Measurement of respirable dust concentration and assessment of health risk due to metals around an opencast coal mine of Talcher, Odisha

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Atmospheric pollution due to particulate matter in opencast coal mining area is a very important environmental problem and is fetching the attention of researchers worldwide since few decades. The particulate matter not only affects human but also have tremendous effects on nearby flora and fauna by degrading the ecological environment in many ways. High mechanization in mining operations leads to add heavy load of dust to the surrounding area. The adverse effects of dust depend on the quantity as well as the characteristics of the dust and the exposure dose. Taking the importance of the dust pollution in mines, a coal mine area of Talcher coalfield, was selected, which is one of the oldest coalfields of India and a very limited work has been carried out in that area on the regards of assessment of health risk due to metals on the local population. Monitoring of respirable dust (PM$_{10}$ & PM$_{2.5}$) were performed at eight monitoring stations around a high mechanised opencast coal mine for three seasons i.e., post monsoon, winter, and summer in the year 2015 as per the standard criteria of Central Pollution Control Board (CPCB), India. The seasonal variation of dust concentration was found in the order of winter > summer > post monsoon. Ten trace metals were analysed from the dust samples. Statistical analysis, such as, univariate (correlation study) and multi-variate analysis were carried out including principal component analysis (PCA) for source identification and respective contribution to particulate matter. Finally, the health risk in terms of hazards quotient (HQ) and hazards index (HI) were calculated for both children and adults for the three exposure path ways (Inhalation, ingestion and dermal exposure). The carcinogenic effects due to the presence of trace metals in the PM$_{10}$ were evaluated for both children and adults in terms of excess cancer risk (ECR). The combined carcinogenic effects of all the trace metals also calculated (ECR$_{Total}$). The HQ values for Cr and Cd were found above the safe limit in that area for both children and adults. Likewise the ECR values for Cr and Cd also were at a very risk level for both the age group. However the risk related to other metals were found well within the safe limit. The HI and ECR$_{Total}$ values were found above the safe limit which indicates the combined effect of trace metals on the children and adult were at and very high risk level in the study area.

Keywords: PM$_{10}$, PM$_{2.5}$, heavy metals, correlation analysis, PCA, health risk
1. Introduction

In opencast mining areas air pollution due to particulate matter (PM) is a serious problem and also is considered as a dominating air pollutant (Ghose and Majee, 2001). All types of mining activities are more or less responsible for the generation of PM. Different mining activities like drilling, blasting, loading, unloading and transportation (coal and overburden material) etc. generates huge quantities of PM, which affect the surrounding environment as well as the human health (Chaulya, 2004). Coal is considered as the cheapest source of energy and fulfil most part of the energy demand of the world (Franco and Diaz, 2009). The increase in the use of electricity enhances the demand of the coal production, which leads to implementation of high mechanization mining method techniques. High mechanized operation of coal extraction produces huge quantity of PM and create air pollution problem directly or indirectly (Baldauf et al., 2001). The health of the mine workers and the nearby residences depends on the dispersion pattern of PM in air. The dispersion and transportation of PM to the surrounding environment depend on the concentration, size, shape, and nature of particles along with the meteorological parameters of the area (Vesovic et al., 2001). Finer particles can be suspended in air for a longer time and transported to long distances as compared to coarse particles. The hazardous nature of the PM goes up with the reduction in the particle size. Finer particles can go directly to the deeper part of the lungs during inhalation and affects respiratory system. Taking the seriousness of the respirable PM towards the human health, it is essential to measure the concentration. The most important emissions during coal mining and coal burning are PM (PM$_{10}$ and PM$_{2.5}$) and its content such as inorganic heavy metals and polycyclic aromatic hydrocarbons associated with PM (Gunawardana et al., 2011; Tsai and Cheng, 2004). Different organic and inorganic compounds are present in the PM. The trace metals present in the PM are emitted from various natural and anthropogenic sources such as crustal materials, road dust, motor vehicles, coal and oil combustion, incineration and other industrial activities (Arditsoglou and Samara, 2010; Shah and Shaheen, 2010).

Apart from the health effects, the PM also affects the surrounding environment, reduces visibility and also affects the flora and fauna (NIOSH, 2005). Several epidemiological studies proved a strong correlation between the exposure of PM concentration and increased mortality (Lin and Lee, 2007; Namdeo and Bell, 2005). The toxic heavy metals associated with respirable PM can cause lung and cardiopulmonary injuries, cardiovascular problems, damaged to various organs, and premature mortality in humans (Callen et al., 2009; Megas et al., 2007; Shaheen et al., 2005). Among the trace metals, Arsenic (As) is a human carcinogen and can cause respiratory tract disorders, skin ailments, cardiovascular and nervous system problem (USEPA 1984). Lead (Pb) and Cadmium (Cd) interference with normal kidney function leads to kidney disorder (USEPA, 1990). Chro-
mium (Cr) causes lung cancer like diseases and Cr (VI) is a human carcinogen. Several studies were performed on the effects of PM and associated heavy metals on the cardiovascular and respiratory system (Kloog, 2016; Yu and Chien, 2016). Limited studies were performed in India on the evaluation of health risk due to the presence of trace metals in PM (Jai Prakash et al. 2018; Samiksha et al., 2017; Jena and Singh, 2017; Izhar et al., 2016). Further the chemical compounds present in the PM differ in the concentration at different locations depending on the sources of contribution and meteorological factors. So it becomes essential to study the health risk due to metals especially in coal mining areas, where a lot of sources contribute the pollutants (Shah and Shaheen, 2010).

The use of measured trace elements concentration in source identification is very common practice. But the evaluation of health risk due to the presence of trace metals in PM for the people residing near a coal mining area is very limited. So in this study, an attempt has been made to measure the PM (PM$_{10}$ and PM$_{2.5}$) concentrations around a highly mechanised coal mine and study the seasonal variations. Source apportionment study was carried out using statistical techniques like Principal Component Analysis (PCA) and correlation analysis. Finally the health risk was calculated for both children and adults residing near the mining area due to the presence of trace metals in the respirable PM.

2. Study area

In this study a highly mechanized opencast coal mine was selected in an area, which was one of the critically polluted area of the state Odisha, India. The mine is located in the city of Talcher and the mine is lies within latitude 20° 57′ 39″ and 20° 58′ 18″ (N) and longitude 85° 09′ 33″ and 85°12′ 12″ (E). The elevation of the study area is 85 to 120 m above the sea level. The mean annual precipitation was recorded as 1277 mm and most of which occurs during rainy season. Total mining area of the studied mine was 1410.01 ha. (CMPDI Report, 2013). Talcher is one of the oldest industrial clusters located in the central part of Odisha state of India. This location is about 120 km from the state capital Bhubaneswar and 160 km from the Bay of Bengal. With two national highways and well-connected railway lines, now the area become an industrial destination of the country. The core zone of the mine covers partly and /or fully the land from seven villages. Other coal projects situated in the buffer zone of the studied mine are Balaram opencast project (OCP), Ananta OCP, Bharatpur OCP, Bhubaneswari OCP, Jagannath OCP etc. Other than the coal mines several industries also situated in and around the buffer zone of the mine and those are Talcher Thermal Power Station (TTPS/NTPC), Talcher heavy water plant at FCI, coal washery at Balanda. The buffer zone of the studied mine also contain eight reserve forests. The map of the study area with sampling stations is shown in Fig. 1.
3. Methodology

3.1. Respirable dust measurement

Both PM$_{10}$ and PM$_{2.5}$ samples were collected from eight sampling stations during three seasons i.e., post monsoon (October and November), winter (December to February), and summer (March to June) of the year 2015–16. The sampling was carried out for 24 hourly basis. The PM$_{10}$ and PM$_{2.5}$ samples were collected weekly twice from each stations. Total 72 samples from PM$_{10}$ and PM$_{2.5}$ were collected for the three seasons from each sampling stations. The ambient air quality monitoring was done as per the siting criteria provided by IS: 5182 Part XIV, 2000. The sampling stations were selected in order to cover up the total mining area including mining as well as residential area around the mine. The measured concentration of PM$_{10}$ and PM$_{2.5}$ at different sampling locations.
were compared with the National Ambient Air Quality Standards (NAAQS, 2009) (Tab. 1). PM$_{10}$ samples were collected using respirable dust samplers (Envirotech APM 460 NL) with flow rate of 1.1 m$^3$/min on EPM2000 filters (8" × 10"). The basic mechanism of respirable dust sampler is based on the cyclonic separation of particles by the action of centrifugal force. The PM$_{10}$ fraction separated by the centrifugal force deposited on the EPM2000 grade glass fibre filter paper.

