Evaluation of Metal Contamination, Flux and the Associated Human Health Risk from Atmospheric Dustfall in Metal Mining Areas of Southern Jharkhand, India.

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Abstract

Metals can be apprehended in the atmospheric environment of copper and iron mining areas of Jharkhand, which falls in one of the most mineralised areas of India with extensive mining and industrial activities. The study was taken up to appraise the metal contamination in the atmospheric dust to evaluate the metal fluxes and associated health risk considering the seasonal variations. Sixty samples were analysed for As, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb and Zn using the inductively coupled plasma mass spectrometer (ICP-MS) and the contamination levels were assessed by various indices. The metal content of dustfall samples exceeded the average shale values for most of the metals. Higher metal concentrations were found in the locations in close vicinity of mining and industrial areas. The principal component analysis suggested both geogenic and anthropogenic sources for metals in the atmospheric dustfall. Human health risk as determined by hazard quotient (HQ) and hazard index (HI) suggested considerable risk to the child populace through the ingestion pathway for both the mining areas, higher being in iron mining areas. The metal flux and the health risk were higher in summers as compared to winters for both the mining areas. Consequently, the results advocate the necessity of periodic monitoring of the freefall dust of the mining areas and development of proper management strategies to reduce the metal pollution.

Introduction

With the rapid growth of industrialization, urbanization and mining activities in recent years, significant environmental issues have arisen in the atmosphere. One of the vital air contaminants is atmospheric dustfall, which is an accumulation of naturally occurring and anthropogenic solid particles (Mostafaii et al. 2021). Natural dust particles are generated by soil erosion, whereas human activities such as traffic, industrial emissions, and rehabilitation or construction produce a significant amount of anthropogenic dust to the atmosphere (Adachi and Tainosho 2005). The anthropogenic dust is largely caused by rapid and non-methodical growth of industries set up for the development of a region (Singh and Mondal 2008; Holnicki et al. 2017). Dust from man-made activities contributes significantly to the transfer of high concentrations of metal from the atmosphere to the topsoil through absorption, deposition and impacts processes (Li et al. 2001). Also, atmospheric dust contaminants constituting of potentially toxic elements have contributed to extreme air pollution causing various health effects, including bronchial diseases caused by inhalation of dust (Zhou et al. 2014; Lu et al. 2015). Other than inhalation; prolonged exposure to polluted dust by absorption, dermal contact and ingestion of food contaminated with dust can also cause chronic health problems (Neil 1990; Radha et al. 1999). Metals are known to initiate a number of health implications like damage in central nervous system, cardiovascular diseases, gastrointestinal problems, infertility, carcinogenicity, neurological, bone and mental disorders (Kulshestha and Sharma 2015; Fo et al. 2016).

Several studies have measured the rate of emissions and the associated health threats posed by atmospheric dust worldwide (Abuduwailil et al. 2015; Jeena and Singh 2017; Ishtiaq et al. 2018; Rani et al. 2019; Tiwari et al. 2020). However, little work has been done in the mining and industrial areas of East and West Singhbhum districts which form the most important mineralized belts of India. Due to mining of copper, iron, manganese, uranium and other minerals along with their processing activities, the districts represents a worst scenario with respect to particulate matter and dust with PM10 and PM2.5 concentrations higher than National Ambient Air Quality standards (Chaulia et.al. 2019). However, a systematic study of metals in the dust along with human health risk assessment has not been carried out. Therefore, a comprehensive analysis on atmospheric dustfall was imperative. Consequently, the study was taken up with the objectives (1) to study the seasonal and regional inconsistency of a number of heavy metals found in the dust (As, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb and Zn) contents; (2) to evaluate the fluxes of potentially toxic elements through dustfall and (3) to determine whether heavy metals have natural or human origins in the dust of the atmosphere; (4) to evaluate the risk to human health due to these metals.

Materials And Methods

Site description

The study was carried out in the copper mining areas of East Singhbhum district and iron ores mining areas of West Singhbhum (**Fig. 1**). Both the districts are situated in the Southern Jharkhand of Eastern India and also associated with industries like steel manufacturing, power generation, etc. along with mining and processing entities forming India’s most mineralized and industrialized zones.

The copper mining areas of East Singhbhum district form a part of Singhbhum shear zone and lies between latitude 22° 12' N to 22° 55' N, longitude 86° 05' E to 86° 42' E. The area is known to be the most potential sulphide-bearing stretch of India and mineral resources particularly iron, copper, uranium, gold and kyanite are abound in the study area. The main rock types of the region are soda granite, Dhanjori lavas, and epidiorite-schist (Dunn and Dey, 1942).

The iron mining areas of the West Singhbhum are situated in the Singhbhum craton between the 22° 00' N to 22° 50' N latitude and 85° 00' E 86° 00' E longitudes. The craton is a part of volcano-sedimentary Archean Iron ore group (IOG) that harbors one of the largest iron and manganese deposits of India (Upadhyay et al. 2010). The minerals abundant in the area are such as chromites, magnetite, manganese, kainite, lime stone, iron ore, asbestos and soap-stone.

