumar, et al., 2021b). Here, we have addressed the detrimental effects to both ecological and human health.

This study will give an idea about the current environmental status of heavy metals in street dust, and their consequent risks. The ecological risk from the pseudo-total metal concentrations and health risks (carcinogenic and non-carcinogenic risks) from pseudo-total and bioaccessible metal concentrations were calculated. Statistical analysis like ANOVA and principal component analysis were implemented for interpreting our results both season-wise and city-wise.

Materials and methods

Study area

Jharkhand is a minerally enriched state, characterized by dense forests and hilly topography. This study has been conducted in two of its cities: Jamshedpur (industrial) and Ranchi (commercial) considering Birla Institute of Technology, Mesra as control. Jamshedpur is located between 22° 40’–22° 58’ N and between 86° 03’–86° 23’ E. It has a tropical wet and dry climate, with temperatures varying from 35 to 49 °C in summers, to 5 °C in winters. It is considered as the industrial city, due to its oldest and major industries manufacturing iron, steel, truck, and cement (Tata Steel, Tata Iron, and Steel Company. Tata Motors, JUSCO), and small-medium scale industries producing tool, paint, and chemicals (K. A Industries, Krishna Industries, ASL industries, Golcha Chemical industries, Allied Chemical Industries) among others. Ranchi is located between 23° 22’ N, 85° 20’ E, having a humid subtropical climate, temperatures ranging from 20 to 42 °C in summers and to 25 °C in winters. It is considered a commercial city, due to its massive retail and wholesale markets trading food, garments, electronic items, offices, restaurants, and shopping malls. The control site is located away from the main city, in the premises of lush-green forests and agricultural fields. Figure 1 shows sampling points within these cities.

Sampling

Jamshedpur and Ranchi are well known for their high vehicular densities, industries, and commercial activities (Roy et al., 2020). Depending on the predominant anthropogenic activities of the cities, Jamshedpur will be referred to as industrial and Ranchi as a commercial city. Being a minerally enriched state, the chances of heavy metal pollution in Jharkhand are higher. From an annual average data from 2017 to 2019, the concentrations in industrial city were as follows: SO_2 (37.2 ± 1.2 μg/m^3), NO_2 (46.3 ± 1.0 μg/m^3), PM_{10} (132.5 ± 4.9 μg/m^3) and SO_2 (18.3 ± 0.6 μg/m^3), NO_2 (34.7 ± 0.6 μg/m^3), PM_{10} (124.3 ± 16.6 μg/m^3) in commercial city respectively (http://www.cpcbenvis.nic.in/air_quality_data.html). The corresponding 18 years average $PM_{2.5}$ values in the industrial and commercial city were 43.30 μg/m^3 and 40 μg/m^3 respectively (Pal et al., 2018). These values were higher than the prescribed limits (10 μg/m^3 annual mean) of WHO air quality guidelines (WHO, 1996).

The cities were broadly divided into five zones (North, South, East, West, and Central). A total of 48 (Industrial = 21, Commercial = 27) and 51 (Industrial = 24, Commercial = 27) samples were collected during monsoon and postmonsoon seasons respectively. Dust was collected using the brush and pan method from either side of the roads. Dry leaves, oil stains, cigarette buds, and extraneous materials were avoided. Between each sampling, thorough cleaning of the brush ensured no prior contamination (Banerjee, 2003). The samples were carefully labelled and stored in zip lock bags, with their GPS locations. The operating conditions were as follows: 2200 W power, optimum temperature of 20 ± 2 °C, flow rate of 1.5 ml/min, time delay of 15 s per element, and analysis time of 25–32 s/element. The nebulizer flow is maintained by He and N gas, plasma flow by He and auxiliary flow by compressed air.

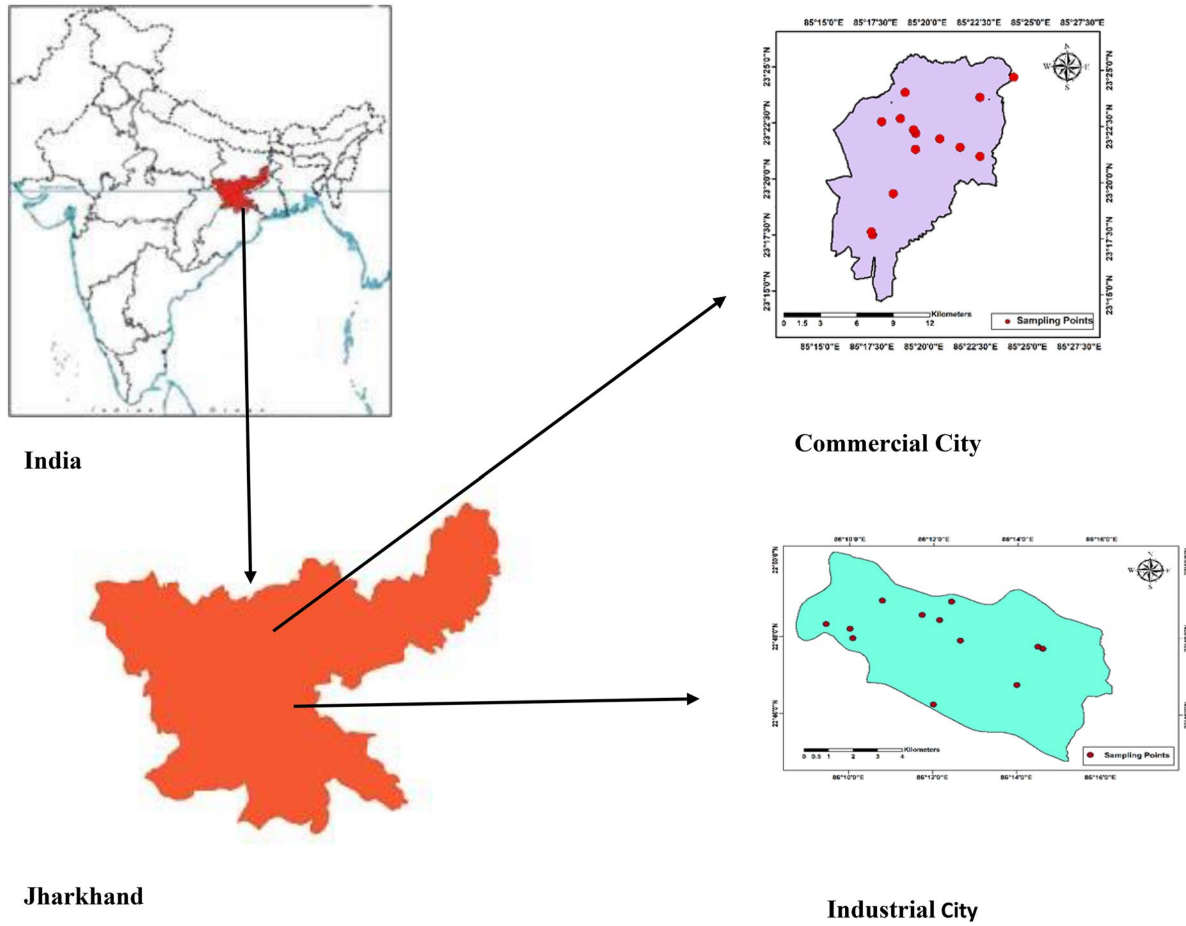

Fig. 1 Study area map

Experimental analysis

Heavy metal analysis in street dust

Pseudo-total metals in street dust samples were assessed by the 3050B USEPA method (Kingston et al., 1996). Oven-dried samples were sieved through 2-mm mesh size, from which 0.1 g was digested using 10 mL aqua—regia in Advanced Microwave Digestor (Milestone Connect ETHOS EASY) at 1800 MW, 220 °C, and 35 bar pressure. The final volume was made up to 50 mL using 1% HNO_3 and centrifuged. The supernatant was transferred to acid-resistant vessels, for further analysis. The heavy metal content of each sample was analysed using ICP-OES (Perkin Elmer, USA Optical 2100 V ICP-OES) (Kumar, et al., 2021a, b, c).

A. Ecological risk assessment

Ecological risk assessment evaluates the probability of detrimental effects on ecology, resulting from exposure to physical and chemical stressors. Here, we discuss various parameters, accountable for the adverse responses in the environment.

Geo-accumulation index

This index helps in assessing contamination levels, by comparing to its background concentrations (Antoniadis et al., 2017; Roy et al., 2020).

$$I_{geo} = Log_2\left(\frac{C_n}{1.5B_n}\right) \quad (1)$$

Geo-accumulation index was calculated using Eq. (1) where, Cn = element concentration in street dust, Bn = Geochemical background value. The effect of fluctuations in the background values attributed to lithologic variations is minimized by the constant 1.5, hence detecting even a small anthropogenic influence.

The background values were reported taking the average world concentration of elements in shale (Turekian & Wedepohl, 1961). Bn values for Cd, Cu, Ni, Zn, Cr, Fe, Mn, and Pb were as 0.3, 45, 68, 95, 90, 47,200, 850, and 20 respectively (Atiemo et al., 2012).