**Table 1. NAAQS, 2009 for annual respirable particulate matter (CPCB, 2011).**

| Sl. No. | Pollutants                                                                 | Concentration in ambient air | Methods of measurement |
|--------|-----------------------------------------------------------------------------|-------------------------------|------------------------|
| 1      | Particulate matter (size less than 10 μm) or PM$_{10}$, μg/m$^3$            | 100                           | Gravimetric            |
| 2      | Particulate matter (size less than 2.5 μm) or PM$_{2.5}$, μg/m$^3$          | 60                            |                        |
| 3      | Lead (Pb), μg/m$^3$                                                         | 0.5                           | AAS/ICP method after sampling on EPM 2000 or equivalent filter paper |
| 4      | Arsenic (As), ng/m$^3$                                                      | 0.06                          |                        |
| 5      | Nickel (Ni), ng/m$^3$                                                       | 20                            |                        |

**Table 2. Monitoring locations in details with major activities.**

| Station Code | Geographic Location | Mean Sea Level (MSL), in m | Dominating Activity                                                                 |
|--------------|---------------------|----------------------------|-------------------------------------------------------------------------------------|
| ST1          | 20057′28.80″ N 85012′45.1″ E 96 | Vehicular movement, coal transportation road, railway siding 500m                 |
| ST2          | 20057′16.00″ N 85012′06.4″ E 112 | Mining activity, coal transportation road, haul road, exposed dump, exposed dump surface, weigh bridge, coal burning, CHP |
| ST3          | 20056′59.50″ N 85012′33.0″ E 104 | Residential activity, normal vehicular movement, domestic coal burning            |
| ST4          | 20056′45.30″ N 85011′40.3″ E 110 | Main road towards Dera, coal and non-coal transportation road, residential activity, domestic coal burning |
| ST5          | 20057′11.10″ N 85010′42.0″ E 131 | Exposed dump, CHP, Bypass road to Dera, mining activity 500m away                |
| ST6          | 20057′27.20″ N 85010′14.3″ E 131 | Vehicle maintenance workshop, exposed mining pit. OB pit, residential area 100m. |
| ST7          | 20057′56.50″ N 85011′02.0″ E 123 | Rehabilitee village having very low population, mining activity, normal transportanion, domestic coal burning. |
| ST8          | 20057′53.05″ N 85012′02.2″ E 101 | Railway siding area, coal stock yard, OB exposed, residential area, domestic coal burning etc. |
Similarly PM$_{2.5}$ samples were collected using fine particulate samplers (Enviro-tech APM 550) with flow rate of 16.7 lpm on a 47 mm diameter PTFE filter. The filters were conditioned in a desiccator for 24 hours before and after sampling. The differences in the weight of the filters before and after sampling were used to calculate PM$_{10}$ and PM$_{2.5}$ concentrations. The monitoring was performed in accordance with the IS: 5182 Part XXIII, (BIS 2006). The sampling was done at stations with geographic locations and characteristics are shown in Tab. 2.

3.2. Analysis for trace metals from the PM$_{10}$

After the gravimetric analysis for PM$_{10}$, the EPM2000 filters were digested in nitric acid and the concentration of heavy metals were analysed by using Atomic Absorption Spectrophotometer (AAS – Model ThermoFisher iCE 3300) (Katz, 1977). By using the same digestion method and chemicals a blank sample was prepared. The chemical reagents and standards used for the calibration of the instrument were of AR grade. The trace metal amounts in the samples were calculated by subtracting the blank value for the respective metal. The detection limit of various trace metals were Fe – 0.032 µg/m$^3$, Pb – 0.063 µg/m$^3$, Ni – 0.6 ng/m$^3$, Cu – 0.02 µg/m$^3$, Cd – 0.006 µg/m$^3$, Cr – 0.032 µg/m$^3$, Hg – 0.38 ng/m$^3$, As – 0.44 ng/m$^3$, and Se – 0.5 ng/m$^3$. The absorbance of both standard metal solution and digested sample of respective metal were compared to find the metal concentration. The digested samples were directly introduced into the flame of the instrument. Seven elements i.e., Cu, Pb, Cd, Cr, Zn, Ni, and Se were directly analysed in the AAS. Hg and As were analysed by VG-AAS (Vapour Generation Atomic Absorption Spectrometer). Vapour generation is a technique performed by an additional attachment connected with AAS for the detection of trace elements like Hg and As. Iron was analysed by titration method. The concentration of the object element (µg/mL) was obtained from the calibration plot. The concentration of an element in the atmosphere is obtained from the following relation (eq. 1):

$$C\left(\frac{\mu g}{m^3}\right) = \frac{\text{Concentration of the element in the digested sample (µg / mL)}}{\text{Volume of air sampled in m}^3}$$

$$\times \frac{\text{Total volume of sample (mL)}}{\text{Percent of filter area used for analysis}}$$

$$\text{(1)}$$

3.3. Data analysis techniques

Obtained data were processed for statistical analysis includg univariate and multivariate methods. Basic statistical parameters such as standard deviation, mean, median, and range were computed along with correlation analysis among the different parameters (Pandit et al., 2011) using IBM SPSS version 20.
3.4. Evaluation of health risk associated with trace metals

Human health risk was assessed on the basis of observed mean concentrations of particulate-bound trace elements and it depends on specific locations and its exposure route, i.e., ingestion, dermal, and inhalation (Du et al., 2013; Jai Prakash et al., 2018; Jai Prakash et al., 2018; Du et al., 2013). This study used the equations developed by USEPA to evaluate the exposure of humans to atmospheric particle bound trace elements. Mainly there are three main exposure paths through which the atmospheric elements can enter to the human body and these are ingestion, dermal absorption and inhalation through mouth and nose (Li et al., 2015). The exposure due to these paths was separately calculated by three different equations and these are given below (USEPA, 2009; USEPA, 2004a; USEPA, 1989). After the calculation of the exposure doses for the different elements and for all the pathways in exposure, the risk were calculated for both non-carcinogenic health risk and excess cancerous risk. The exposure dose for the three exposure routes were calculated by using the following equations (eqs. 2–4)

\[
ED_{\text{ing}} = \frac{C \times IR_{\text{ing}} \times CF \times EF \times ED}{BW \times AT} \tag{2}
\]

\[
ED_{\text{der}} = \frac{C \times SA \times AF \times EVF \times DAF \times EF \times ED \times CF}{BW \times AT} \tag{3}
\]

\[
ED_{\text{inh}} = \frac{C \times IR_{\text{inh}} \times CF \times EF \times ED}{BW \times AT} \tag{4}
\]

where:

- \(ED_{\text{ing}}\) = Exposure dose due to ingestion pathway
- \(ED_{\text{der}}\) = Exposure dose due to dermal contact
- \(ED_{\text{inh}}\) = Exposure dose due to inhalation pathway
- \(C\) = Concentration of metal in ambient air
- \(IR_{\text{ing}}\) = Ingestion rate
- \(IR_{\text{inh}}\) = Inhalation rate
- \(ED\) = Exposure duration
- \(EF\) = Exposure frequency
- \(BW\) = Body weight
- \(SA\) = Skin surface area
- \(AF\) = Adherence factor soil to skin
- \(EVF\) = Event frequency
- \(DAF\) = Dermal absorption fraction
- \(AT\) = Average time
- \(ET\) = Exposure time
- \(CF\) = Conversion factor
3.4.1. Non-carcinogenic risk

For the calculation of non-carcinogenic risk, hazard quotient \((HQ)\) and hazard index \((HI)\) were calculated for the trace elements for all the three exposure routes \(i.e.,\) ingestion, dermal contact, and inhalation. \(HQ\) via ingestion \((HQ_{ing})\), inhalation \((HQ_{inh})\) and dermal \((HQ_{der})\) contact were calculated by equations below (eqs. 5–7).

\[
HQ_{ing} = \frac{ED_{ing}}{RfD} \tag{5}
\]

\[
HQ_{inh} = \frac{ED_{inh}}{RfC} \tag{6}
\]

\[
HQ_{der} = \frac{ED_{der}}{RfD \times GIAF} \tag{7}
\]

were:

- \(RfD\) = Oral reference dose (mg/kg/day),
- \(RfC\) = Inhalation reference concentrations (mg/m³/day)
- \(GIAF\) = Gastrointestinal absorption factor.