Site selection for monitoring of atmospheric dustfall

The sampling sites for atmospheric dustfall were selected considering the land use plan, meteorological conditions and human activities in the study areas. Five sampling sites were set up in the copper mining areas, inclusive of a control site Dalma (ED-1). Dalma was chosen as the control site because of its location at the hilltop of the Dalma wildlife sanctuary far from mining and industrial activities. Similarly, five sampling sites were set up in the iron mining areas including a control site i.e Chaibasa (WD-1). Chaibasa was choosen as a control site with reference to the iron mining areas because it is free from industrial operations and mining activities. The dustfall monitoring sites of the copper and iron mining areas are shown in **Fig. 1.**

Sampling and sample preparation

Atmospheric dustfall samples were collected in accordance to the Indian standard methods for air pollution measurement (IS 5182- part-1, 2006). Gravity methods are adopted for collection of dust particles that fall freely in the air (Lodge, 1988). The free fall dust sampling was carried out with an assembled unit which include a high density open-mouthed plastic bucket of 30 cm diameter fixed on an iron tripod stand **(Supp. Fig. 1)**. The height of the iron tripods were 1.2 m above ground to avoid the collection of dust accumulated by wind eddies. Spherical glass marbles were used to trap the dust samples and prevent finer particles from being re-suspended into the atmosphere from dust sampling assembly (Sow et al. 2006; Rahman and Plater 2021). The unit was exposed to the atmosphere for a month and the dust samples were collected at the end of the month. Samples were collected on a monthly basis for the 3 months of summer season (March-May, 2018) and 3 months of winter season (October-December, 2018). Since, the total locations selected for the study were 10 (5 locations each from copper and iron mining areas) and sampling was done for 6 months (3 each from winter and summer seasons), a total of sixty dustfall samples were collected from both the study areas. The representative dust samples were grinded in a mortar and pestle and the whole amount was passed through a 200 mesh sieve, thoroughly mixed and then stored in HDPE Tarson vials for acid digestion and further chemical analysis.

Laboratory experiment

To determine the total metal content in atmospheric dust, 0.25±0.001 g of the dried dust sample was digested using a microwave digestion system (Anton Paar, Model: Multiwave 3000) using HNO_3-HF-HCl-H_2O_2 mixture in the ratio 4.5:2:1:0.5 as per EPA method 3052 (USEPA 1996). After completion of the digestion process, digested solution was cooled, filtered by What man 42 filter paper and then the final volume was made up to 50 ml with 2% (v/v) diluted HNO_3. Aliquots taken from this were further diluted as appropriate for heavy metal analyses by ICP-MS (Perkin Elmer Elan DRC-e). The instrument was calibrated using ICP multi-elemental standard (Merck, Darmstadt, Germany). The stability of the calibration curve was ensured and confirmed after every 15th sample using calibration blank and a standard not used in the calibration. Triplicates of sample analysis yielded relative percent differences of <5%. As, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb and Zn were selected for the study in view of their association with copper and iron mining and their toxic nature to human health.

Quality assurance and quality control

Analytical procedure for metal analysis of atmospheric dust samples were validated through recovery study using standard reference material (SRM). Two SRM were used; one being from NIST for estuarine sediment (SRM 1646a) and other from USGS for green river shale (SGR-1). The recoveries of the metals ranged from 88.2-114.3 % and the results are provided as **Supplementary Table 1**.

Metal fluxes of atmospheric dustfall

Metal flux can be defined as the concentration of metals in dust per unit area per unit time and expressed as t/km^2/month. The mean concentration of the potentially toxic metals in the dustfall was multiplied by the total dustfall to get the metal fluxes.

Statistical source apportionment

Correlation analysis and principle component analysis (PCA) was carried out on log transformed data by using SPSS version 17.0 statistical software. Pearson's correlation analysis and its coefficient were used to measure the strength of inter-relationship between two quantitative variables (heavy metals). A correlation coefficient close to -1 or +1 indicates a negative or positive linear relationship (LeBlanc 2007). Multivariate analysis (PCA) was used to reduce the data and extract a smaller number of artificial variables (principal components) for evaluating the relationships among the observed variables (Tokalioglu and Karta 2006). These extracted principal components can be attributed to the sources of the metals since metals with strong inter-relationships are believed to be from similar origin (Yuan et al. 2013, 2014).

Calculation of pollution indices

Numbers of pollution indices, namely, Geo-accumulation index (I_{geo}), Enrichment factor (EF) and Pollution load index (PLI) were calculated based on the heavy metal load of atmospheric dustfall samples to assess the influence of anthropogenic activities on the heavy metal contamination level of the dusts. Expressions used in calculating these indices have been tabulated in **Table 1**.