Contamination factor

The fraction of available metal concentration in street—dust to their background determines the contamination factor (Antoniadis et al., 2017; Roy et al., 2020). It is calculated as:

$$CF = \frac{C_n}{Bn} \quad (2)$$

where, Cn = Trace element concentration in street-dust, Bn = Geochemical background value.

These are categorised depending on their different ranges (Seshan et al., 2010), CF < 0 = None, CF (0 – 1) = None to medium, CF (1- 2) = Moderate CF (2—3) = Moderate to strong, CF (3—4) = Strongly polluted, CF (4—5) = Strong to very strong, CF (5—6) = Very strong. The Bn values are the same as used in geo-accumulation index.

Pollution Load Index

The magnitude of metal pollution from pseudo-total toxic metals in road dust was evaluated (Tomlinson et al., 1980). Concentration factors were used to evaluate single site Pollution Load Index (PLI) as per (Mohiuddin et al., 2010).

$$PLI\ for\ site = (CF1 * CF2 * CF3 * \ldots.. * CFn)^{\frac{1}{n}} \quad (3)$$

where CF1 = contamination factor of 1st metal and henceforth, n = number of metals.

$$PLI\ for\ zone = (PLIsite1 * PLIsite2 * PLIsite3 \ldots.. * PLIsite\ n)^{\frac{1}{n}} \quad (4)$$

where PLIsite = Pollution Load Index of site 1 and likewise, here n = number of sampling sites. PLI < 1 = absence of pollutants, PLI = 1 = presence of baseline pollutants, PLI > 1 = progressive deterioration of the site (Tomlinson et al., 1980). The number of sites varied slightly for industrial city ($n = 21$ for monsoon and $n = 24$ for postmonsoon), while for commercial city $n = 27$, in both seasons.

Ecological risks and risk indices

The ecological risks are categorised from low to very high, differing as per the following ranges:—ER < 40 = low, 40 ≤ ER < 80 = moderate, 80 ≤ ER < 160 = considerable, 160 ≤ ER < 320 = High, ER ≥ 320 = Very high (Gope et al., 2018a).

$$ER = TRF * (Ci/Co) \quad (5)$$

where, TRF = toxic response factor for a substance, accounting for the toxic and sensitivity requirement (Cd = 30, Pb = Cu = Ni = 5, Cr = 2, Zn = Mn = 1), Ci = concentration of heavy metal in street—dust, Co = background value of street—dust.

Further, the ecological risk index (ERI) is used to evaluate the extent of heavy metal pollution in street-dust as per its environmental response and toxicity (Gope et al., 2018b).

$$\mathrm{ERI} = \Sigma\ Er^i \quad (6)$$

where, ERI = total of risk factors for metals, i = monomial potential ecological risk factor.

B. Human health risk assessment

Human health risk assessment characterizes exposure to metals through street-foods via ingestion, finer air particulates, which reach the lungs via inhalation, and inevitable physical contact at public places in adults and through pica in toddlers via dermal pathways. This methodology was based on the Exposure Factors Handbook guidelines (EPA, 1989, 2001; US EPA, 1996). The following equations, given by (EPA, 1989; Ferreira-Baptista & De Miguel, 2005), were used for the exposure estimations.

Simple Bioaccessibility Extraction Test

Street-dust samples were extracted using 0.4 M glycine solution of, 1.5 ± 0.05 pH, to imitate the gastric juice action (USEPA, 2008). 0.5 g dust (passed through a 250-µm mesh) (Das et al., 2013; Ruby et al., 1996; USEPA, 2008) was weighed into a polypropylene tube to which 50 ml of 0.4 M glycine solution (1:100 w/v) was added. These tubes were incubated at 37 °C and shaken for an hour. Finally, 10 ml of solution was filtered by passing through a 0.45-µm pore size filter paper. Final analysis for metals was done by ICP-OES.

Non-carcinogenic risks

The non-carcinogenic risks are estimated by evaluating the hazard indices of each metal. HI > 1, denotes presence of non-carcinogenic risk, while HI < 1 represents its absence. Humans are exposed to the non-carcinogenic risks mainly from the three exposure routes: ingestion, inhalation and dermal contact as given below:

1) Ingestion

The average daily dose of exposure through ingestion is given as:

$$CDIing\left(\frac{mg\frac{dust}{kg}}{day}\right) = \frac{C * Ring * Fexp * Texp * 10^{-6}}{ABW * Tavg} \tag{7}$$

2) Inhalation

The average daily dose of exposure through inhalation is given as.

$$CDIinh\left(\frac{mg\frac{dust}{kg}}{day}\right) = \frac{C * Rinh * Fexp * Texp}{PEF * ABW * Tavg} \tag{8}$$

3) Dermal

The average daily dose of exposure through dermal contact is given as.

$$CDIdermal\left(\frac{\frac{mg\ dust}{kg}}{day}\right) = \frac{C * SAF * Askin * DAF * Fexp * Texp * 10^{-6}}{ABW * Tavg} \tag{9}$$

where, CDI = chronic daily intake (mg dust/kg/day), C (mg/kg) = metal concentration, Ring (mg dust/day) = 200 for child upto 6 years, 100 for adults, Fexp (day/year) = exposure frequency 365 days/year, Texp (years) = exposure duration:—24 for adults, 6 for child, ABW (kg) = average body weight, (average time) Tavg (years) = 365*Texp (Gope et al., 2017), Askin = skin area (2800 cm^2 = for child, 5700 cm^2 = adults), Rinh (inhalation rate) (m^3/day) = 20 for adults, 7.6 for child (Gope et al., 2017; Soltani et al., 2015), PEF (m^3/kg) is particle emission factor = 1.36*109 m^3/kg in both adult and child, (SAF) is skin adherence (mg $cm^{-2\ h-1}$) = 0.2 for child and 0.07 for adults,, DAF is dermal absorption factor = 0.001 for both child and adults.

Carcinogenic risk

where, i = different exposure routes i.e., ingestion, inhalation or dermal contact; CSF = carcinogenic slope factor for inhalation (Cd = 6.3, Cr = 42, Ni = 0.84 respectively) (Gope et al., 2018a). It is categorised as:—no significant health effects ($< 10^{-6}$), chance of carcinogenic health effect (10^{-6} – 10^{-4}) and unacceptable ($> 10^{-4}$) (Chen et al., 2015; Gope et al., 2018a, b).

$$CR = \Sigma\ CDIiX\ CSFi \tag{10}$$

Hazard quotient and hazard index

The hazard quotient determines the non-carcinogenic risks due to a particular metal (Chen et al., 2015) via ingestion, inhalation, and dermal contact. Although these do not have any potency to cause cancer, extended periods of exposure can prove detrimental health impacts.

$$\text{Hazzard quotient (HQ)} = \text{CDI/RfD} \tag{11}$$

where, CDI = chronic daily intake, RfD = reference dose.

While, hazard index evaluated the cumulative effect through ingestion, inhalation, or dermal contact

$$\text{Hazzard Index (HI)} = \Sigma \text{ HQ (ingestion/inhalation/dermal)} \quad (12)$$

where, CDIing/inh/dermal is the chronic daily intake rate through ingestion, inhalation, or dermal contact, respectively. Hazard index (HI) is the summation of HQs. HI > 1 indicates the occurrence of significant non-carcinogenic effects and HI < 1 refers to no significant risk (EPA, 2001).

Statistical analysis

The strength of relationships between the metals was determined by the Pearson correlation coefficient. ANOVA was run to check significant variations in metals. Principal component analysis (PCA) was done in SPSS 21, Chicago. Origin 9 Pro, U. S was used to plot the histograms and box—plots. Arc Map 10.1, U.S was used to prepare the study area map.

Quality control and quality assurance

Analytical grade reagents were used, from which internal standards of varying dilutions were made. ICP muti-element standard solution IV (Al) and XVI (Cr, Cd, Cu, Ni, Pb, Zn, AS, Co, Mn) (Make: MERCK, Germany) were used as standard solutions. The average values of triplicates are reported. A relative percentage difference below 20% was observed. With each batch, a NIST-certified soil reference material (GBW07411) of China was run to ensure quality control. 122.963%, 121.972%, 103.634%, 103.00%, and 100.912% metal recovery rates in the certified reference soil were reported for Zn, Cu, As, Pb, and Ni respectively, which confirmed accurate metal concentrations. A continuous check of variation (CCV) was run at an interval of 10 samples to check the instrument precision for ICP-OES. A metal standard of 30 ppb in 2% HNO_3 solution made the CCV of the sample. Further, each sample was diluted in 2% HNO_3 solution to minimize matrix effects. Metal detectable ranges were as follows: Cd (0.01–10 ppm), Cr (0.02–20 ppm), Cu (0.04–40 ppm), Fe (0.01–10 ppm), Mn (0.001–10 ppm), Ni (0.05–50 ppm) and Pb (0.01–100 ppm). Dilutions were performed for samples recording metal concentrations above the detectable range.