The values of \(RfD, RfC\) and \(GIAF\) were adopted from US EPA, 2015. If \(HQ < 1\), there is no adverse effects on health and if \(HQ > 1\), there is likely adverse health effects due to exposure (USEPA, 1989). To avoid the underestimate of hazard potential of one element at a time with the simultaneous exposures to multiple elements hazards index is calculated by taking the sum of all the \(HQ\) s values of all the metals. \(HI\) was calculated as given in eq. 8 following the method earlier used by researchers (Zheng et al., 2010). The \(HI < 1\) indicates no risk from non-carcinogens, while \(HI > 1\) indicates significant non carcinogenic risk.

\[
HI = \sum_{i=1}^{n} HQ_{1} + HQ_{2} + \ldots + HQ_{i} \tag{8}
\]

where:

- \(HQ_{1}\) = \(HQ\) for 1st metal, let say Cr,
- \(HQ_{2}\) = \(HQ\) for 2nd metal, let say Cd, likewise
- \(HQ_{i}\) = \(HQ\) for \(i\)th metal

3.4.2. Excess cancer risk

Excess cancer risk (ECR) is the probability of developing cancer over the lifetime period of exposure to carcinogenic metals. The ECR were calculated for each of the analysed carcinogenic metals, and the combined effects were calculated in terms of \(ECR_{Total}\). The ECR can be expressed as follows (eq. 9) (USEPA, 2011):

\[
ECR_{Total} = HQ_{1} + HQ_{2} + \ldots + HQ_{i} \tag{9}
\]
\[ ECR = \frac{C \times ET \times EF \times ED \times IUR}{AT} \]  

where:

- \( C \) = Concentration of metal in ambient air
- \( ET \) = Exposure time
- \( EF \) = Exposure frequency
- \( ED \) = Exposure duration
- \( IUR \) = Inhalation unit risk of element
- \( AT \) = Average time

The value of \( IUR \) (µg/m³)⁻¹ of the element, obtained from the USEPA database, Integrated Risk Information System (IRIS) (https://www.epa.gov/iris). The details of the values of all the parameters used in equation and calculations are given in the supplementary material. The range of excess cancer risk has been recommended by the USEPA (2015) for public health. The acceptable value for carcinogenic risk falls between \( 10^{-6} \) to \( 10^{-4} \), above which there will be potential carcinogenic health risk. In the present study, the excess cancer risk was calculated for Cr, Ni, Pb, Zn, Cd and As out of 10 trace elements which are well-known.

**Table 3. Factors for exposure dose calculation.**

| Factors        | Definition                                           | Units                                                                 | Value          | Source                  |
|----------------|------------------------------------------------------|-----------------------------------------------------------------------|----------------|-------------------------|
| \( C \)        | Concentration of the metal in Ambient air            | mg/kg for ingestion and dermal exposure, and µg/m³ for inhalation exposure | Children Adult | US EPA (2004b)          |
| Ring           | Ingestion rate                                       | mg/day                                                               | 60             | 30                      | US EPA (2007)          |
| Rinh           | Inhalation rate                                      | m³/day                                                               | 10             | 20                      | US EPA (2011)          |
| EF             | Exposure Frequency                                   | day/year                                                             | 350            | 350                     | US EPA (2016b)         |
| ED             | Exposure Duration                                    | year                                                                 | 6              | 24                      | US EPA (2011)          |
| BW             | Body Weight                                          | kg                                                                   | 15             | 70                      | US EPA (2013)          |
| SA             | Skin surface Area Parameter                          | cm²                                                                  | 2800           | 5700                    | US EPA (2004b)         |
| AF             | Adherence Factor soil to Skin                        | mg/cm²/event                                                         | 0.2            | 0.07                    | US EPA (2004b)         |
| EVF            | Event Frequency                                      | event/day                                                            | 1              | 1                       | US EPA (2004b)         |
| DAF            | Dermal absorption fraction                           |                                                                      | 0.001          | 0.001                   | US EPA (2004a)         |
| AT             | Average time                                         | days/year                                                            | 365*ED         | 365*ED                  | US EPA (2004b)         |
| ET             | Exposure Time                                        | hours/day                                                            | 24             | 24                      | US EPA (2016b)         |
| \( CF(ED_{ing/der}) \) | Conversion Factor                                 | kg/mg                                                                | \( 10^{-6} \) | \( 10^{-6} \)           | US EPA (2004b)         |
| \( CF(ED_{inh}) \) | Conversion Factor                                | µg/m³                                                                | \( 10^{-3} \) | \( 10^{-3} \)           | US EPA (2004b)         |
carcinogens and whose IUR values are given in IRIS, 1995. Different factors for exposure calculation is tabulated in Tab. 3, whereas the reference doses for metals are tabulated in Tab. 4.

4. Results and discussion

4.1. Particulate matter

The statistical distribution of the particulate matter (PM$_{10}$ & PM$_{2.5}$) are presented in Table 5. The distributions of PM$_{10}$ and PM$_{2.5}$ along different locations in three different seasons are plotted in Figs. 2 and 3 respectively. From these figures, the seasonal variation in particulate concentrations is quite evident. The concentrations of PM$_{10}$ and PM$_{2.5}$ were observed highest during the winter season, followed by summer then post monsoon. Similar findings were also obtained by Dubey et al. (2012), Pandey et al. (2014), Jena and Singh (2017) around mining areas in Jharia Coalfield. Higher concentration of PM during winter is attributed to the prevalence of anti-cyclonic conditions, characterized by calm or light winds and limited mixing depth due to a stable or inversion of atmospheric lapse rate (Chaulya, 2004). The average PM$_{10}$ concentration of all the three seasons at all the sampling stations was observed as 338.43 µg/m$^3$, which was about 5.64 times above the NAAQS, 2009. Similarly, the average PM$_{2.5}$ concentration of all the three seasons at all the sampling stations was observed as 103.50 µg/m$^3$, which was about 2.59 times above the NAAQS, 2009. The annual mean concentration of PM$_{10}$ at different location shows that ST4 was experienced higher concentration of PM$_{10}$ (483.94 µg/m$^3$) followed by ST2 (420.22 µg/m$^3$), ST6 (380.85 µg/m$^3$), ST8 (369.92 µg/m$^3$), ST5 (333.35), ST7 (267.27 µg/m$^3$), ST1 (229.69 µg/m$^3$) and least at ST3 (221.20 µg/m$^3$). Similarly, the highest mean concentration of PM$_{2.5}$ was observed at ST4 (123.84 µg/m$^3$), followed by ST8 (107.86 µg/m$^3$), ST6 (107.55 µg/m$^3$),
ST2 (106.65 µg/m³), ST5 (100.74 µg/m³), ST7 (94.89 µg/m³), ST3 (94.47 µg/m³), and least at ST 1 (92.00 µg/m³). For all three observed seasons, the average particulate concentration was found highest in ST4. The highest concentrations of PM at ST4 were due to the continuous impact of mining activities in nearby locations as well as due to vehicular emissions from mining and non-mining transportation (Dubey et al., 2012; Huertas et al., 2012). All the stations were showing the average particulate concentrations above the standard value as prescribed in NAAQS 2009 (National Ambient Air Quality Standard, 2009). The maximum value of PM₁₀ was
found at ST 4 (1092.93 µg/m$^3$). The ratios of PM$_{2.5}$ and PM$_{10}$ (PM$_{2.5}$/PM$_{10}$) calculated at all monitoring stations illustrate significant contribution of PM$_{2.5}$ to the total PM$_{10}$ concentrations (Tab. 5). Mining operations generally contribute more fraction of large sized dust particles along with fine particles in very less fraction. High PM$_{2.5}$ to PM$_{10}$ ratio represents significance influence of vehicular emissions (especially, tail pipe emissions), while low ratio depicts the influence of fugitive emission as well as resuspension of settled dusts. The lowest value of PM$_{2.5}$ and PM$_{10}$ ratio in ST2 and ST4 suggested that the PM constitute more fraction of coarse particulate as compared to rest of the stations. ST2 and ST4 were more exposed to mining and transportation activity and thus having more coarse particles from crustal generation. ST5, ST6, and ST8 had slightly higher ratios, whereas ST1, ST3 and ST7 were higher PM$_{2.5}$ and PM$_{10}$ ratio indicated more fraction of finer particles in the PM mass.

