Bioavailability and Risk Profile of Toxic Metals in Size Segregated Particulate Matter at different Traffic Junctions of Northern India

Rahul Tiwari

GLA University

Akshay Botle

Institute of Science

Prabal Singh

GLA University

Ajay Taneja (✉ ataneja5@hotmail.com)

Institute of Basic Science, department of chemistry, Dr. B. R. Ambedkar University, Agra

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Abstract

Air quality at two traffic junctions representing GLA (highway pollution) and Iradatnagar (rural pollution) was evaluated in India. Present study aimed to determine the concentration of size-segregated PM with characterization of metals at different traffic junctions (Agra and Mathura). $PM_{2.5-1.0}$ and $PM_{1.0-0.5}$ was measured with the help of Cascade Sioutas Impactor during the study period December to January 2018. The size fraction of $PM_{2.5-1.0}$ was found higher at GLA ($350.92\mu\text{g}/\text{m}^3$) followed by Iradatnagar site ($329.12\mu\text{g}/\text{m}^3$) whereas average value of size fraction of $PM_{1.0-0.5}$ was found higher at Iradatnagar site ($361.01\mu\text{g}/\text{m}^3$) in comparison with GLA ($313.47\mu\text{g}/\text{m}^3$) respectively. The average $PM_{2.5}$ concentration in all the sampling sites was found 7-8 higher times than National Ambient Air Quality Standards ($60\mu\text{g}/\text{m}^3$) (NAAQS, India). Twelve Metals (Al, Ba, Ca, Cd, Cr, Cu, Fe, Mg, Mn, Ni, Pb and Zn) subsequently determined by ICP-OES. Al, Ba, Ca, and Mg, were found higher comparison to other metals. Metals source identification was done by PCA (Principal Component Analysis). The average value of HQs was found higher for $PM_{1.0-0.5}$ size fraction. HQ values were recorded higher for GLA sampling site it was 7.95 for $PM_{2.5-1.0}$ and 9.50 for $PM_{1.0-0.5}$ fraction. Overall, the observed HQs values far exceeded the acceptable level. The trend of average value of carcinogenic risk factor was found higher than prescribed limit (1×10^{-6}) for an adult and child respectively.

1. Introduction

Urbanization and industrialization growths are deteriorating the air quality. Air pollution is as vindicated as one of the lung causing cancer. The main source of air pollution is vehicular emissions, solid waste burning, coal combustion and soil dust. Heavy traffic through-out in modern societies increasing air pollution and declining the air quality. Vehicles contribute about 70% of CO, 50% of HC, 30–40% of NO_x and it has been found that vehicular emission acts as major contributing sources (62–85%) prior over crustal source (10–35%). (Pant et al. 2015; Villalobos et al. 2015). Particulate emission from on road vehicles contains a wide range of particle size from ultrafine ($< PM_{2.5}$) to coarse range ($> PM_{10}$). Vehicle emissions have been receiving increasing attention, and epidemiological studies show elevated risk to commuter and individuals living near roadways (Brugge et al. 2007; Singh et al. 2014). Vehicular emissions are not homogeneous it has a complete range of technological mixture that could be defined in terms of fuels (Gasoline diesel, Petrol, CNG) or engine used (2 stroke or 4 stroke). Particles emission from transport includes contribution from exhaust emission (fuel & lubrication), emission from anthropogenic process (Tyre wear and brake lining emission) are responsible for secondary PM (Thorpe & Harrison 2008). Globally, urban environment is contributing 25% of air pollution by $PM_{2.5}$, 15% by industrial activities, 20% from burning of domestic fuel, 22% undetermined source of human origin and 18% by natural dust and soils (Karagulian et al. 2015). Air pollution started in India with the development of transport system in 20th century and mass use of petrol and diesel (Srivastava & Sarkar 2017). India is one of the fastest growing passenger car markets in the world; it is the second largest two wheeler maker and the fifth largest commercial vehicle manufacturer. In India, the industry produced a total of