Human Health risk assessment (Non-carcinogenic)

Human health risk assessment was carried out with reference to metal exposure through dust using the methodology of Environmental Protection Agency of United State (USEPA, 1996). The non-carcinogenic risk to the human health was evaluated by using USEPA model of risk assessment for the soil since any such model for the dust in particular is not available. Non-carcinogenic risk posed by each metal present in the atmospheric dust was typified by a Hazard Quotient (HQ) through three different pathways i.e. ingestion, inhalation and dermal contact. **Table 2** depicts the expressions for estimating HQ for various pathways. Reference doses for the ingestion pathway (RfD_{ing} in mg/kg/day), dermal pathway (RfD_{derm} in mg/kg/day), and inhalation pathway (RfC in mg/m^3) are obtained from USEPA (2011). These represent the safe doses with reference to a particular metal that a human body can allow without any probable adverse health effects. Hazard Index (HI) is used to represent the total non-carcinogenic considering all metals and all pathways. HI of the dust comprising n number of metals and arising from three pathways (ingestion, inhalation and dermal absorption) may be expressed as Equation 1 (modified from Giri et al., 2021).

$$HI = \sum_{j=1}^{3} \sum_{k=1}^{n} HQ_j^k \quad (1)$$

For instance, if a atmospheric dust comprised three heavy metals, namely, Fe, Mn and Cu, the comprehensive hazard index arising from ingestion, inhalation and dermal might be expressed as,

$$HI = [HQ^{Fe}_{ingestion} + HQ^{Mn}_{ingestion} + HQ^{Cu}_{ingestion}] + [HQ^{Fe}_{inhalation} + HQ^{Mn}_{inhalation} + HQ^{Cu}_{inhalation}] + [HQ^{Fe}_{dermal} + HQ^{Mn}_{dermal} + HQ^{Cu}_{dermal}] \quad (2)$$

Each of the terms on the right-hand side of equation 2 is calculated using equations depicted in **Table 2**.

$HQ_j^k > 1$ indicates that the health risk associated with a specific metal via a specific pathway exceeds the acceptable level.

Noteworthy is the fact that HI can be greater than unity even if each of the risk from dust's constituent components (metals) is within safe limits. The concept of HI, though popularly used worldwide comes with a caveat. HI, as defined herein, does not take into consideration the synergistic/antagonistic interactions between different metals. Also, it does not differentiate mechanisms between various metals and target organs. This over simplified approach may lead to over or underestimation of the health hazard (Wilbur et al. 2004).

Results And Discussion

Distribution of metals in dustfall in copper mining area

The geometric mean (GM) concentrations of As, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb and Zn was 47.9, 1.01, 13.4, 154.8, 1141.4, 32113, 385.1, 38.9, 99.7 and 526.2 mg/kg during the summer season. While in case of winter season the geometric mean concentrations were found to be 37.4, 0.80, 10.9, 140.4, 968.4, 20642, 355.0, 29.1, 83.6 and 495.5 mg/kg as shown in **Table 3**. The order of the metal concentration was found as Fe > Cu > Zn > Mn >Cr >Pb > As >Ni > Cd> Co during both the seasons. The metal concentrations were observed to be generally higher at the locations of Benasol and Ghatsila. Both the locations are in vicinity to existing or abandoned copper mining and mills area and also under the influence of heavy vehicular load.

Distribution of metals in dustfall in Iron mining area

The geometric mean concentrations of As, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb and Zn was 53.4, 0.77, 4.1, 158.1, 240.2, 124923, 689.0, 25.3, 156.5 and 446.6 mg/kg during the summer season (**Table 3**). While in case of winter season the geometric mean concentrations was found to be 53.1, 0.55, 3.7, 116.0, 162.1, 79487, 557.1, 22.0, 118.9 and 383.2 mg/kg. The order of the metal concentration was found as Fe > Mn> Zn >Cu >Cr >Pb > As >Ni > Co >Cd during both the seasons. The concentrations of metals were observed to be generally higher at the locations of Hathigate and Barajamda which were under heavy vehicular load. Both the locations were situated in close vicinity to Iron and Manganese mining areas.

For almost all metals, metal concentrations in the dustfall for both study areas exceeded the average metal concentration in the shale (Turekian and Wedepohl 1961). The study areas are characterised by the presence of metal bearing formations influenced by extensive mining and industrial activities and thus high metal levels can be anticipated in atmospheric dust (Preston and Chester 1996). However, the increase in concentration was more noticeable for Cu, Pb and Zn for copper mining areas and for Fe, Pb and Zn for iron mining areas.