4.2. Trace elements

The average concentration of trace elements in all the three seasons at all the sampling stations was observed highest for Cd (3.465 µg/m$^3$) followed by Fe (2.26 µg/m$^3$), Zn (0.857 µg/m$^3$), Cr (0.748 µg/m$^3$), Pb (0.07 µg/m$^3$), Cu (0.03 µg/m$^3$), Ni (0.015 µg/m$^3$), As (0.004 µg/m$^3$), Se (0.0013 µg/m$^3$) and Hg (0.0012 µg/m$^3$). The decreasing elemental concentration trend of the study area was Cd>Fe>Zn>Cr>Pb>Cu>Ni>As>Se>Hg. The concentration of Fe was highest in summer and the values

| 6,5 | Particulate | Maximum | Minimum | SD  | Arithmetic mean | Geometric mean | Median | Ratio PM$_{2.5}$/PM$_{10}$ |
|-----|-------------|---------|---------|-----|----------------|---------------|--------|--------------------------|
| ST1 | PM$_{10}$   | 582.91  | 94.07   | 133.23 | 232.36          | 204.67        | 180.17 | 0.40                     |
|     | PM$_{2.5}$  | 173.84  | 38.85   | 37.51  | 92.52           | 85.11         | 94.02  |                          |
| ST2 | PM$_{10}$   | 960.23  | 149.16  | 199.22 | 425.51          | 385.59        | 372.14 | 0.25                     |
|     | PM$_{2.5}$  | 199.12  | 27.07   | 46.39  | 107.28          | 97.60         | 95.32  |                          |
| ST3 | PM$_{10}$   | 421.71  | 99.69   | 92.44  | 220.51          | 202.44        | 193.21 | 0.43                     |
|     | PM$_{2.5}$  | 208.84  | 36.17   | 42.14  | 94.73           | 85.95         | 88.52  |                          |
| ST4 | PM$_{10}$   | 1092.93 | 97.40   | 241.22 | 484.37          | 425.17        | 403.30 | 0.26                     |
|     | PM$_{2.5}$  | 276.66  | 38.46   | 53.27  | 124.29          | 114.14        | 118.16 |                          |
| ST5 | PM$_{10}$   | 630.23  | 121.16  | 139.90 | 334.81          | 306.68        | 309.66 | 0.30                     |
|     | PM$_{2.5}$  | 209.69  | 42.37   | 54.19  | 100.64          | 95.52         | 97.85  |                          |
| ST6 | PM$_{10}$   | 787.64  | 200.90  | 152.15 | 393.68          | 369.08        | 351.88 | 0.28                     |
|     | PM$_{2.5}$  | 223.43  | 58.37   | 41.66  | 110.34          | 103.78        | 101.32 |                          |
| ST7 | PM$_{10}$   | 572.12  | 117.10  | 118.03 | 279.56          | 256.42        | 261.85 | 0.35                     |
|     | PM$_{2.5}$  | 196.25  | 67.45   | 26.10  | 96.87           | 94.22         | 88.33  |                          |
| ST8 | PM$_{10}$   | 685.84  | 170.66  | 126.50 | 374.89          | 354.44        | 330.56 | 0.29                     |
|     | PM$_{2.5}$  | 165.29  | 69.42   | 24.24  | 108.71          | 106.18        | 104.63 |                          |
ranged from 3.82 µg/m³ to 1.37 µg/m³ (Post monsoon). Similarly the average value of Cu ranged from 0.037 µg/m³ in summer to 0.029 µg/m³ in post monsoon, Pb 0.09 µg/m³ (summer) to 0.04 µg/m³ (Post monsoon), Cd 6.92 µg/m³ (winter) to 3.45 µg/m³ (post monsoon), Cr 1.54 µg/m³ (winter) to 0.67 µg/m³ (post monsoon), Zn 1.02 µg/m³ (Post monsoon) to 1.00 µg/m³ (winter). Hg 0.0016 µg/m³ (winter) to 0.0012 µg/m³ (post monsoon), Ni 0.018 µg/m³ (post monsoon) to 0.015 µg/m³ (winter), As 0.0069 µg/m³ (winter) to 0.0035 µg/m³ (post monsoon) and Se 0.0019 µg/m³ (winter) to 0.0011 µg/m³ (winter). The value of Pb in the area was minimum at ST7 in post monsoon season (0.032 µg/m³) and maximum found at ST4 in winter season (0.149 µg/m³). In all the stations the observed values were well within the standard of NAAQS 2009 (0.5 µg/m³). The low concentration of Pb even along the transportation routes may be due to use of unleaded fuels. Ni concentrations were observed higher than the NAAQS (0.02 µg/m³) at ST1 in post monsoon (0.0211 µg/m³), ST2 in winter (0.0217 µg/m³) and summer (0.027 µg/m³), ST5 in post monsoon (0.0318 µg/m³) and summer (0.0199 µg/m³), ST7 in summer (0.446 µg/m³). The Ni concentration in ST5 in summer (0.0199 µg/m³) and ST8 in post monsoon (0.0199 µg/m³) just touched the limit of NAAQS and all other locations were well within the range. The increased concentrations of Ni in this area indicates the influence of transportation activities. The average concentration of As was from 0.0004 µg/m³ at ST1 & ST8 in summer season to 0.0152 µg/m³ at

Figure 4.1. Seasonal distribution of iron.

Figure 4.2. Seasonal distribution of copper.

Figure 4.3. Seasonal distribution of lead.

Figure 4.4. Seasonal distribution of cadmium.
ST4 in winter season. In the study area the values of As was minimum at ST1 in summer (0.0004 µg/m³) and maximum at ST4 in winter (0.0152 µg/m³). The value of As were found far above the standard limit (0.0060 µg/m³) at ST2 (0.0082 µg/m³), ST4 (0.0152 µg/m³), ST5 (0.0067 µg/m³), ST6 (0.0060 µg/m³), ST7 (0.0090 µg/m³) and ST8 (0.0064 µg/m³). All other stations were within the standard limit. As is originated from automobile emissions, industrial emissions (Karar et al., 2006) and coal burning (Xie et al., 2006; Zhang et al., 2009). Even though Hg is not
listed in NAAQS, the analysis value of dust samples of all the stations are showing some amount of Hg in all the season. The dust of ST7 and ST1 showed higher Hg content as compared with all the stations. Figures 4.1.–4.10. presented below are showing the variation of trace metals in different stations in different seasons.