29,075,605 vehicles in March-April 2018, including passenger vehicles, commercial vehicles, three wheelers and two wheelers, statistics showed that vehicle growth increased by 14.78% over the years. The overall Commercial Vehicles segment grew by 19.94%, Medium & Heavy Commercial Vehicles grew by 12.48% and Light commercial vehicles grew by 25.42%, three wheelers grew by 24.19%. Within the three wheelers, passenger carrier & goods carrier sales registered a growth of 28.65% and 7.83% respectively in April-March 2018. (<http://www.motorindiaonline.in/commercial-vehicles/indian-cv-industry-in-full-throttle/>). Percentage emissions of PM_{2.5} from vehicles (old than 10 years) contribution reported as 2Wheelers (30%), 3Wheelers (42%), 4Wheelers (58%), buses (26%), Light Duty vehicles (39%) and high duty vehicles (46%). The major twenty-nine cities of India account for 30–40% of the national on-road total emissions. **(Guttikunda & Mohan 2014)**. Current trends indicate that the vehicle movement on the road is one of the major contributors to urban air quality problems in India. Characterization of PM_{2.5} and its sources has been investigated in many studies **(Yu et al. 2013; Tiwari et al. 2020)**. Adverse health effects are mainly associated with particle chemical composition with heavy toxic metals **(Singh et al. 2017; Hildemann et al. 1991)**. Exposure to PM is the world's largest environmental health risk **(Wallner et al. 2014)** causing an estimated seven million deaths each year, equivalent to one in eight deaths across the globe **(WHO, 2016)**. Numerous epidemiological studies have proposed a statistical association between health effect and ambient fine particle concentrations **(Schwartz et al. 1996; Pope. 2002)**. PM_{2.5-1.0} and PM_{1.0-0.5} can penetrate deep into the alveolar region and thus should be specifically focused from an epidemiological viewpoint **(Obersdoster, 2001)**. Numerous cardiovascular and respiratory illness studies have revealed the effects of fine aerosol on cardiopulmonary functions **(Delfino et al. 2008; Kloog 2016)**. In India research across the country regarding PM pollutant concentration were found to be well above the permissible limit. Information of pollutant on size segregated PM (PM_{2-5-1.0} and PM_{1.0-0.5}) is still sparse. The present study is aimed to provide information on the concentration level of size segregated PM at two different traffic junctions GLA University, Mathura (NH-19) and Iradatnagar (Rural traffic site) of Agra. The key objectives of this study are (1) To examine the concentration of metal constituent and size distribution of PM in different size fraction (2) To assess the bioavailability of metals (3) To assess the health risk assessment in terms of carcinogenic (Excess cancer risk) and non-carcinogenic (Hazard's quotient) through inhalation pathway. The results of this study could help the health officials/ environmentalists/ scientists and policy makers to gain insight about the toxicity of metal bound particles with a better understanding to control them.

2. Methods And Methodology

2.1. Sampling Site

Sampling was carried out at traffic site on National Highway-2 which has been renumbered as NH-19 (Agra-Delhi National Highway) at GLA University Mathura, to explore the trends of concentration of pollutants on highway, 2nd site was rural traffic junction (Iradatnagar) in Agra district. The climate of Agra is a semi-arid. During summer, the day time temperature hovers around 46–48°C. The city geography mild winters, hot summers and a monsoon season. Winters are bit chilly; temperature

sometimes goes as low as 2 or 3°C but usually soars in the range of 6 to 8°C. Sampling site GLA University, Mathura (27.28°N 77.41°E) is situated on National Highway-2, which is busiest highway of country; on an average fourteen to fifteen thousand vehicles move per day on this highway. Iradatnagar(26.9665° N, 78.0438° E) site is situated 36 kms far away from Agra city. Iradatnagar, sampling site is exclusively an agricultural area and contains large agricultural farms where most of the agricultural practices like field plowing, irrigation and biomass burning have been done. Traffic load at this site is very low but most of diesel vehicles ply on this site. Total 12,84,676 commercial and non-commercial vehicles are registered in Agra region. four major highways and two expressways pass through the city namely Agra-Jaipur Highway NH-21 (Old number NH-11), Agra-Gwalior Highway NH-44 (old number NH-3), Agra- Aligarh Highway NH 509 (old number NH-93), Agra-Delhi Highway NH-19 (old number NH-2), Yamuna expressway (Delhi-Agra) and Agra-Lucknow expressway. These highways take a toll of nearly 10⁵ vehicles per day¹¹.

2.2. Sampling Protocol

Sampling was conducted in the month of December to January 2017-18 using Cascade Impactor in combination with a 2 stage cut point (2.5µm and 0.5µm). Drycal DC-2 calibrator was used to calibrate the instruments (Bios International Corporation, NJ USA). In this study, PM samples were collected on 25 mm PTFE (Poly Tetra Fluor Ethylene) filters with pore size 0.5µm in two stage fractions (PM_{2.5-1.0} & PM_{1.0-0.5}).The instrument was fixed at breathing height above the ground level on tripod photographic stand. Pump was operated at 9 liters per minute and 54 samples were collected as per the Central Pollution Control Board guidelines (CPCB 2010). The PM concentration was calculated by dividing the difference in pre- and post-weight of filters by the sampled air volume (Rohra et al. 2018). Microbalance model No. (CAI-35) (Contech analytical balance) used for weighing of filters. The ambient parameter (carbon dioxide and temperature) were measured using Handy Air Quality monitor (TELAIRE). To keep the quality control all the glassware were cleaned by soaking in 2% HNO₃ overnight in follow up with rinsing it with de-ionized water. Half filter paper was used for the total concentration (through acid extraction) and the remaining was used for the soluble fraction (through ammonium acetate) (Varshny et al. 2015). Inductive Coupled Plasma–Optical Emission Spectroscopy was employed for multi-elemental analysis.