For both the study areas, the dustfall rate was higher in summer as compared to winter which may be attributed to the meteorological factors. The high wind strength at higher temperature range and low relative humidity in summer months is responsible for erosion of earth crust which results in increased levels of coarse crustal metals in the atmospheric dust as coarse particles tends to get settled down due to gravity (Singh and Mondal 2008; Mondal et al. 2010; Moja and Mnisi, 2013). The high humidity and low temperature during the winter result in stable condition which encourages the long-lasting life of atmospheric particles in the environment, entrapping them and preventing their free fall. The average dustfall rates in summer and winter for the copper mining areas were 20.5 and 15.9 g/m^2/month, respectively, while for iron mining areas the dust fall rates were 37.2 and 34.5 g/m^2/month, respectively.

The concentrations of metals in the dustfall were also higher in the summer season than the winter season that can be attributable to the meteorological conditions and anthropogenic activities. In the summer the relative humidity is lower which results in lower moisture content of the soil which facilitates the mobilization of the soil particles that is rich in metals (Tanushree et al. 2011). Moreover, the mining activities are higher during the summer as compared to the winter which may also be considered a reason for the high concentrations of the metals related to the mining during the summer (Vega et al. 1998).

Comparison of metals in dustfall of the study area with other studies

A comparison of metals in the atmospheric dust of the present study with other studies is provided in **Table 4**. The table suggest that for most of the considered metals, the concentrations in the east and west Singhbhum areas were higher than other areas of India and worldwide. This may be attributed to the high mineralisation of the study areas along with extensive mining and other industrial activities. However, differences in the metal concentration in the free fall dust of different areas are obvious due to differences in geographic settings, traffic arrangements, and the type of industries that run across the area.

Metal fluxes of atmospheric dustfall

Seasonal and spatial variations were observed for most of the metals in both the study areas considering the metal fluxes (**Table 5**). The metal fluxes were higher in summer than winter considering the seasons which is in accordance to other studies (Rout et al. 2014). This may be attributed to the high dustfall and high metals concentration in dustfall during the summer as compared to winters. Also, the flux was higher in the mining and industrial sites as compared to the control site for most of the considered metals. Considering both the mining areas, significant differences were observed for Cu, Fe, Mn and Cr with higher Cu flux being observed in copper mining areas and Fe, Mn and Cr observed to be higher in iron mining areas. The results are in accordance to the related mining activities in both the mining areas. The sequence of the metal flux was found as Fe>Cu>Zn>Mn>Cr>Pb>As>Ni>Cd>Co in copper mining area while in case of iron mining areas, the order was observed to be Fe>Mn>Zn>Cu>Cr >Pb>As>Ni>Co>Cd.

Assessment of contamination indices with respect to metals of atmospheric dustfall

Large variations were observed in the I_{geo} for the metals in both the study areas as metals widely varied from class 0 to class 6 indicating large spatial variations; representing the background status for some metals to extremely polluted status for others (**Table 6**). Largest variation was observed for Cu in the copper mining areas for which the I_{geo} values ranged from 1.66 to 6.90; thus falling under the Igeo class of 2–6, i.e., moderately polluted to extremely polluted status. As, Cd, Zn and Pb showed moderate to high contamination in the dustfalll of the area. In case of iron mining area, Cu, Fe, Pb and Zn depicted moderately to highly polluted status according to I_{geo} classification.

The analysis of the enrichment factor showed significant to extremely high Cu contamination in the atmospheric dustfall of the copper mining area for all the sites (**Table 7**). Moderate to high contamination was depicted for Pb, Zn, As and Cd as per calculated EF. For the iron mining areas, enrichment factor suggested lower contamination than copper mining areas. Significant contamination was observed for As, Cd and Pb at few samples while the other metals had no to moderate contamination as per EF classification.

The contamination factor (CF), revealed that Cu had the highest contamination in the dust samples considering the copper mining area while in case of iron mining area, the highest CF was calculated for Pb. The sequence of CF for the different metals were in the order of Cu < Pb < Ni < As < Cd < Zn< Cr < Fe < Co < Mn and Pb <Zn < Cu< As < Fe < Mn < Cd < Cr < Ni < Co for copper and iron mining areas, respectively (**Table 7**). PLI was determined to study the cumulative effect of the metals analyzed, ranged from 1.04 to 3.33 for the copper mining area advocating moderate to extremely heavy pollution for the area. The range of PLI for iron mining area was 0.94 to 2.63 suggesting no pollution to heavy pollution status of the locations. The average PLI values in the study areas were estimated to be 1.99 and 1.75, respectively for copper and iron mining areas.

Thus, the findings, based on EF, I_{geo}, CF, and PLI, confirm that metal contamination in the copper mining area ranges from moderate to severe, with Cu, Pb and Zn being the metals of greatest concern. The locations closest to Cu mining and processing operations have the highest levels of pollution. However, in iron mining area is moderately to extremely serious with Cd, Pb and Zn being the metals with most concern.