4.3. Principal component analysis

PCA is one of the best method used for source apportionment study of metals in terms of quantitative information (Tsai and Cheng, 2004). The main application of the factor analysis is to reduce the number of variables. Hence PCA can be useful as a data reduction method. Varimax Rotated Factor Matrix method, based on the orthogonal rotation criterion was used in the PCA analysis in this study, which maximizes the variance of the squared metals in the column of a factor matrix (IBM SPSS 20.0) (Winner and Cass, 2001). This method focuses on cleaning up the factors. It produces factors that have high correlations with one smaller set of variables and little or no correlation with another set of variables. The average concentration for every trace elements in all the three seasons at all the sampling stations were taken for PCA study. Four components (principal components) having eigen values > 1 were extracted.

Table 6. Principal component analysis of PM and trace metals.

| Factors | Component |
|---------|-----------|
|         | PC1 | PC2 | PC3 | PC4 |
| PM10    | 0.759 | 0.079 | 0.594 | 0.021 |
| PM2.5   | 0.748 | -0.034 | 0.620 | 0.210 |
| Fe      | 0.385 | 0.859 | 0.118 | 0.256 |
| Cu      | 0.827 | -0.067 | 0.414 | 0.011 |
| Pb      | 0.911 | -0.080 | 0.227 | 0.277 |
| Cd      | 0.956 | 0.008 | 0.001 | 0.054 |
| Cr      | -0.284 | 0.916 | 0.202 | -0.124 |
| Zn      | -0.100 | 0.932 | -0.174 | 0.225 |
| Hg      | -0.243 | -0.054 | -0.953 | 0.051 |
| Ni      | 0.197 | 0.628 | -0.525 | -0.470 |
| As      | 0.973 | 0.083 | -0.025 | 0.170 |
| Se      | 0.350 | 0.227 | -0.018 | 0.883 |
| Total   | 4.970 | 2.919 | 2.229 | 1.288 |
| % Variance | 41.413 | 24.327 | 18.577 | 10.735 |
| % Cumulative Variance | 41.413 | 65.740 | 84.317 | 95.052 |

Extraction Method: – Principal Component,  
Rotation Method: – Varimax with Kaiser Normalization
6 represents the Principal Component (PC) loadings for the different factors during the study period. PC1 with variance 41.41% shows higher loading of Cu, Pb, Cd and As which indicates close association of these elements with particulate matter. Cd and Pb are associated with mining and allied activities (Chen et al., 2015). Apart from mining activity Cd is also associated with the resuspension of road dust (Sternbeck et al., 2002). In addition to mining activity, Pb and Cd is also related to vehicular emission (Kulshrestha et al., 2009; Querol et al., 2007). Cu is mainly related to coal combustion (Zhang et al., 2014). Arsenic is associated with vehicular emission. PC2 is represented by Fe, Cr, Zn and Ni with variance 24.33%. Cr is mainly generated by coal combustion (Pandey et al., 2014; Zhang et al., 2014). Fe and Zn is from crustal origin. Fe is crustal in origin and associated with road dust or dust from OB dumps (Chakraborty and Gupta, 2009; Ragosta et al., 2002). The origin of Ni is from vehicular emission (Chen et al., 2015; Hafner et al., 2004). PC3 is represented by Hg with variance 18.58%. The negative sign of Hg indicate the negative correlation of Hg with other parameters. PC4 is represented by Se with variance 10.74%. The scree plot and component plot in rotated space for the PCA analysis is shown in Figs. 5 and 6, respectively. The scree plot shows that out of the all twelve components, four components are having eigen value greater than 1. These four components explain 95.05% of the variation in the data. The scree plot shows that the eigenvalues start to form a straight line after the fourth principal component and so these four components are adequate amount of variation explained in the data to explain the component analysis.

Figure 5. Screen plot for PCA analysis.
4.4. Correlation analysis

Pearson’s correlation analysis was performed to examine the correlation between all the trace metals and PM under consideration in terms of their concentrations. Correlation study was performed to identify the respective sources of generation of PM$_{10}$ and trace metals. It is evident that elements that are strongly correlated indicate some common sources (Basha et al., 2014; Shah and Shaheen, 2010). The average concentration of all the twelve measured parameters (PM$_{10}$, PM$_{2.5}$ and ten trace metals) of all the three seasons of each monitoring stations were taken for correlation analysis. PM PM$_{10}$ was significantly correlated with PM$_{2.5}$ (r=0.950) at level 0.01, Cu (r=0.788), Pb (r=0.826), Cd (r=0.739) and As (r=0.731) at level 0.05. Likewise PM$_{2.5}$ also shown same level of co-relation with the metals as PM10. Very strong correlation was observed between Cu-Cd (r=0.767), Pb-Cd (r=0.840) and Pb-Cu (r=0.881). Fe, Cr were observed correlated well with each other (Fe-Cr; r =0.655). Fe and Cr are lithophile i.e., concentrated more in earth’s crust (White, 2013; Nordbeg et al., 2005), hence these elements are likely to be contributed from windblown dust (Basha et al., 2014). Significant correlation were also observed between Zn-Cr (r=0.801) and Zn-Fe (0.819). Strong correlation were found between As-Cu(r=0.771), As-Pb (r=0.916) and As-Cd (r=0.925) whereas significant co-relation were also observed between As-Fe (r=0.487), Ar-Se (r=0.519), Se-Fe (r=0.522) and Se-Pb (r=0.562). These metals are generally anthropogenic by origin, therefore activities like metal corrosion (Cu, Zn, Cd) (Basha et al., 2014), vehicular emission, coal burning (As, Cr, Pb) (Zhang et
al., 2009) were the responsible contributing sources. Zn is emitted utterly from vehicular sources like, wear and tear of vulcanized tyres, and oil combustion (Shah and Shaheen, 2012; Kulshrestha et al., 2009; Thorpe and Harrison, 2008; Karar et al., 2006; Khillare et al., 2004). Hence, the most prominent sources of trace elements in the study area were resuspension of road dust due to vehicular emission and coal burning. Correlation matrix were developed and shown in Tab. 7 for clear indication of relations between data points.

### 4.5. Health risk assessment

#### 4.5.1. Non carcinogenic health risk of trace elements via ingestion exposure and dermal exposure

The exposure of atmospheric particulates via ingestion may be through the food, drinks and hand to mouth or object to mouth transfer of particles (Hu et al., 2012). Therefore, the ingestion exposure to PM was calculated. Similarly the HQ ad HI vales for dermal exposure was also calculated. The HI value of different location for both children and adults due to ingestion is plotted in Fig. 7 and due to dermal exposure is plotted in Fig. 8. It is quite evident from the results that the non-carcinogenic risk due to ingestion and dermal exposure were well within the safe limit for all the people groups in all the locations. The details of the calculated results for ingestion are given in Tab. 8 and for dermal exposure are given in Tab. 9.

| PM10 | PM2.5 | Fe   | Cu   | Pb   | Cd   | Cr   | Zn   | Hg   | Ni   | As   | Se   |
|------|-------|------|------|------|------|------|------|------|------|------|------|
| PM10 | 1.00  | .950 | .390 | .788 | .826 | .739 | -.008| -.122| -.761| -.085| .731 | .330 |
| PM2.5| 1.00  | .379 | .851 | .867 | .748 | -.152| -.157| -.766| -.300| .749 | .427 |
| Fe   | 1.00  | .372 | .376 | .389 | .655 | .819 | -.232| .399 | .487 | .522 |
| Cu   | 1.00  | .881 | .767 | -.212| -.199| -.555| -.158| .771 | .228 |
| Pb   | 1.00  | .840 | -.301| -.174| -.414| -.097| .916 | .562 |
| Cd   | 1.00  | .801 | -.165| .482 | -.241| .019 | .339 |
| Cr   | 1.00  | .162 | .504 | .019 | .519 |     |     |
| Zn   | 1.00  | .364 | -.230| -.053|     |     |     |
| Hg   | 1.00  | .195 | -.139|     |     |     |     |
| Ni   | 1.00  | .519 |     |     |     |     |     |