Results and discussion

A. Ecological risks

Pseudo-total metal concentrations

The present study revealed that concentrations of pseudo-total metals were higher for street dust of industrial city compared to commercial (Table 1). The concentrations for Cd, Zn (both the cities) and Cr, Ni (only in industrial city) surpassed the WHO (1996) permissible limits of soil during both the seasons (Ni = 35 mg/kg, Cu = 36 mg/kg, Pb = 85 mg/kg, Zn = 50 mg/kg, Cr = 100 mg/kg and Cd = 0.8 mg/kg) (Roy et al., 2020). Among all the metals, the street dust of both the cities recorded much higher than permissible limits for Cd and Zn, and higher for Ni. In recent times, several studies on heavy metal concentrations have been reported worldwide like Spain, Poland, China, Iran, Saudi Arabia and Bangladesh (Ghanavati et al., 2019; Valido et al., 2018; Moradi et al., 2020; Safiur Rahman et al., 2019; Trojanowska & Świetlik, 2020; Xiao et al., 2020). The metal concentration ranges in Jharia coalfield (Jharkhand) were Pb = 12.55–14.99 mg/kg, Cd = 2.29–3.49 mg/kg, Cr = 43.8–62.8 mg/kg, Cu = 9.15–19.85 mg/kg, Mn = 181.8–251.7 mg/kg, Zn = 18.5–29 mg/kg (Raj et al., 2017). Even groundwaters and PM10 from ambient air in Jharkhand are highly loaded with Cr, Cd, Pb, Cu, Zn, and Ni (Singh et al., 2018; Tirkey et al., 2016).

Among the studied cities, the highest values of Cd were observed in Dhaka for its extensive use in textile, glass, ceramic, battery, and pharmaceutical industries. Its values in (POM) industrial city were similar to that reported (Zhong et al., 2020) at Huangshi city of China. Pb values of the industrial city fell within the range as reported in Anand City (65.91–105.39 mg/kg), probably as an after–effect of the phasing out of leaded gasoline (Tanushree et al., 2011). In contrast, very high values of Pb and Zn were observed in Kolkata (Das et al., 2018), majorly due to its sampling from major roadway intersections with high traffic volume, attrition of tire, and its use as additives in lubricating oils. The average concentrations for Cr were higher in both seasons only at the industrial city (Table 1). Cr values in industrial city (MO) were comparable to those reported

Table 1 Pseudo-total metal concentrations in average ± SD (mg/kg) of street dusts in India and worldwide

Location	Author	Cr	Cd	Cu	Ni	Pb	Zn	As	Co	Al	Mn
Ind MO (n = 21)	Present study	175.31 ± 157.26	7.16 ± 4.27	71.45 ± 48.90	43.74 ± 15.56	78.36 ± 35.74	289.97 ± 237.32	BDL	n.d	9826.90 ± 2174.58	1138.79 ± 814.62
Ind POM (n = 24)		143.79 ± 37	9.76 ± 6.2	59.40 ± 53.4	36.79 ± 8.51	66.13 ± 29.59	245.81 ± 29.59	BDL	n.d	9983.45 ± 4674.25	1098 ± 333.2
Comm MO (n = 27)		65.68 ± 12.67	5.68 ± 4.60	67.40 ± 55.99	28.09 ± 9.56	53.24 ± 19.73	163.61 ± 50.07	BDL	n.d	6830.59 ± 1713.9	442.41 ± 137.20
Comm POM (n = 27)		53.87 ± 21.67	3.93 ± 3.04	BDL	22.74 ± 7.31	54.15 ± 39.60	170.28 ± 54.89	BDL	n.d	9190.00 ± 4193.65	479.52 ± 124.29
Barcelona, Spain	Valido et al., 2018	19	0.97	26	9.3	62	166	12	3.7	75,571	887
Radom, Poland	Trojanowska et al., 2020	53.5	–	239	50	88	618	–	–	–	565
(Anshan), Liaoning, NE China	Xiao et al., 2020	150.36	1.17	57.41	29.59	63.01	325.26	–	–	–	1170
Tianjin	Živančev et al., 2019	47.6	0.6	62.7	18.4	28.4	–	19.3	6.83	–	–
Kashan, Iran	Moradi et al., 2020	37.12	0.43	45.58	13.62	45.18	237.21	–	–	–	–
58 cities in China	Zhaoyong et al., 2019	278.76	3.09	139.69	43.47	146.92	792.32	43.97	18.8	–	828.9
Huangshi City, Central China	Zhong et al., 2020	–	9.54	1628.54	–	401.52	593.16	–	–	–	–
Khames-Mushait, Saudi Arabia	Idris et al., 2020	186.49	1.16	49.37	–	126.43	117.98	–	34.17	–	802.58
Dhaka (Bangladesh)	Safiurrahman et al., 2019	144.3	11.6	49.8	37.1	18.9	239.1	8.1	–	–	261.5
Jinhua	Bartholomew et al., 2020	105.25	4.9	133.72	76.32	110.6	133.72	8.69	–	–	451
Nicosia, Cyprus	Musa et al., 2019	321.14	–	51.86	64.79	35.62	136.13	17.48	–	–	–
Abadan, Iran	Ghanavati et al., 2019	50	0.52	113	57	59	288	7.1	8		
Punjab, Pakistan	Mohmand et al., 2015	–	1.3	28.6	–	140	152	–	–	–	–
Guwahati	Deka et al., 2012	–	–	–	–	43.03	4.23	–	–	–	171.78
Kathmandu, Nepal	Raj et al., 2014	–	1.34	62.3	–	44.5	99	–	–	–	–
Asansol	Gope et al., 2017	–	0.75	132	–	110	192	–	–	–	–
Kolkata	Das et al., 2018	43.25	–	60.72	–	383.42	303.23	95.64	12.56		392.87
Jharia	Rhout et al., 2013	75.4	0.78	56.8	66	67.8	163	4.08	16.9	–	658
Dhanbad and Bokaro	Singh et al., 2011	73—146	–	39	–	100	130	–	15	–	–
Delhi	Rajaram et al., 2014	170.8	–	168.7	–	128.7	–	–	23.3	–	–

Table 1 (continued)

Location	Author	Cr	Cd	Cu	Ni	Pb	Zn	As	Co	Al	Mn
Faridabad	Pathak et al., 2013	996	1.2	178.6	–	56.6	–	–	13.5	–	–
Tamil Nadu	Sujatha et al., 2017	17.85	0.41	20.68	1.93	2.97	93.8	–	–	–	–
Gujarat, Anand City	Tanushree et al., 2011	–	–	51.60–130.00	–	65.90- 105.00	43.60- 92.80	–	–	–	–
Bhopal (India)	Ambade et al., 2012	121.5	–	126.4	45.3	534.6	813.2	18.4	–	–	708.5

Ind industrial city, *Comm* commercial city, *MO* monsoon season, *POM* post-monsoon season, *BDL* below detection limit

in Delhi (Rajaram et al., 2014). The highest values were observed at Nicosia, Cyprus (321.14 mg/kg), followed by China (Zhaoyong et al., 2019) and Saudi Arabia (Idris et al., 2020). The control site had the lowest metal concentrations due to its serene unpolluted environment, even during post-monsoon season (Cd = 5.5 mg/kg, Cr = 31 mg/kg, Mn = 265.5 mg/kg, Ni = 8 mg/kg, Pb = below detection limit, Zn = 30 mg/kg). Their corresponding levels in monsoon were as follows: Cd = 0.6 mg/kg, Cr = Ni = Pb = BDL, Mn = 22.9 mg/kg, Zn = 4.2 mg/kg. On comparing our results using ANOVA for pseudo-total metals, significant differences were found both site-wise (Ind: F = 0.006, Fcrit = 4.41; Comm: F = 0.02. Fcrit = 4.49) and season-wise (MO: F = 0.31, Fcrit = 4.41; POM: F = 0.24, Fcrit = 4.49).

A very good correlation existed between Fe-Cu (0.712) and Pb–Zn (0.785) during the monsoon at the industrial city (S1). Fe is used in steel and motor industries (TATA Steel, TATA Motors), while Cu in electrical equipment such as wiring and motors (Synergy Power Equipment Pvt. Ltd., Havells Galaxy Store, M. G. Agencies). Pb is usually found in ore with Zn and hence is extracted together. Both Pb and Zn are used in the paint (TATA Pigment Ltd.), cosmetic batteries (Jamshedpur batteries, Shyam Electrical), textiles (Mittal, Kishor, Harnathka), ammunition (A.t Daw & Co, Premier Arms Corporation, United Enterprises), and electrical equipment at an industrial city; hence, they are having the strongest correlation. Similar correlation values were found between Pb–Zn (0.655) even in the post-monsoon season. The correlations between metals at the commercial city were not very strong except that of Mn-Ni (0.77) postmonsoon season (S2). Both ores of manganese and nickel are naturally found in the ores of Singhbhum district, which is bounded in the north by Ranchi. This may be the reason for the strong correlation existing between these metals in the commercial city as well.