Statistical source apportionment

The Pearson's correlation coefficients of the metals in the dustfall samples of the copper and iron mining area are depicted in **Table 8**. Considering the copper mining areas, there was a strong positive correlation ($p < 0.01$) for As with Cd, and Fe; Co with Cu and Ni; Cr with Ni, Pb and Zn; Cu with Ni; Fe with Mn and Pb with Zn. The positive correlations between Cu, Co and Ni indicated a possibility of a common source which may be derived from mining and processing of copper ores. For iron mining areas, significant positive association were seen ($p < 0.01$) for Cd with Co; Cr with Fe, Mn and Zn; Cu with Fe, Ni and Pb; Fe with Mn and Zn; Ni with Pb and Zn; Pb with Zn. Positive associations between Fe, Mn, and Cr may be a suggestive of a possible shared source originating from iron ore mining and processing (Chen et al. 2014).

Principal component analysis

Principal component analysis (PCA) was carried out on the heavy metal data of the atmospheric dust samples in order to obtain significant interrelationships and to reduce the dimensionality of the dataset, since a few of the new components could explain the major variance in the data. It also helps in assigning source identity to each one of the PCs (Miller and Miller 2000).

For metals data of dustfall of copper mining area PCA was performed and four principal components were extracted explaining 91.1% of total variance (**Table 9**). According to the loading factors, the first principal component (PC-1) was associated with Co, Cu and Ni explaining 30.9% of the total variance. The factor may be attributed seems to the extensive copper mining and processing industries since Ni and Co are associated with copper deposits (Ikenaka et al. 2010). The second component (PC-2) explained 25.9 % of total variance and have considerable factor loading for Cr, Pb and Zn. Vehicular and industrial emissions can be attributed to this factor. The increase in concentration of Pb in the environment is identified to be associated to human made activities such as industrial uses, waste incineration, coal burning, etc. (Cheng and Hu 2010). Zinc is used in a wide variety of materials including galvanizing on iron products, in alloys, in rubber, glazes, enamels, paper and glass (Belliles 1978). Environmental pollution with various forms of Cr results from its numerous uses in the chemical industry, production of dyes, wood preservation, leather tanning, chrome plating, manufacturing of various alloys and many other applications and products (Alimonti et al. 2000; ATSDR 2000). All the 3 metals; Cr, Zn and Pb are associated with vehicular sources also. The wearing down of vehicular brake linings and the use of catalytic converters represents vehicular source of chromium (Fishbein 1981). Lead is used for batteries, fuel tanks, solder, seals, bearings, and wheel weights (Sander et al. 2000; Lohse et al. 2001; USDI 2003). Lead also comes from the wear of tyres since Pb oxide is used as filler materials in some overseas makes of tyres (Sharheen 1975). As Zn is used as a vulcanization agent in vehicle tyres (Alloway 1990) and the higher wearing rate at the high temperature in the area may contribute to the high Zn content in the dust (Davis et al. 2001). Zn is used as minor additive to gasoline and various auto lubricants and released during combustion and spillage (Ipeaiyeda and Dawodu 2008). The third and fourth factors (PC-3 and PC-4) having high loadings for As, Cd, Fe and Mn explicated 34.3% of the variance in combination and the possible source appeared to be associated to the earth's crust and geology of the study area.

The PCA performed on the metal data of the dustfall samples from iron mining areas resulted in extraction of three principal components were extracted explaining 75.0 % of total variance (**Table 9**). The first principal component (PC-1) was associated with Cu, Ni, Pb, and Zn, accounting for 29.7% of the total variance. It may be related to vehicular and industrial emissions in the study area. The second component (PC-2) explained 25.5 % of total variance, as seen by significant factor loading for Cr, Fe and Mn. This factor may be due to the iron ore mining and related activities. The third factor (PC-3), explained 19.8% of the variance with high loadings for As Cd and Co can be related to the geogenic origin.

Human health risk from metals exposure through atmospheric dustfall

Human health risk was estimated by calculating Hazard Quotients (HQ) and Hazard Index (HI) for the considered metals for both summer and winter season. If HQ and HI are greater than unity then considerable risk may be anticipated on the human health. The HQ and HI values considering the pathway of ingestion has been depicted in **Supplementary Table 2** taking into account both the adult and child populations. The HQs for all the metals irrespective of the pathways were <1 for adult population, suggesting that the metals posed little hazard individually for adult for both the study areas. However, for the sensitive child population, the HQs of As through the ingestion pathway were higher than one in copper mining area, thus predicting risk for the child populace during both the season. Moreover, in the iron mining area HQs of As and Fe through the ingestion pathway were higher than unity thus predicting risk for the child group during both seasons. The uppermost contributors to non-cancer chronic risks via the ingestion route were As, Cr, Fe, Co and Cu in the copper mining area (**Fig. 2**) where as in case of iron mining area, the uppermost contributors of risks via the ingestion route were As, Fe, Cr, Pb and Mn (**Fig. 3**). Considering the cumulative risk of metals, HI through ingestion pathway (HI_{ing}) for child populace is evaluated to be 4.48 and 3.60 in the copper mining area and 6.00 and 4.79 in the iron mining area during summer and winter seasons, respectively suggesting substantial risk. The HI_{ing} for adults of West Singhbhum area is also impending 1 (0.939) during the summer season, suggesting a likelihood of non-carcinogenic risk in the near future. The overall HI for the study area, taking into account the ten metals and the three pathways were evaluated during the summer and winter seasons for the adult and child population, respectively (**Supplementary Table 3**). The HI of the other 2 routes i.e. dermal contact and inhalation risk are negligible as compared to the ingestion pathway. Accordingly, it can be implied that the oral intake of the dust was the primary exposure pathway.