** Correlation is significant at the 0.01 level *Correlation is significant at the 0.05 level
Table 8. Calculated values of HQ and HI for different locations due to ingestion.

|      | Cr     | Cu     | Cd     | Ni     | Pb     | Zn     | As     | Se     | HI     |
|------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| ST1  |        |        |        |        |        |        |        |        |        |
| Children | 1.10E-02 | 2.78E-06 | 7.44E-03 | 2.08E-06 | 4.82E-05 | 1.01E-05 | 2.65E-05 | 5.69E-07 | 1.86E-02 |
| Adult  | 1.18E-03 | 2.98E-07 | 7.97E-04 | 2.23E-07 | 5.17E-06 | 1.08E-06 | 2.84E-06 | 6.10E-08 | 1.99E-03 |
| ST2  |        |        |        |        |        |        |        |        |        |
| Children | 1.69E-02 | 3.48E-06 | 1.35E-02 | 4.27E-06 | 8.44E-05 | 1.08E-05 | 5.67E-05 | 1.02E-06 | 3.05E-02 |
| Adult  | 1.81E-03 | 3.73E-07 | 1.44E-03 | 4.57E-07 | 9.04E-06 | 1.16E-06 | 6.08E-06 | 1.09E-07 | 3.27E-03 |
| ST3  |        |        |        |        |        |        |        |        |        |
| Children | 8.71E-03 | 2.08E-06 | 4.25E-03 | 1.90E-06 | 4.93E-05 | 1.12E-05 | 3.75E-05 | 1.14E-06 | 1.31E-02 |
| Adult  | 9.33E-04 | 2.23E-07 | 4.55E-04 | 2.04E-07 | 5.28E-06 | 1.20E-06 | 4.02E-06 | 1.22E-07 | 1.40E-03 |
| ST4  |        |        |        |        |        |        |        |        |        |
| Children | 2.88E-03 | 7.13E-06 | 2.44E-02 | 1.66E-06 | 1.25E-04 | 9.55E-06 | 8.12E-05 | 1.15E-06 | 2.75E-02 |
| Adult  | 3.09E-04 | 7.64E-07 | 2.61E-03 | 1.78E-07 | 1.33E-05 | 1.02E-06 | 8.70E-06 | 1.23E-07 | 2.94E-03 |
| ST5  |        |        |        |        |        |        |        |        |        |
| Children | 2.22E-02 | 2.94E-06 | 1.38E-02 | 5.15E-06 | 5.88E-05 | 1.53E-05 | 5.18E-05 | 7.85E-07 | 3.62E-02 |
| Adult  | 2.38E-03 | 3.15E-07 | 1.48E-03 | 5.51E-07 | 6.30E-06 | 1.64E-06 | 5.55E-06 | 8.41E-08 | 3.87E-03 |
| ST6  |        |        |        |        |        |        |        |        |        |
| Children | 4.09E-04 | 2.56E-06 | 1.34E-02 | 1.42E-06 | 6.43E-05 | 6.26E-06 | 4.52E-05 | 7.21E-07 | 1.39E-02 |
| Adult  | 4.38E-05 | 2.74E-07 | 1.44E-03 | 1.52E-07 | 6.89E-06 | 6.71E-07 | 4.84E-06 | 7.73E-08 | 1.49E-03 |
| ST7  |        |        |        |        |        |        |        |        |        |
| Children | 4.09E-04 | 2.49E-06 | 1.87E-02 | 4.53E-06 | 7.96E-05 | 1.03E-05 | 6.44E-05 | 9.79E-07 | 1.93E-02 |
| Adult  | 4.38E-05 | 2.67E-07 | 2.01E-03 | 4.86E-07 | 8.53E-06 | 1.11E-06 | 6.89E-06 | 1.05E-07 | 2.07E-03 |
| ST8  |        |        |        |        |        |        |        |        |        |
| Children | 1.44E-02 | 2.65E-06 | 1.63E-02 | 1.99E-06 | 7.31E-05 | 1.42E-05 | 5.32E-05 | 1.36E-06 | 3.09E-02 |
| Adult  | 1.54E-03 | 2.84E-07 | 1.75E-03 | 2.14E-07 | 7.83E-06 | 1.52E-06 | 5.70E-06 | 1.46E-07 | 3.31E-03 |
Table 9. Calculated values of HQ and HI for different locations due to dermal exposure.

| Location | HQ/NI | Cr    | Cu    | Cd    | Ni    | Pb    | Zn    | As    | Se    | HI    |
|----------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| ST1      |       |       |       |       |       |       |       |       |       |       |
| Children | 7.93E-03 | 2.60E-08 | 2.78E-03 | 4.86E-07 | 4.50E-07 | 9.39E-08 | 2.47E-07 | 5.31E-09 | 1.07E-02 |       |
| Adult    | 1.21E-02 | 3.96E-08 | 4.24E-03 | 7.41E-07 | 6.87E-07 | 1.43E-07 | 3.77E-07 | 8.11E-09 | 1.63E-02 |       |
| ST2      |       |       |       |       |       |       |       |       |       |       |
| Children | 1.21E-02 | 3.25E-08 | 5.03E-03 | 9.96E-07 | 7.88E-07 | 1.01E-07 | 5.29E-07 | 9.53E-09 | 1.72E-02 |       |
| Adult    | 1.85E-02 | 4.96E-08 | 7.68E-03 | 1.52E-06 | 1.20E-06 | 1.54E-07 | 8.08E-07 | 1.45E-08 | 2.62E-02 |       |
| ST3      |       |       |       |       |       |       |       |       |       |       |
| Children | 6.25E-03 | 1.94E-08 | 1.59E-03 | 4.44E-07 | 4.60E-07 | 1.04E-07 | 3.50E-07 | 1.06E-08 | 7.84E-03 |       |
| Adult    | 9.55E-03 | 2.96E-08 | 2.42E-03 | 6.78E-07 | 7.03E-07 | 1.59E-07 | 5.35E-07 | 1.62E-08 | 1.20E-02 |       |
| ST4      |       |       |       |       |       |       |       |       |       |       |
| Children | 2.07E-03 | 6.65E-08 | 9.10E-03 | 3.87E-07 | 1.16E-06 | 8.91E-08 | 7.58E-07 | 1.07E-08 | 1.12E-02 |       |
| Adult    | 3.16E-03 | 1.02E-07 | 1.39E-02 | 5.91E-07 | 1.78E-06 | 1.36E-07 | 1.16E-06 | 1.64E-08 | 1.71E-02 |       |
| ST5      |       |       |       |       |       |       |       |       |       |       |
| Children | 1.59E-02 | 2.74E-08 | 5.17E-03 | 1.20E-06 | 5.49E-07 | 1.43E-07 | 4.83E-07 | 7.33E-09 | 2.11E-02 |       |
| Adult    | 2.43E-02 | 4.19E-08 | 7.89E-03 | 1.83E-06 | 8.38E-07 | 2.19E-07 | 7.38E-07 | 1.12E-08 | 3.22E-02 |       |
| ST6      |       |       |       |       |       |       |       |       |       |       |
| Children | 2.94E-04 | 2.39E-08 | 5.01E-03 | 3.32E-07 | 6.00E-07 | 5.85E-08 | 4.22E-07 | 6.73E-09 | 5.30E-03 |       |
| Adult    | 4.48E-04 | 3.64E-08 | 7.65E-03 | 5.07E-07 | 9.16E-07 | 8.93E-08 | 6.44E-07 | 1.03E-08 | 8.10E-03 |       |
| ST7      |       |       |       |       |       |       |       |       |       |       |
| Children | 2.94E-04 | 2.33E-08 | 7.00E-03 | 1.06E-06 | 7.43E-07 | 9.63E-08 | 6.01E-07 | 9.14E-09 | 7.29E-03 |       |
| Adult    | 4.48E-04 | 3.55E-08 | 1.07E-02 | 1.62E-06 | 1.13E-06 | 1.47E-07 | 9.17E-07 | 1.40E-08 | 1.11E-02 |       |
| ST8      |       |       |       |       |       |       |       |       |       |       |
| Children | 1.04E-02 | 2.48E-08 | 6.10E-03 | 4.65E-07 | 6.82E-07 | 1.32E-07 | 4.97E-07 | 1.27E-08 | 1.64E-02 |       |
| Adult    | 1.58E-02 | 3.78E-08 | 9.31E-03 | 7.10E-07 | 1.04E-06 | 2.02E-07 | 7.59E-07 | 1.94E-08 | 2.51E-02 |       |
Table 10. Calculated values of HQ and HI for different locations due to inhalation.