Geo-accumulation index

In this study, Cd showed the strongest contamination in both cities for monsoon and post-monsoon seasons ranging from 2.61 to 3.93, followed by moderate contamination of Pb (range = 0.78–1.34), Table 2. Similar values of Cd were recorded in China (Bartholomew et al., 2019; Zhaoyong et al., 2019) which could be due to the prominent electronic, textile, automobile, and

Table 2 Geochemical and pollution indices of two seasons in study sites

Site and season	Igeo						
	Cd	**Cr**	**Cu**	**Mn**	**Ni**	**Pb**	**Zn**
Ind MO (n = 21)	3.64 ± 1.18	0.48 ± 0.70	BDL	0.49 ± 9.64	BDL	1.34 ± 0.51	0.85 ± 0.69
Ind POM (n = 24)	3.93 ± 1.50	0.04 ± 0.21	0.80 ± 1.11	0.25 ± 0.11	BDL	0.93 ± 0.48	0.68 ± 0.39
Comm MO (n = 27)	3.32 ± 1.47	BDL	0.63 ± 0.57	BDL	BDL	0.92 ± 0.39	0.41 ± 0.29
Comm POM (n = 27)	2.61 ± 1.37	BDL	BDL	BDL	BDL	0.79 ± 0.68	0.49 ± 0.26
	Contamination factor						
Ind MO (n = 21)	23.89 ± 14.25	1.95 ± 1.27	1.59 ± 1.08	1.34 ± 0.23	0.64 ± 0.23	3.92 ± 1.78	3.05 ± 2.49
Ind POM (n = 24)	32.54 ± 20.67	1.59 ± 0.41	1.32 ± 1.18	1.29 ± 0.39	0.54 ± 0.13	3.31 ± 1.48	2.59 ± 0.97
Comm MO (n = 27)	18.94 ± 15.56	0.73 ± 0.14	1.50 ± 1.24	0.52 ± 0.16	0.41 ± 0.14	2.66 ± 0.98	1.72 ± 0.52
Comm POM (n = 27)	13.10 ± 10.16	0.60 ± 0.24	BDL	0.56 ± 0.14	0.33 ± 0.10	2.70 ± 1.98	1.79 ± 0.57
	PLIsite		**PLIzone**				
Ind MO (n = 21)	0.73 – 6.35 (mean = 2.17)		1.99				
Ind POM (n = 24)	0.75 – 2.84 (mean = 2.10)		2.01				
Comm MO (n = 27)	0.58 – 1.81 (mean = 1.20)		1.15				
Comm POM (n = 27)	0.55 – 2.05 (mean = 1.09)		1.04				

Ind industrial city, *Comm* commercial city, *MO* monsoon season, *POM* post-monsoon season, *BDL* below detection limit

food processing industries of China. Other metals like Cr, Cu, Fe, Mn, Ni, and Zn fell into the category of uncontaminated to moderately contaminated. In recent literature, according to the geo-accumulation index (Igeo) values, Nanjing recorded extreme contamination from Pb (10.9) followed by Cd (4.37 = strongly to extreme contamination), Zn (3.78 = strongly contaminated), and Ni (2.66 = moderately to strongly contaminated) (Wang et al., 2001a, b) which originated from anthropogenic sources. Among Indian cities, Kolkata had a significantly high Igeo of As (3.6), which fell under the category of strongly contaminated. Such high values for As may be due to the influence of parent bedrock, having higher proportions of As. In Durgapur (Gope et al., 2018b) sampling was done for three seasons: summer, monsoon, and winter. During summers, heavy contamination was found in industrial cities (Igeo = 4.35), while in monsoon, the values felt under the category of uncontaminated to moderately contaminated. Maximum contamination of Cr, Mn, and Cd was found in winters due to the stable atmospheric conditions and coal combustion activities in thermal power – plants.

Contamination factor

This index is used extensively in monitoring heavy metal contamination, by comparing the concentrations of individual metal to their respective background levels. As it is metal-specific, we can identify the major metals of concern contributing to pollution. The contamination factor (CF) values followed the trend Cd (23.89 – 32.54) > Pb (3.31– 3.92) > Zn (2.59 – 3.05) > Cr (1.59 – 1.95) > Cu (1.32 – 1.59) > Mn (1.29 – 1.34) > Ni (0.54– 0.64) at industrial city in both the seasons. A similar trend was seen in the commercial city too, except for Cu in the postmonsoon season, which was found below the detection limit (Table 2). Another industrial city, Durgapur (Gope et al., 2018a, b), followed a similar trend as Cd (21.1) > Pb (5.28) > Cr (3.75) > Zn (3.67) > Mn (3.34) > Cu (2.77). In both industrial cities (Jamshedpur and Durgapur), coal combustion and thermal powerplant might have played a key role in higher Cd values (Verma et al., 2015).

Comparatively lower values were found at Asansol (Cd = 3.76, Zn = 2.74, Cu = 2.40) barring Pb (8.79) (Gope et al., 2017). Here, Pb is a priority pollutant, which can be traced to sources from exterior wall paints, gasoline, tire bearings weathering, gasoline, lubricant, and its anti-wear agent, graphics, and printing waste (Okorie et al., 2012).

Other countries like Poland and China had low contamination factor values (CF = 2) for both Cd and Cr, but they were higher for Cu (China = 6.65, Poland = 34) and Ni (China = 2.52, Poland = 4.9) respectively

(Trojanowska & Świetlik, 2020). Although the trends were similar, the industrial city had comparatively higher values 23.88 (MO) and 32.54 (POM) than the commercial city 18.93 (MO), 13.10 (POM) Table 2.

Pollution load index

This index denotes the severity of pollution and its variation along with the cities. It represents the magnification of the metals relative to their background. It is symptomatic of the overall heavy metal toxicity level in a particular sample. Among the recently reported studies, Greece had the highest PLI (4.05) (Bourliva et al., 2018), followed by Asansol = 3.80 (Gope et al., 2017), Liaoning = 3.08 (Xiao et al., 2020), and Nanjing = 3.08 (Wang et al., 2016). This parameter was calculated for both cities in two seasons – monsoon, postmonsoon. Zone-wise the industrial city recorded higher PLI compared to commercial in both monsoon (1.99 > 1.16) and postmonsoon (2.01 > 1.40). Single-factor ANOVA indicated that there were no significant seasonal variations in the metal concentration of street dust in both industrial (F = 0.09, Fcrit = 4.06) and commercial cities (F = 1.21, Fcrit = 4.03), at a significance of 0.05 level (S3). While a significant city-wise variation in both monsoon (F = 17.54, Fcrit = 4.06) and post-monsoon seasons (F = 12.77, Fcrit = 4.04), at 0.05 significance level. The highest PLI (1.81, monsoon) was recorded for road dust samples of a major commercial hub (main road to Kutcchery) during monsoon and office areas (MECON Limited, Doranda, PLI = 1.73) during postmonsoon in the commercial city as shown in Table 2.

During monsoon season, the highest values were recorded for Adityapur (PLIsite = 6.35), while the lowest was at (PLIsite = 0.73) in the Green Enclave of Kadma (residential area). Such high values may be attributed to the several small and medium scale industries located in Adityapur, which is one of the biggest industrial belts in India. Few of these are involved in the huge production of vehicle parts for TATA Motors, metal fabricator, and paint manufacturer. On the other hand, Green Enclave locality is situated in the outer circular road, slightly away from the main town, facing the Kharkai river. As it is away from the major traffic roadways, this place is comparatively cleaner offering a serene environment. All other sites recorded PLIsite > 1, which indicated the presence of pollution. While in POM, the highest PLI was recorded in Nildih-Dalma road (Burma mines, highway) PLIsite = 3.31. The region of Burma mines houses air separation plants like Linde India (produces gases like liquefied oxygen, nitrogen, argon), TRF Limited involved in the business of automotive applications (manufactures equipment used in infrastructure industry), Jamshedpur Injection Powder Limited (produces and markets de – sulphurising products for steel industry) and Tata Tube Division manufacturing precision and commercial steel tubes.

Also, as it is a major highway road connecting Jamshedpur to West Bengal, the influence of vehicular pollution is immense. The general trend of PLI was Cd > Pb > Zn > Cr > Cu > Ni. While Fe < Mn in the industrial city and vice-versa at the commercial city.

Ecological risks and risk indices

High metal content can cause adverse effects in the environment and the organisms related to it. Hence, the coining of two parameters:—ecological risk (ER) and ecological risk index (ERI). Ecological risk is metal-specific, which gives an idea of the threats incurred from individual metals, while the ecological risk index is city-specific, denoting the additive dangers from all the metals together. Cadmium (Cd) recorded the highest ecological risk at the industrial city (976) and lowest in the commercial city during the post-monsoon season (393.18). Our ER values were similar to those observed in Greece (ER = 238.7–816, (Bourliva et al., 2018). ER of other metals, Cr, Cu, Mn, Ni, Pb, and Zn, were comparable falling in the range of 0.52–7.93. An overall trend of Cd > Pb > Cu > Cr > Ni > Zn > Mn was followed in Greece (Thessaloniki city) (Bourliva et al., 2018), Iran (Abadan) (Ghanavati et al., 2019) and China (Liaoning, Beijing, Tianjin) (Xiao et al., 2020). A very distinct trend was observed at Ahvaz city of Iran:—Pb > Cu > As > Cd > Zn > Cr (Ghanavati et al., 2019).