Conclusions

From the estimation of metal concentration in the dust samples collected from this study from both copper and iron mining areas, we obtained a better knowledge regarding the impact of the mining and allied activities on the atmospheric environment and the potential risk to the local population. The metal concentrations in the analyzed atmospheric dustfall samples were higher than the average metal concentration in the shale for most of the metals in both the areas. The calculated EF, I_{geo}, and PLI, confirm moderate to extremely severe metal contamination due to Cu, Pb and Zn in the copper mining areas and moderately to heavy contamination due to Cd, Pb and Zn in the iron mining area. The principal component analysis suggests geogenic and anthropogenic activities such as mining, industrial and vehicular sources to be the causative of metals in the atmospheric dust in the studied areas. Season and meteorological conditions play a significant role in affecting the metal flux in the dustfall with higher metal flux in summer as compared to winter. It has also been observed that deposition of metal was much pronounced in the mining and industrial sites. Human health risk assessment advocates considerable risk to the child population for both the mining areas with ingestion pathway as the predominant route of exposure. Hence the study recommends a strong need of monitoring the atmospheric dust quality around the mining and industrial sites at a regular time span in order to control and manage the specific dust emission sources and reduce the risk on human health.

Declarations

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Author contribution

The work is a part of post-doctoral research of Mukesh Kumar Mahato who designed the study outline, analysed and interpreted the data and wrote the manuscript draft. Soma Giri was involved statistical analysis of data and human health risk assessment. Abhay Kumar Singh reviewed the scientific content of the manuscript and provided valuable guidance for the improvement of the manuscript. All authors participated in field work, acquisition of data, editing and reviewing of the manuscript.

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Data availability

All data generated or analysed during this study are included in the manuscript and supplementary information files.