| Location | HQ   | Cr     | Cu     | Cd     | Ni     | Pb     | Zn     | As     | Hg     | HI    |
|----------|------|--------|--------|--------|--------|--------|--------|--------|--------|-------|
| ST1      |      | 1.93E+01 | 4.61E-04 | 1.24E+00 | 1.97E-03 | 7.99E-03 | 1.67E-03 | 4.41E-03 | 3.14E-03 | 2.06E+01 |
|          | Adult| 8.27E+00 | 1.98E-04 | 5.31E-01 | 8.44E-04 | 3.42E-03 | 7.16E-04 | 1.89E-03 | 1.35E-03 | 8.81E+00 |
| ST2      | Children | 2.96E+01 | 5.78E-04 | 2.25E+00 | 4.04E-03 | 1.40E-02 | 1.79E-03 | 9.45E-03 | 2.02E-03 | 3.18E+01 |
|          | Adult | 1.27E+01 | 2.48E-04 | 9.62E-01 | 1.73E-03 | 5.99E-03 | 7.68E-04 | 4.05E-03 | 8.68E-04 | 1.36E+01 |
| ST3      | Children | 1.52E+01 | 3.45E-04 | 7.08E-01 | 1.80E-03 | 8.17E-03 | 1.85E-03 | 6.26E-03 | 2.98E-03 | 1.60E+01 |
|          | Adult | 6.52E+00 | 1.48E-04 | 3.03E-01 | 7.73E-04 | 3.50E-03 | 7.95E-04 | 2.68E-03 | 1.28E-03 | 6.84E+00 |
| ST4      | Children | 5.04E+00 | 1.18E-03 | 4.06E+00 | 1.57E-03 | 2.06E-02 | 1.59E-03 | 1.35E-02 | 1.31E-03 | 9.14E+00 |
|          | Adult | 2.16E+00 | 5.07E-04 | 1.74E+00 | 6.73E-04 | 8.85E-03 | 6.80E-04 | 5.80E-03 | 5.63E-04 | 3.92E+00 |
| ST5      | Children | 3.88E+01 | 4.88E-04 | 2.31E+00 | 4.87E-03 | 9.75E-03 | 2.55E-03 | 8.63E-03 | 2.32E-03 | 4.11E+01 |
|          | Adult | 1.66E+01 | 2.09E-04 | 9.89E-01 | 2.09E-03 | 4.18E-03 | 1.09E-03 | 3.70E-03 | 9.92E-04 | 1.76E+01 |
| ST6      | Children | 7.15E-01 | 4.24E-04 | 2.24E+00 | 1.35E-03 | 1.07E-02 | 1.04E-03 | 7.53E-03 | 1.73E-03 | 2.97E+00 |
|          | Adult | 3.07E-01 | 1.82E-04 | 9.58E-01 | 5.78E-04 | 4.57E-03 | 4.46E-04 | 3.23E-03 | 7.40E-04 | 1.27E+00 |
| ST7      | Children | 7.15E-01 | 4.13E-04 | 3.12E+00 | 4.29E-03 | 1.32E-02 | 1.71E-03 | 1.07E-02 | 4.67E-03 | 3.87E+00 |
|          | Adult | 3.07E-01 | 1.77E-04 | 1.34E+00 | 1.84E-03 | 5.66E-03 | 7.34E-04 | 4.60E-03 | 2.00E-03 | 1.66E+00 |
| ST8      | Children | 2.52E+01 | 4.40E-04 | 2.72E+00 | 1.89E-03 | 1.21E-02 | 2.36E-03 | 8.87E-03 | 2.66E-03 | 2.80E+01 |
|          | Adult | 1.08E+01 | 1.89E-04 | 1.17E+00 | 8.09E-04 | 5.19E-03 | 1.01E-03 | 3.80E-03 | 1.14E-03 | 1.20E+01 |
4.5.2. Non carcinogenic health risk of trace elements via inhalation exposure

Inhalation exposure is typically the principle way of direct exposure to atmospheric particulate bound trace elements (USEPA, 1989). HQ of 8 out of 10 trace elements (Cr, Ni, Pb, Zn, Cd, As, Hg and Cu) for inhalation pathway for both adults and children were calculated and given in Tab. 10. The HQ and HI values for Fe and Se could not been calculated in this study as their threshold values (RfD and RfC) for different exposure routes are not listed by US EPA. Table 10 represents that the HQ values for Cr are higher than the safe limit (=1) in in all the locations except ST6 and ST7 for both children and adults showing it might pose non-carcinogenic risk. Similarly the HQ value of Cd in ST1 (1.24), ST2 (1.25), ST5 (2.31) and ST6 (2.24) were higher than the limit for children and the values were within the limit for adult. In ST4 (4.06 children, 1.74 adult),

![Distribution of HI values for ingestion exposure](image1)

**Figure 7. HI values due to ingestion route at different locations.**

![Distribution of HI values for dermal exposure](image2)

**Figure 8. HI values due to dermal route at different locations.**
ST7 (3.12 children, 1.33 adult) and ST8 (2.72 children, 1.17 adult), both for adult and children the values were far above the limit indicating no carcinogenic health risk due to Cadmium in those locations. Besides the two metals the HQ for all other considered metals the values were in acceptable range. However the combine effect of all the metals i.e., the HI values cannot be ignored as for all the locations and for both children and adult the values were above the limit (=1) showing a deep consideration of health risk due to metal pollution. The HI values for both children and adult in all the sampling locations were shown in Fig. 9.

4.5.3. Carcinogenic health risk assessment

To estimate the carcinogenic risks of the particulate bound trace metals six trace element (Cr(VI), Ni, Pb, Zn, Cd, and As) from the total ten measured metals were taken into consideration by taking the carcinogenicity (IARC: International Agency for Research on Cancer) of the metals. As, Ni, Cd and Cr (VI) compounds are classified under class 1 carcinogen while Pb compounds class 2A carcinogen elements (IARC, 2013). The concentration ratio of Cr (VI) to Cr (III) is about 1:6. So, for the calculation of carcinogenic health risk due to Cr (VI), the concentration of Cr (VI) was taken as 1/7 of the total concentration of PM bound chromium (Massey et al., 2013; USEPA, 2004b). Due to unavailability of reference values of carcinogenic risk through dermal exposure and ingestion pathway, the carcinogenic risk assessment only through inhalation pathway were considered. The estimated ECR of PM bound carcinogenic elements for all the locations are presented in Tab. 11.