On comparing the ERI for both seasons in the two cities, the industrial city recorded higher ERI than the commercial one (Fig. 2). The ERI values had a larger range in the commercial city (339.13–489.15). Post-monsoon values (964.47) were higher than monsoon (755.69) values at an industrial city in contrast to the commercial city (POM = 339.13. MO = 489.50). The

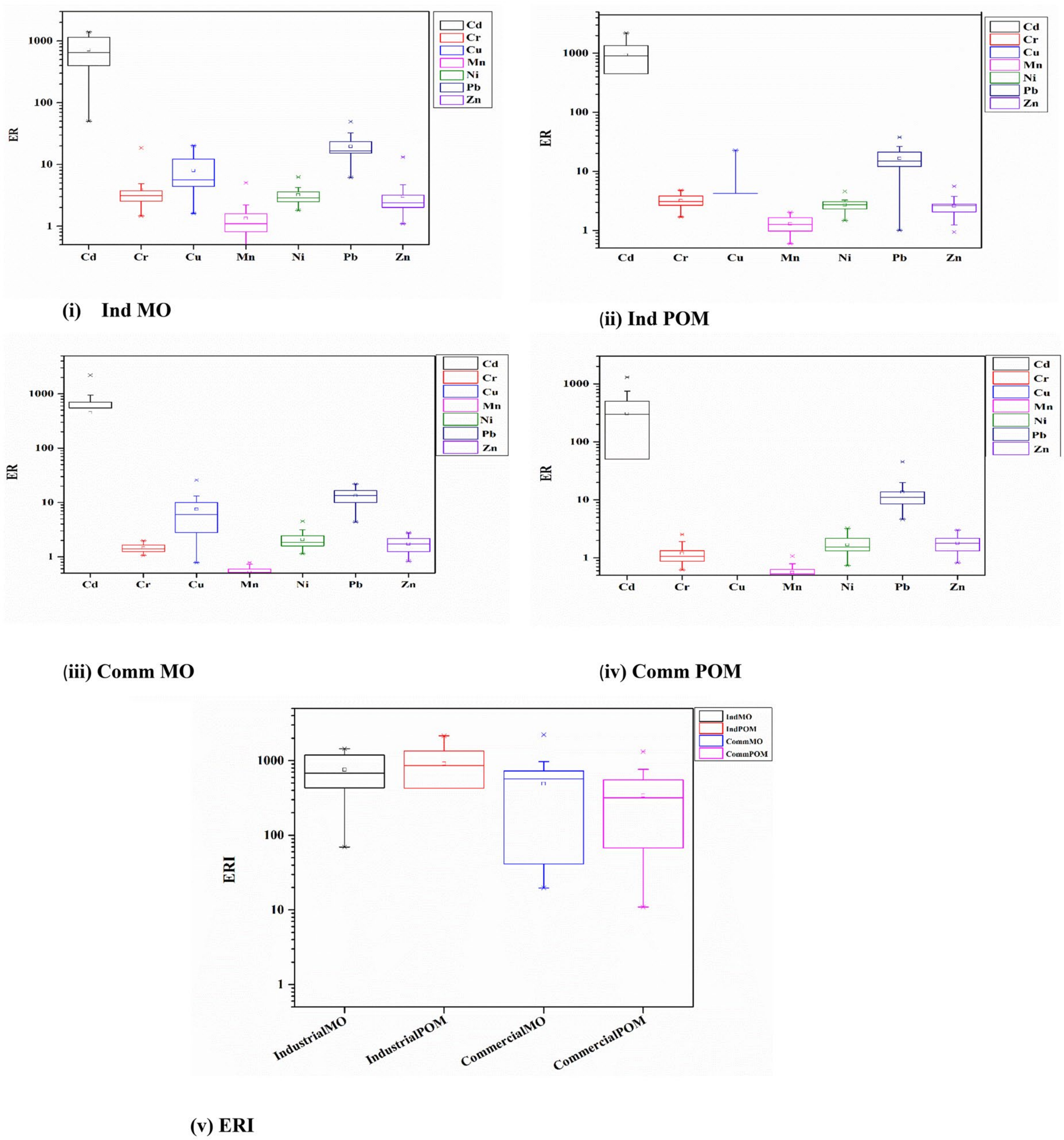

Fig. 2 Ecological risks (ER) and ecological risk indices (ERI) of two cities for two seasons. Ind industrial city, Comm commercial city, MO monsoon season, POM post-monsoon season. (i) Ind MO. (ii) Ind POM. (iii) Comm MO. (iv) Comm POM

lower ERI values during the postmonsoon season in the commercial city might have been attributed to the rainfall occurring during this season. Comparable values were observed in Tianjin, Iran (Keshavarzi et al., 2015) which had similar triggers of air pollution like automobile exhaust, factory chemicals, primitive heating forms, rapid urbanization, and population growth.

Principal component analysis

Principal component analysis (PCA) was done to find the origin of heavy metals in the street dust. Pseudo-total metal concentrations were used for PCA calculations. Varimax rotation along with Kaiser Normalization was done to reduce the redundancy of the data. Components with Eigenvalues close to one or more were considered (Gope et al., 2018b). Closely associated variables are grouped in different components, where each component is indicative of a single source and its associated metals. In the industrial city, during monsoon season, PCA showed that 82.059% of the information in the data were in the first three components (56.19% in component 1, 15.12% in component 2, and 10.73% in component 3) (S4). In the first component, Pb, Zn, Cr, and Mn loadings were strong and Ni loading was moderate (Fig. 3), whereas in component 2, Cu and Cd loadings were strong. This indicates that in monsoon season, most probably due to wet deposition and surface runoff, the sources of metals in street dust were mostly mixed in nature. The chief sources may be the industrial (chiefly steel industry and thermal power plant) and vehicular emissions or both. In component 3, Mg and Al load were strong indicating geogenic influence (RamyaPriya & Elango, 2018; Rao et al., 2018). Interestingly, in the post-monsoon season, 4 components were containing 85.26% of information and loadings of metals in various components indicating distinct sources and not the mixed type of sources like that of the monsoon season. In component 1 Cr, Fe and Mn loadings were the strong indicating influence of the steel and metal processing industry (Gope et al., 2018a), while component 3 showed strong loadings of Pb and Zn (Fig. 3) indicating vehicular emission, wear and tear of paints as probable sources. In post-monsoon season also, strong loadings of Al, Mg was in component 2, maybe by the influence of geogenic sources.

In the case of the commercial city, during monsoon season, 69.42% of the information was in the first three components (S4). Cu and Zn had strong loadings in component 1, Fe and Cd in component 2 and Cr in component 3 (Fig. 3). Whereas, Mg, Ni, Mn, and Pb had moderate loadings in component 1. Most metals originating from vehicular emissions are clubbed in component 1. Due to monsoon runoff from various sources, strong loadings in other components were also evident. In the post-monsoon season, 81.74% of the information was in the first four components. Al,

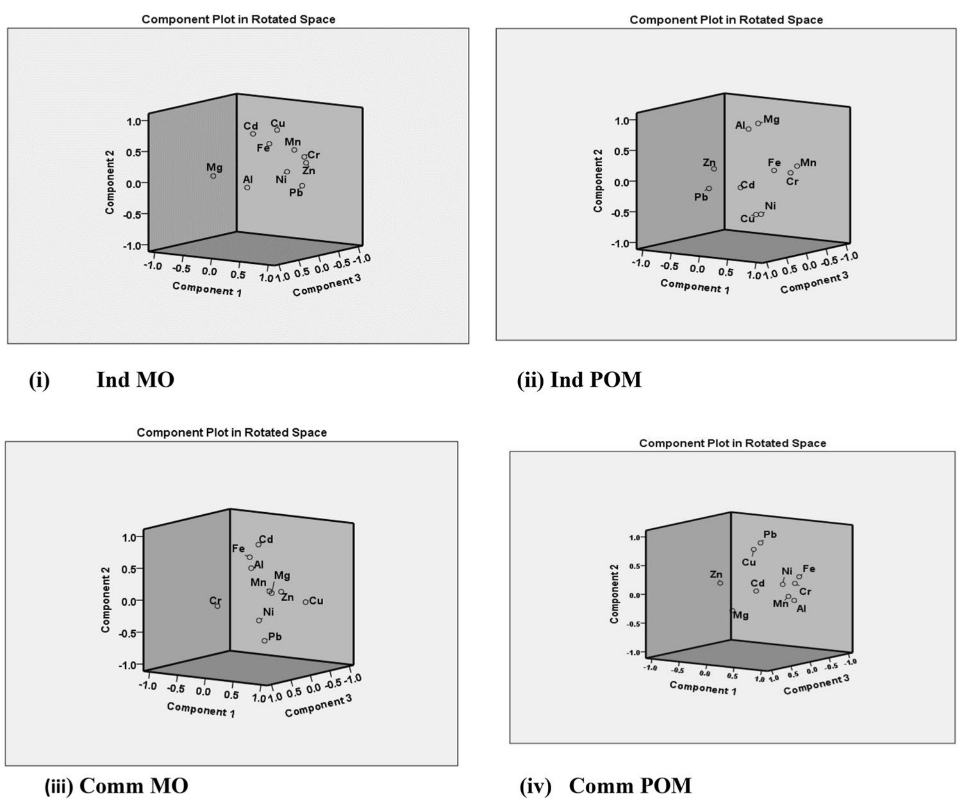

Fig. 3 Principal component analysis of two cities in two seasons (Ind industrial city, Comm commercial city, MO monsoon season, POM post-monsoon season). (i) Ind MO. (ii) Ind POM. (iii) Comm MO. (iv) Comm POM

Mn, Cr, Fe, and Ni had strong loadings in component 1 indicating vehicular emission as the chief source. Pb and Cu showed high loadings in component 2 and Cd in component 4, which can be from geogenic sources as well as from anthropogenic sources like wear and tear of paints used in streets and vehicles.