Ethics approval

Not applicable

Consent to participate

Not applicable

Consent for publication

Not applicable

Competing interest

The authors declare that they have no competing interests

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Figures

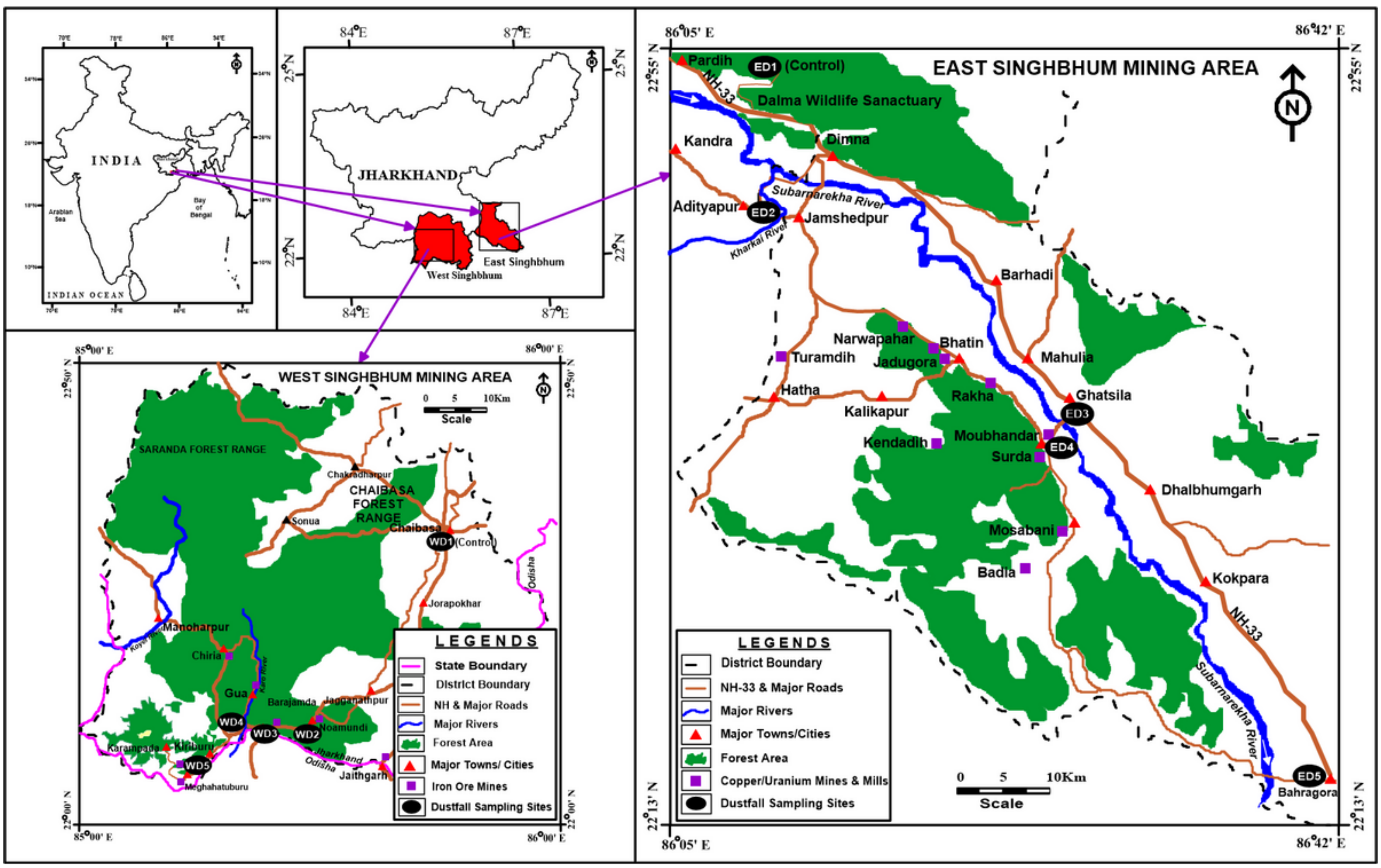

Figure 1

Map of the study area with sampling locations