The observed ECR values for Cr exceeds the acceptable limit for both children and adult in ST1, ST2 ST5 and ST8. In ST3 the ECR value of Cr for children (0.0001) was within the limit and for adult exceeded the safe limit (0.0004). In ST4 the children were safe from the carcinogenicity effects of Cr having ECR value 0.00003 where the adults were at risk 0.00013. In ST6 and ST7 both the
groups were safe in the term of carcinogenicity effects of Cr. The ECR value of Cd for the both group of people in all the locations were above the safe limit showing the carcinogenic effect due to Cr pollution in that area. Except Cr and Cd the ECR value of all other metals were found well within the safe limit. The combined

| Age group | Cr     | Ni     | Pb     | Zn     | Cd     | As     | ECR<sub>Total</sub> |
|-----------|--------|--------|--------|--------|--------|--------|---------------------|
| **ST1**   | Children 1.2E–04 2.1E–07 4.3E–08 7.8E–07 2.9E–04 7.3E–07 4.10E–04 |  |  |  |  |  |  |
|           | Adult 4.9E–04 1.2E–07 1.7E–07 3.1E–06 1.1E–03 2.9E–06 1.64E–03 |  |  |  |  |  |  |
| **ST2**   | Children 1.9E–04 4.4E–07 7.6E–08 8.3E–07 5.2E–04 1.6E–06 7.09E–04 |  |  |  |  |  |  |
|           | Adult 7.5E–04 2.5E–07 3.0E–07 3.3E–06 2.1E–03 6.3E–06 2.83E–03 |  |  |  |  |  |  |
| **ST3**   | Children 9.6E–05 2.0E–07 4.4E–08 8.6E–07 1.6E–04 1.0E–06 2.62E–04 |  |  |  |  |  |  |
|           | Adult 3.8E–04 1.1E–07 1.8E–07 3.4E–06 6.6E–04 4.2E–06 1.05E–03 |  |  |  |  |  |  |
| **ST4**   | Children 3.2E–05 1.7E–07 1.1E–07 7.4E–07 9.4E–04 2.2E–06 9.75E–04 |  |  |  |  |  |  |
|           | Adult 1.3E–04 9.7E–08 4.5E–07 2.9E–06 3.8E–03 9.0E–06 3.90E–03 |  |  |  |  |  |  |
| **ST5**   | Children 2.4E–04 5.3E–07 5.3E–08 1.2E–06 5.3E–04 1.4E–06 7.82E–04 |  |  |  |  |  |  |
|           | Adult 9.8E–04 3.0E–07 2.1E–07 4.7E–06 2.1E–03 5.7E–06 3.12E–03 |  |  |  |  |  |  |
| **ST6**   | Children 4.5E–06 1.5E–07 5.8E–08 4.8E–07 5.2E–04 1.2E–06 5.24E–04 |  |  |  |  |  |  |
|           | Adult 1.8E–05 8.4E–08 2.3E–07 1.9E–06 2.1E–03 5.0E–06 2.10E–03 |  |  |  |  |  |  |
| **ST7**   | Children 4.5E–06 4.7E–07 7.2E–08 8.0E–07 7.2E–04 1.8E–06 7.30E–04 |  |  |  |  |  |  |
|           | Adult 1.8E–05 2.7E–07 2.9E–07 3.2E–06 2.9E–03 7.1E–06 2.92E–03 |  |  |  |  |  |  |
| **ST8**   | Children 1.6E–04 2.1E–07 6.6E–08 1.1E–06 6.3E–04 1.5E–06 7.92E–04 |  |  |  |  |  |  |
|           | Adult 6.4E–04 1.2E–07 2.6E–07 4.4E–06 2.5E–03 5.9E–06 3.17E–03 |  |  |  |  |  |  |

Figure 10. ECR total values due to inhalation route at different locations.
carcinogenic effect of all the metals were calculated by taking the summation of the ECR values of each metal under consideration. The sum of all the ECR values termed as ECR\textsubscript{Total} and the same were calculated for all the locations of the study area. The results reviled that the ECR values in all the locations were far above the safe limit (10^{-6} to 10^{-4}) for both children and adult prescribed by USEPA, indicating very high risk of cancer in the study area. The ECR\textsubscript{Total} for both children and adults in all the locations were plotted in Fig. 10.

5. Concluding remarks

The result obtained by the monitoring of particulate matter suggested that the study area is highly loaded with particulate pollution from mining and non-mining sources. The seasonal variations of particulate matter (PM\textsubscript{10} and PM\textsubscript{2.5}) confirms about the highest concentration of particulate matter in winter season followed by summer and post monsoon. The concentrations of particulate matter were above the standard level all over the year as prescribed by NAAQS, 2009. After analysis of results it can be concluded that in the study area, source contribution is mainly due to earth crust \textit{i.e.}, mining and associated mining activities, vehicular emissions and road dust through unpaved roads. The characterization of trace metal sources in the study area is quite challenging due to a large number of source contributions to the study area. Factor analysis (PCA) suggested the dominance of Cd, Cu, As, and Pb in dust of the study area and represented as PC1. These were mainly contributed by vehicular emission from transportation of coal, running of mine machineries and coal burning in the study area. PCA also suggested the abundance of Fe, Zn, Cr, and Ni in the study area represented by PC2, Hg show its abundance by representing in the PC3 and Se as PC4. The correlation analysis supports the relationship between different parameters in the study area. The calculated HQ value for Cr and Cd were found above safe limit in most of the location of the study area for both children and adults. The inhalation route was found as the major route of trace metal exposure for human being as compared to ingestion and dermal route. Furthermore very significant health effects were observed due to combine effects of metals in the study area. The potential carcinogenic risk via inhalation route observed for each elements and the risk due to Cr (VI) and Cd were found above the safe limit, where all others were in the safe limit. The ECR\textsubscript{Total} values at all the locations were far above the safe limit. The health risk assessment study on the nearby resident of the coal mine suggested high intensification of both carcinogenic and non-carcinogenic risk from the PM bound trace metals although found in very low concentration.

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Mjerenje koncentracije respiratorne prašine i procjena zdravstvenog rizika od teških metala u području otvorenog rudnika ugljena tvrtke Talcher, Odisha

Debi Prasad Tripathy i Tushar Ranjan Dash

Atmosfersko onečišćenje uzrokovano lebdećim česticama u blizini površinskog rudnika ugljena vrlo je važan ekološki problem i privlači pozornost istraživača diljem svijeta već nekoliko desetljeća. Lebdeće čestice ne utječu samo na ljude, već imaju i ogromne učinke na obližnju floru i faunu, degradirajući okoliš na mnogo načina. Visoka mehanizacija u rudarstvu dovodi do velikog opterećenja okoliša prašinom. Štetni učinci prašine ovise o njenoj količini, svojstvima i izloženosti. S obzirom na važnost onečišćenja prašinom u rudnicima, odabrana je studija izvršena uz otvoreni rudnik Talcher, u staništvo kojem se onečišćenje utječe. Koncentracije respiratorne prašine (PM$_{10}$ i PM$_{2.5}$) provedene su prema standardima Indijanske odbor za kontrolu zagađenja (CPCB) na osam mjernih postaja tijekom tri sezone: poslije monsuna, te tijekom zime i ljeta 2015. godine. Utvrđene su sezonske varijacije koncentracije prašine: zima > ljeto > monsun. U utjecaju prašine analizirano je deset teških metala u tragovima. Utvrđene su sezonske varijacije koncentracije prašine. Zdravstveni rizik je procijenjen pomoću koe-
ficijenta opasnosti ($HQ$) i indeksa opasnosti ($HI$) te je za djecu i za odrasle izračunat zasebno za tri načina izlaganja (inhalacija, gutanje i izloženost kože). Kancerogeni učinci zbog prisutnosti metala u tragovima u PM$_{10}$ procijenjeni su i za djecu i za odrasle pomoću prekomjernog rizika od raka ($ECR$). Kombinirani kancerogeni učinci svih metala u tragovima također su izračunati ($ECR_{Total}$). Vrijednosti $HQ$ za Cr i Cd u promatranom području bile su iznad praga sigurnosti i za djecu i za odrasle. Isto tako, vrijednosti $ECR$ za Cr i Cd bile su za obje dobne skupine iznad praga. Međutim, rizik povezan s drugim metalima bio je ispod praga. Vrijednosti $HI$ i $ECR_{Total}$ bile su iznad praga što ukazuje na kombinirani učinak metala u tragovima na djecu i odrasle u istraživanom području te na vrlo visoku razinu rizika.

Ključne riječi: PM$_{10}$, PM$_{2.5}$, teški metali, korelacijska analiza, PCA, zdravstveni rizik

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