As the study area surrounds one of the richest coal reserves of the country, so the coal mining activities, surface runoff, wet and dry deposition of particulates, and transportation of coal can also contribute to the metal sources in the street dust. This can also be a possible reason for metals like Cr, Cd, Pb showing strong loadings in different components (Raj et al., 2017). Strong correlations were found between pseudo-total metal fractions in the dust (city-wise during the postmonsoon season), except that for Ni in industrial city and Cd in the commercial city. While in monsoon season correlation was strong only for Cd and Cr in the industrial city.

B. Human health risks

Bioaccessible metals

The amount of soluble contaminant in the gastrointestinal environment available for absorption can be

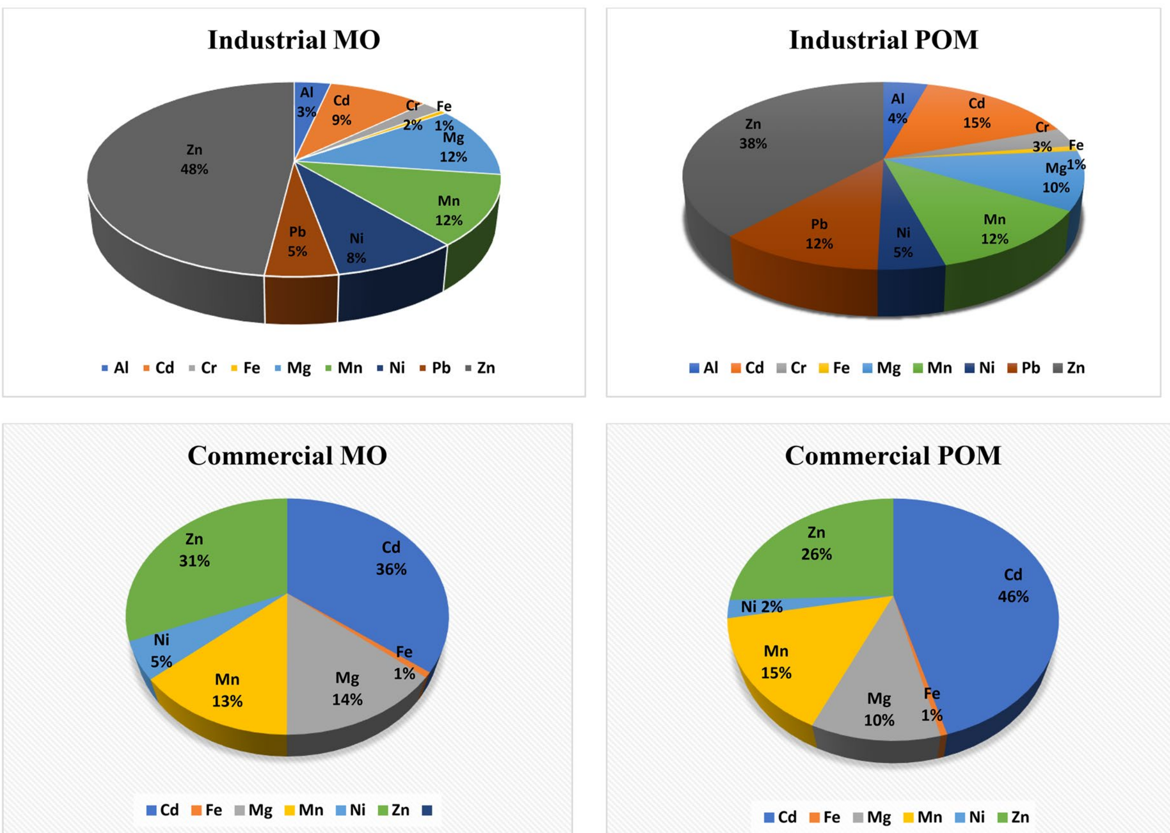

Fig. 4 Percentage bio-accessibility of elements in both the cities for monsoon and post-monsoon

Table 3 Non carcinogenic risk from pseudo-total metal concentrations in dust

City and Season	Pathway	Target	Hazard quotient of pseudo-total metals								
			Cd	Cr	Cu	Fe	Mn	Ni	Pb	Zn	HI
Ind MO	CDIing	Adult	0.011	0.097	0.003	0.010	0.040	0.003	0.002	0.001	0.169
		Child	0.079	0.649	0.019	0.068	0.275	0.024	0.248	0.011	**1.375**
	CDIinh	Adult	0.000	0.002	4.40E-07	0.000	0.020	5.20E-07	5.50E-06	2.40E-07	0.021
		Child	0.000	0.002	5.50E-07	0.000	0.025	6.60E-07	6.90E-06	3.00E-07	0.027
	CDIdermal	Adult	0.004	0.016	4.00E-05	0.156	0.004	5.40E-05	0.001	3.20E-05	0.181
		Child	0.022	0.073	0.000	0.727	0.019	0.000	0.00469	0.000	0.847
Ind POM	CDIing	Adult	0.016	0.08	0.003	0.011	0.040	0.003	0.031	0.001	0.185
		Child	0.108	0.533	0.017	0.075	0.265	0.020	0.210	0.009	**1.238**
	CDIinh	Adult	4.20E-04	0.001	4.00E-07	2.00E-04	0.019	4.00E-07	5.00E-06	2.00E-07	2.07E-02
		Child	5.32E-04	0.002	4.00E-07	3.00E-04	0.024	6.00E-07	6.00E-06	3.00E-07	2.62E-02
	CDIdermal	Adult	0.006	0.013	3.00E-05	0.172	0.004	5.00E-05	8.00E-04	3.00E-05	0.19629
		Child	0.030	0.060	0.000	0.805	0.019	0.000	0.004	0.000	0.918
Comm MO	CDIing	Adult	0.009	0.036	0.003	0.005	0.016	0.00234	0.025	0.001	0.099
		Child	0.063	0.243	0.019	0.035	0.107	0.01561	0.169	0.006	0.658
	CDIinh	Adult	0.000	6.00E-04	4.10E-07	9.40E-05	0.008	3.30E-07	2.00E-06	1.30E-07	0.008
		Child	0.000	7.00E-04	5.20E-07	0.000	0.010	4.20E-07	4.70E-06	1.70E-07	0.011
	CDIdermal	Adult	0.003	0.006	3.70E-05	0.081	0.002	3.50E-05	0.001	1.80E-05	0.093
		Child	0.017	0.027	1.75E-04	0.38098	0.007	1.62E-04	0.00319	8.48E-05	0.436
Comm POM	CDIing	Adult	0.006	0.030	BDL	0.006	0.017	0.0019	0.026	0.000	0.088
		Child	0.040	0.200	BDL	0.040	0.116	0.0125	0.171	0.006	0.589
	CDIinh	Adult	6.09E-01	3.57E-04	BDL	0.000	0.007	2.70E-07	3.70E-06	1.30E-07	6.16E-01
		Child	0.070	0.179	BDL	0.0429	3.357	9.70E-05	0.001	5.70E-05	**3.651**
	CDIdermal	Adult	0.003	0.005	BDL	0.090	0.002	2.80E-05	0.001	1.90E-05	0.102
		Child	0.012	0.023	BDL	0.409	4E-04	0.000	0.010	8.30E-05	0.455

Ind industrial city, *Comm* commercial city, *MO* monsoon season, *POM* post-monsoon season, *BDL* below detection limit derived from the bioaccessibility results (Padoan et al., 2017; Paustenbach, 2000). The highest bio accessible metals were Zn (MO = 25.64% of the pseudo-total metal, POM = 14.96%) at industrial city and Cd at commercial city (MO = 11.26%, POM = 13.23%). In Italy too, street dusts had higher Zn concentrations (Padoan et al., 2017), which they related to its geogenic origin. In contrary, higher proportions of bioaccessible Cd indicate their anthropogenic origin. The bioaccessible concentrations of Cd (0.36–0.64 mg/kg), Cr (BDL–1.87 mg/kg), Ni (0.16–1.94 mg/kg) and Zn (12.62–74.34 mg/kg) are given in (S5) (Fig. 4). Interestingly, the bioaccessible fractions of Al, Cd, Cr, Cu and Pb in commercial city and Cu in industrial city fell below detection limit for both the seasons. Significant differences were observed both season-wise (Ind: F = 0.103, Fcrit = 4.49; Comm: F = 0.029, Fcrit = 4.96) and site-wise (MO: F = 1.45, Fcrit = 4.96; POM: F = 1.34, Fcrit = 4.96) in the concentrations of bioaccessible metals. The pH of the samples was comparable between the cities with an average of 8.52. The EC was between 0.083 and 0.45 and total organic carbon of 4.65. pH showed weak to moderate correlation, while EC had no statistically significant correlation with both pseudo-total and bio-accessible metal concentrations. Both grain size and organic carbon content play an important role in forming soluble organic complexes, and hence their bioaccessibilities (Padoan et al., 2017; Yu et al., 2014).