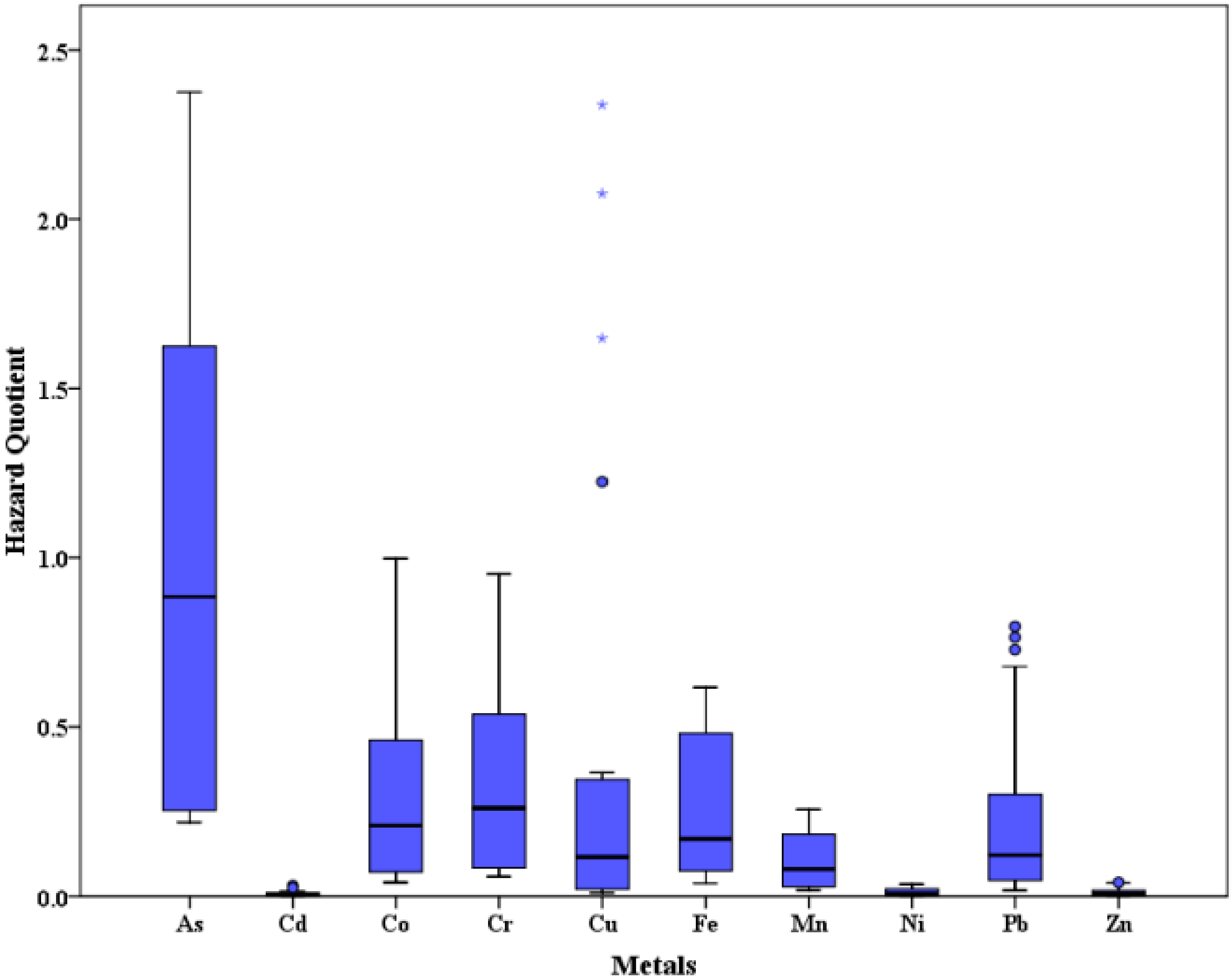

Figure 2

Boxplots of hazard quotient for atmospheric dust of each metal of the copper mining area

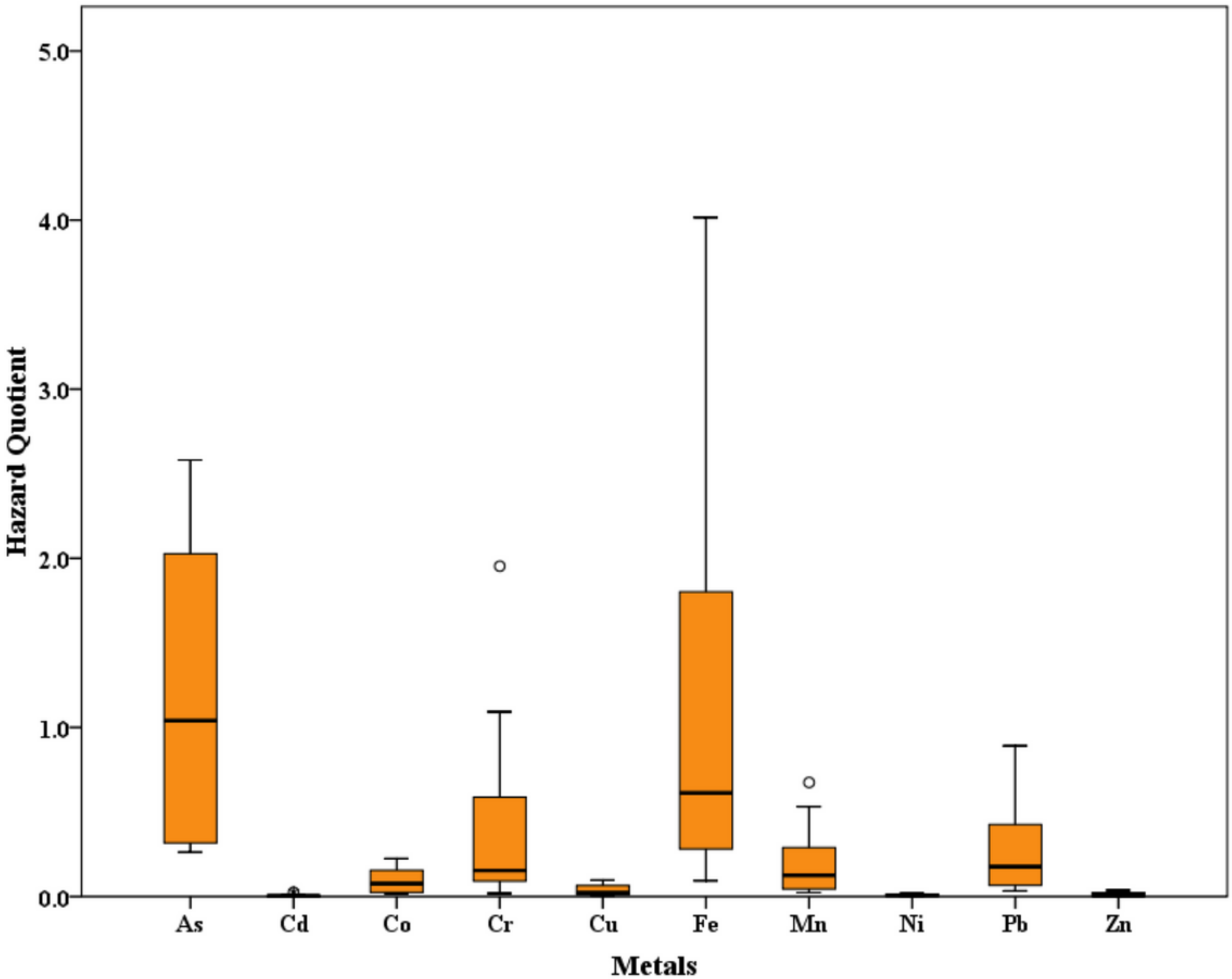

Figure 3

Boxplots of hazard quotient for atmospheric dust of each metal of the iron mining area

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