Table 4 Non-carcinogenic risks from bio-accessible metal in dust

City and season	Pathway	Target	Bioaccessible metals hazard quotient							HI
			Cd	Cr	Fe	Mn	Ni	Pb	Zn	
Ind MO **Cu BDL**	CDIing	Adult	6E-04	0.001	3E-05	0.003	2E-04	1E-03	4E-04	0.006
		Child	0.004	0.007	2E-04	0.017	0.001	0.006	0.003	0.038
	CDIinh	Adult	2E-05	2E-05	6E-07	0.001	2E-08	1E-07	6E-08	0.001
		Child	2E-05	2E-05	8E-07	0.002	3E-08	2E-07	8E-08	0.002
	CDIdermal	Adult	2E-04	2E-04	5E-04	3E-04	2E-06	3E-05	8E-06	0.001
		Child	0.001	8E-04	0.002	0.001	1E-05	1E-04	4E-05	0.006
Ind POM **Cu BDL**	CDIing	Adult	9E-04	0.001	4E-05	0.002	6E-05	0.001	2E-04	0.006
		Child	0.006	0.007	3E-04	0.013	4E-04	0.009	0.001	0.037
	CDIinh	Adult	2E-05	2E-05	7E-07	9E-04	8E-09	2E-07	3E-08	9E-04
		Child	3E-05	2E-05	9E-07	0.001	1E-08	3E-07	4E-08	0.001
	CDIdermal	Adult	4E-04	2E-04	6E-04	2E-04	8E-07	4E-05	4E-06	0.001
		Child	0.002	8E-04	0.003	9E-04	4E-06	2E-04	2E-05	0.006
Comm MO **Cr, Cu both BDL**	CDIing	Adult	0.001	BDL	1E-05	7E-04	4E-05	BDL	9E-05	0.002
		Child	0.007	BDL	8E-05	0.005	3E-04	BDL	6E-04	0.013
	CDIinh	Adult	3E-05	BDL	2E-07	3E-04	6E-09	3E-08	1E-08	4E-04
		Child	3E-05	BDL	3E-07	4E-04	7E-09	BDL	2E-08	4E-04
	CDIdermal	Adult	4E-04	BDL	2E-04	7E-05	6E-07	BDL	2E-06	7E-04
		Child	0.002	BDL	8E-04	3E-04	3E-06	BDL	8E-06	0.003
Comm POM **Cr, Cu both BDL**	CDIing	Adult	9E-04	BDL	9E-06	8E-04	3E-05	BDL	7E-05	0.002
		Child	0.006	BDL	6E-05	0.005	2.353	BDL	5E-04	0.012
	CDIinh	Adult	2E-05	BDL	2E-07	4E-04	5E-09	BDL	1E-08	4E-04
		Child	3E-05	BDL	2E-07	5E-04	6E-09	BDL	1E-08	5E-04
	CDIdermal	Adult	3E-04	BDL	1E-04	8E-05	5E-07	BDL	1E-06	6E-04
		Child	0.002	BDL	7E-04	4E-04	2E-06	BDL	7E-06	0.003

Ind industrial city, *Comm* commercial city, *MO* monsoon season, *POM* post-monsoon season, *BDL* below detection limit

Non-carcinogenic risks from bio-accessible portion of Cu were BDL at industrial city (both the seasons), while it was BDL both for Cr and Cu at commercial city (both the seasons)

Table 5 Carcinogenic risks from pseudo-total and bio-accessible metal concentrations through inhalation route (in this study) and all routes in other studies

Carcinogenic risks from pseudo-total metal concentrations												
Authors	**Location**	**Target**	**Cd**	**Cr**	**Cu**	**Fe**	**Mn**	**Ni**	**Pb**	**Zn**	**As**	**Co**
Present study	Ind MO	Adult	2.32E-07	**3.79E-05**	–	–	–	1.89E-07	–	–	–	–
	(n = 21)	Child	2.94E-07	**4.80E-05**	–	–	–	2.40E-07	–	–	–	–
	Ind POM	Adult	3.47E-07	**3.55E-05**	–	–	–	1.82E-07	–	–	–	–
	(n = 24)	Child	4.39E-07	**4.50E-05**	–	–	–	2.30E-07	–	–	–	–
	Comm MO	Adult	1.93E-07	**1.87E-05**	–	–	–	1.56E-07	–	–	–	–
	(n = 27)	Child	2.44E-07	**2.31E-05**	–	–	–	1.98E-07	–	–	–	–
	Comm POM	Adult	**5.00E-04**	**1.50E-05**	–	–	–	1.26E-07	–	–	–	–
	(n = 27)	Child	**5.48E-05**	**6.00E-03**	–	–	–	**5.19E-05**	–	–	–	–
Chengdu, SW China	Chen et al., 2016	Adult	–	1.40E-05	–	–	–	–	–	–	5.49E-07	–
(n = 27)		Child	–	2.40E-05	–	–	–	–	–	–	1.23E-06	–
Khamees-Mushait	Idris et al., 2020	Adult	1.88E-09	2.60E-07	1.66E-07	9.35E-05	1.03E-06	–	3.20E-07	2.67E-07	–	5.21E-08
(n = 60)	CRinh	Child	1.88E-09	2.60E-07	1.66E-07	9.35E-05	1.03E-06	–	3.20E-07	2.67E-07	–	5.21E-08
Anshan, Liaoning, NE China	Xiao et al., 2020	Adult	1.05E—07	9.07E—05	–	–	–	7.61E—07	–	–	–	–
(n = 89)		Child	2.34E—07	2.02E—04	–	–	–	1.69E—06	–	–	–	–
Thessaloniki, Greece (n = 8)	Bourliva et al., 2017	Adult	8.95E- 09	3.50E + 07	–	–	–	6.43E-09	–	–	–	–
		Child	3.97E- 09	1.53E- 07	–	–	–	2.849E- 09	–	–	–	–
Kashan, Iran (n = 50)	Moradi et al., 2020		1.93E-07	0.00012	-	–	–	–	-	–	–	–
Durgapur	Gope et al., 2018a, b	Adult	4.60E-09	3.60E-06	–	–	–	8.60E-09	–	–	–	–
		Child	5.90E-09	4.60E-06	–	–	–	1.10E-08	–	–	–	–
Ahwaz (Iran)	Ghanavati et al., 2019	Adult	5.40E-08	6.10E-06	–	–	–	-	1.10E-08	–	1.76E-08	–
(n = 81)		Child	4.02E-07	4.60E-05	–	–	–	-	7.90E-08	–	1.31E-07	–
Dhaka, Bangladesh	Safiurrahman et al., 2019	–	4.80E-08	4.00E-06	–	–	–	2.04E-08	-	–	8.79E-07	–
(n = 88)												
Xining valley, China	Li et al., 2018	Adult	–	1.60E-06	–	–	–	1.42E-09	2.00E-10	–	6.99E-10	1.73E-08
(n = 157)		Child	–	6.70E-07	–	–	–	6.18E-10	8.60E-11	–	3.03E-10	7.52E-09

Table 5 (continued)

Carcinogenic risks from pseudo-total metal concentrations												
Authors	**Location**	**Target**	**Cd**	**Cr**	**Cu**	**Fe**	**Mn**	**Ni**	**Pb**	**Zn**	**As**	**Co**
Jinhua, China	Bartholomew et al., 2020	Commercial area	1.08E-09	1.22E-07	–	–	–	2.17E-09	–	–	2.99E-10	–
(n = 40)		Wucheng	5.50E-10	1.32E-07	–	–	–	1.85E-09	–	–	4.10E-10	–
		Jindong	1.48E-09	1.69E-07	–	–	–	2.15E-09	–	–	5.90E-10	–
NW China	Jiang et al., 2018	Adult	1.09E–10	8.93 E–10	–	–	–	–	–	–	–	–
(n = 32)		Child	5.66E–11	4.61 E–10	–	–	–	–	–	–	–	–
Nicosia, North Cyprus	Musa et al., 2019	Adult	–	3.43E – 09	–	–	–	6.92E – 10	1.42E – 05	–	1.87E – 10	–
(n = 20)		Child	–	4.27E – 09	–	–	–	1.72E – 09	9.59E – 10	–	8.30E – 11	–
Khames-Mushait city, Saudi Arabia (n = 60)	Idris et al., 2019	Adult	–	–	–	–	–	–	–	–	7.86E-08	–
		Child	–	–	–	–	–	–	–	–	7.68E-08	–
Anshan, China	Xiao et al., 2020	Adult	1.05E—07	–	–	–	–	7.61E—07	–	–	–	–
(n = 89)		Child	2.34E—07	–	–	–	–	1.69E—06	–	–	–	–
Bandar Abbas city (n = 27)	Keshavarzi et al., 2018		1.12E-10	9.90E-10	–	–	–	–	–	–	2.78E-08	2.56E-09
Shiraz, Iran	Keshavarzi et al., 2015	Adult	1.09E-08	–	–	–	–	8.30E-08	–	–	–	–
(n = 21)		Child	1.09E-08	–	–	–	–	0.76	–	–	–	–
Thessaloniki city, Greece (n = 120)	Bourliva et al., 2018	Adult	1.39E – 12	–	–	–	–	1.13E – 08	–	–	–	2.53E – 10
		Child	6.18E – 13	–	–	–	–	5.00E – 09	–	–	–	1.12E – 10
Huldao Zinc Plant	Zheng et al., 2020	Adult	4.81E-05	–	–	–	–	–	–	–	–	–
	< 100 μm	Child	9.59E-05	–	–	–	–	–	–	–	–	–
	< 63 μm	Adult	5.35E-05	–	–	–	–	–	–	–	–	–
		Child	0	–	–	–	–	–	–	–	–	–

Table 5 (continued)

Carcinogenic risks from pseudo-total metal concentrations												
Authors	**Location**	**Target**	**Cd**	**Cr**	**Cu**	**Fe**	**Mn**	**Ni**	**Pb**	**Zn**	**As**	**Co**
Carcinogenic Risk (Bio-Accessible Metal) through inhalation route (in this study) and all routes in other studies												
Authors	**Location**	**Target**	**Cd**	**Cr**	**Cu**	**Fe**	**Mn**	**Ni**	**Pb**	**Zn**	**As**	**Co**
Ind MO	This study	Adult	3.00E-09	9.00E-08	–	–	–	2.00E-09	–	–	–	–
(n = 21)		Child	4.00E-09	1.00E-07	–	–	–	3.00E-09	–	–	–	–
Ind POM		Adult	3.00E-09	6.00E-08	–	–	–	7.00E-10	–	–	–	–
(n = 24)		Child	3.00E-09	7.00E-08	–	–	–	9.00E-10	–	–	–	–
Comm MO		Adult	5.00E-09	BDL	–	–	–	4.00E-10	–	–	–	–
(n = 27)		Child	6.00E-09	BDL	–	–	–	5.00E-10	–	–	–	–
Comm POM		Adult	4.00E-09	BDL	–	–	–	2.00E-10	–	–	–	–
(n = 27)		Child	5.00E-09	BDL	–	–	–	3.00E-10	–	–	–	–
Durgapur	Gope et al., 2018	Adult	1.16E-09	3.88E-08	–	–	–	2.71E-09	–	–	–	–
		Child	1.47E-09	4.91E-08	–	–	–	3.44E-09	–	–	–	–
Mashhad, Iran	Najmeddin et al., 2018	Adult	2.68E-10	7.03 E – 07	–	–	–	–	–	–	–	4.13E – 08
(n = 22)		Child	2.68E-10	4.48 E – 06	–	–	–	–	–	–	–	4.13E – 08
Nanjing, China	Hu et al., 2011	Adult	–	1.67E-06	–	–	–	–	–	–	2.34E-06	–
		Child	–	3.90E-06	–	–	–	–	–	–	5.44E-06	–
Nanjing, SE China (n = 60)	Wang et al., 2016		60.9 ± 17.5	10.1 ± 2.99	37.9 ± 11.6	-	51.6 ± 10.7	25.5 ± 8.60	63.3 ± 10.5	53.7 ± 14.7	24.0 ± 5.01	32.8 ± 7.85
Panzhihua City, Sichuan (n = 7)	Yang et al., 2015		–	6.37	–	–	64.92	6.93	26.38	43.68	–	–
Kaňk, Czech Republic (n = 5)	Drahota et al., 2018		–	–	6—160	–	–	–	< 0.5—23	6 to 3260	7 – 795	–

Ind industrial city, *Comm* commercial city, *MO* monsoon season, *POM* post-monsoon season, *BDL* below detection limit

No significant health effects ($< 10^{-6}$), chance of carcinogenic health effect (10^{-6}–10^{-4}) and unacceptable ($> 10^{-4}$)

Non-carcinogenic risks

Metals can cause adverse effects to human health at various degrees depending upon their daily intake. Even at lower concentrations, any metal can prove to be toxic, depending upon its dose of exposure (S6). Hence, it becomes quintessential to derive their hazards from various exposure routes (ingestion, inhalation, dermal), for individual metals. Here, we calculated the hazard index (HI) of metals through street dust exposure. In street dust, it was higher than 1 in children for both seasons at the industrial city as shown in Table 3. Vey less variation was present between the HI of monsoon (1.23) and postmonsoon (1.37) seasons. While, in the commercial city, HI > 1 through inhalation route in children during the postmonsoon (3.65) season.

Risks from the bio-available metal portion are all the more important, as it describes the portion of heavy metal that gets absorbed in the human body. From hazard indices of bioaccessible metals, Table 4, we found HI > 1 only in commercial city (2.36), via the ingestion route for children only. Hence, although the industrial city scored higher HI in both seasons from pseudo-total metal concentrations, the risks from bioaccessible portions at the commercial city are of more concern, in children through the ingestion route.

Carcinogenic risks

Metals like As, Cd, Cr, and Ni are extremely carcinogenic. Although several studies have reported carcinogenic risks from the pseudo-total heavy metal concentrations (Moradi et al., 2020; Safiur Rahman et al., 2019; Xiao et al., 2020; Zhaoyong et al., 2019) Table 5, only very few have reported the risks from their bioaccessible fractions (Hu et al., 2011; Najmeddin et al., 2018). There were chances of carcinogenic risks to children from Cr in Mashhad, Iran, (Najmeddin et al., 2018), and from bioaccessible fractions to both children and adults from Cr and As (Hu et al., 2011). In this study, no significant risks were found from the bioccessible fractions in either of the cities for both seasons. Only a few metals fell within the range of causing chances of carcinogenic health effects (10–6–10–4), from their pseudo-total concentrations. Here, carcinogenic risks were calculated only from the inhalation route in the population of both cities in both seasons. The risks were mainly from Cd and Ni in the commercial city, but solely from Cr in the industrial city. Cd and Ni sources can be traced from motor vehicle paintings, tire abrasions, lubricants, and industrial or incinerator emissions among many (Patra et al., 2007). On the other hand, Cr is an indispensable metal for industries, due to its corrosion-resistant nature and hardness it is used in the production of stainless steel, nonferrous alloys, and pigments. These can cause kidney dysfunction, pulmonary disease, lung cancer, an increase in blood pressure, skin ulcer, damage to renal, circulatory, and cardiac systems, DNA, and nervous tissues, as well as a decrease in body weight.

Conclusion

Jharkhand has both tropical moist deciduous and tropical dry deciduous forests. Plants like *Shorea robusta*, *Pterocarpus marsupium*, *Gloriosa superba*, and *Butea monosperma* are commonly found (Rahul Kumar & Saikia, 2020). 45.03% of the forest area comprises of dry peninsular sal (*Shorea robusta*) forests (45.03%) and dry mixed deciduous forests (41.21%) (India State of Forest Report ISFR, 2015). Purbi Singhbhum and Ranchi have a total forest area of 1,079.38 and 1164.49 km^2 (India State of Forest Report ISFR, 2019). *Mangifera indica* and *Azadirachta indica* have a relative abundance of 11.18% and 7.63% respectively in urban Jharkhand. Also, *Ficus benghalensis* and *Ficus religiosa* are among other common trees. Yet, with the existing forest cover also, Jharkhand is experiencing pollution, posing threat to both humans and environment. The pseudo-total metal content of Cd and Zn surpassed the permissible limits of soil (WHO, 1996). A common trend of the geochemical parameters (Igeo, EF, CF) was observed in both cities for two seasons (Cd > Pb > Zn > Cr > Cu > Mn > Ni). The ecological risk was highest predominantly from Cd throughout for both cities in two seasons. ERI was highest in industrial city and lowest in commercial city during post-monsoon. The PCA results indicated mixed and distinctive sources of pollution (monsoon and post-monsoon seasons respectively). In the post-monsoon season, the commercial city majorly had vehicular sources while the industrial city had prominent sources from the industrial origin. Health risks from these metals were studied both from their pseudo-total and the bio-accessible fractions. Significant non-carcinogenic risks were posed to children from the pseudo-total metal fractions, while there were no such threats through their bio-accessible fractions. Carcinogenic risks were posed mainly by Cr, Cd, and Ni from the pseudo-total metal fractions. Bio-accessible portions did not pose any risk (both carcinogenic and non-carcinogenic). Here, particle size fractions play an important role in the bioaccessibilities of metals in the gastro-intestinal tract (stomach, intestine). Although there were no immediate risks from the bio-accessible metal concentrations, chance occurrences of carcinogenic risks from pseudo-total metal concentrations were evident from Cr and Cd. Continuous monitoring of both ecological and health risks is recommended, for maintaining a healthier ecological and biological environment. Improving the present road conditions, opting for chartered app-based cycles/ electric or hybrid vehicles, carpooling, renting cycles/self-drive cars from multiple docks will be effective in controlling vehicular emissions. Also, cleaner emission control technologies, levying energy or carbon taxes, and emission trading schemes can be suggested for curbing pollution originating from industrial sources. Also, plants with higher tolerance to air pollution, like *Mangifera indica*, and high metal accumulation like *Ficus bengalensis* (Roy et al., 2020) can be planted for improving the present air quality in these regions.

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Code availability Not applicable.

Declarations

Ethics approval Not applicable.

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Conflict of interest The authors declare no competing interests.

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