2.3. Health Risk Analysis

The four-stage method set by the USEPA (2009) was performed using all metal-bound particles between PM_{2.5-1.0} and PM_{1.0-0.5} in all the ambient sites for each receptor (children and adults).At the first, Hazards Quotient (HQ) values (Al, Ni, Mn and Cr) were calculated as non-carcinogenic effects whereas Excess cancer risk was calculated (Pb, Ni and Cr (VI)) were calculated as carcinogenic elements. The risk of Cr (VI) was calculated as 1/7th of the total Cr concentration because Cr (VI) and Cr (III) exist in air with ratio of 1:6. (Hieu and Lee 2010). The chronic exposure concentration in the next step was calculated using the following formula (USEPA 2009).

$$EC= (CA \times ET \times EF \times ED) / AT \dots\dots\dots (1)$$

where: EC ($\mu\text{g}/\text{m}^3$) = exposure concentration; CA($\mu\text{g}/\text{m}^3$) = concentration of pollutant in air; ET = exposure time (period over which a person exposed which was 24 h/day); EF = exposure frequency (Taken as 350 days/year); ED = exposure duration which was taken as 20 years and 6 years for adult and child respectively; AT = that equals to ED in years $\times$ 365 days/year $\times$ 24 h/day for non-carcinogens and LT (lifetime of 70 years) $\times$ 365 days/year $\times$ 24 h/day for carcinogens. All the above default values were applied which are mentioned in (USEPA 2014). Eq. 2 and Eq. 3 was used for HQ and ELCR calculation respectively. (Taner et al. 2013)

$$\text{EC} = (\text{HQ}/\text{Toxicity Value} \times 1000 \mu\text{g}/\text{mg}) \dots\dots\dots (2)$$

$$\text{ELCR} = \text{IUR} \times \text{EC} \dots\dots\dots (3)$$

IUR is defined as the upper bound Excess Lifetime Cancer Risk. Values of different metals for IUR and Rfc were taken from USEPA 2009; IRIS.

3. Results And Discussion

3.1 PM concentrations

Comparison of Average Mass concentration of PM in different sampling sites is shown in Fig. 2. The average PM_{2.5-1.0} size fraction concentration in all the sampling sites was found higher 7–8 times than National Ambient Air Quality Standards (60 $\mu\text{g}/\text{m}^3$). Average value of PM_{1.0-0.5} was found higher at Iradatnagar (361.01 $\mu\text{g}/\text{m}^3$) comparison to GLA (313.47 $\mu\text{g}/\text{m}^3$). Present study result was good agreement with another study which was conducted near roadside 328.5 $\pm$ 229.6 $\mu\text{g}/\text{m}^3$ (Goyal and Khare 2009) 259.51 $\pm$ 55.62 $\mu\text{g}/\text{m}^3$ (Habil and Taneja 2011). Prasad et al. 2003 also reported commuter exposure, In Delhi PM₅ concentrations was as high as 2860 $\mu\text{g}/\text{m}^3$ and 810 $\mu\text{g}/\text{m}^3$ for two wheelers and three wheeler respectively. Whereas the size fraction of PM_{2.5-1.0} was found higher at GLA (350.92 $\pm$ 171.28 $\mu\text{g}/\text{m}^3$) followed by Iradatnagar (329.12 $\pm$ 205 $\mu\text{g}/\text{m}^3$) site respectively. Results was found relatively similar with earlier studies (361.1 $\pm$ 251.8 $\mu\text{g}/\text{m}^3$) (Goyal and Khare 2009), (313 $\pm$ 181 $\mu\text{g}/\text{m}^3$)(Das et al. 2015).In winters at rural area (Iradatnagar) combustion of agricultural residue and wood burning are important source of exposure to PM. (Agarwal et al. 2012; Rajput et al. 2014 ;). Biomass burning is the key component of PM_{2.5} in winter and secondary aerosol are the major sources of PM. (Kulshrestha et al. 2009). Over South Asia biomass/residential emissions are major contributor’s toPM_{2.5} which is responsible for burning of crop, wood and cow dung (Nagpure et al. 2014).High values of PM at GLA crossing may be due to high traffic intensity and industrial emission. Vehicle emerges as the most dominating source of PM and it is reported to contribute (5–90%) Industrial emission is identified important contributor of fine particulate (1–58%), on the other hand Mathura oil refinery and Firozabad glass industries along with a number of industrial units serves as a local pollution source (Kulshrestha et al. 2009). During the study period metrological parameters such as temperature (14.07 $\pm$ 2.84⁰c), CO₂ (506.15 $\pm$ 17.85PPM) and relative humidity (77 $\pm$ 9.56%) was recorded, during winter seasons atmosphere

remains foggy and increase secondary aerosol formation which accumulate near ground surface and increase the level of PM (Prakash et al. 2018).

3.2 Metal concentration in size segregated PM

Figure 3 and Fig. 4 tells the average concentrations of twelve elements for $PM_{2.5-1.0}$ & $PM_{1.0-0.5}$. Ni, Mn, Cr, Cu, Mg, Pb were found higher at GLA followed by Iradatnagar for $PM_{2.5-1.0}$ fraction. Pb and Cu contributed from vehicular emissions, come dominantly from wear of tire rather known engine combustion. Universally accepted sources like Cu, Pb, Mn, Ni is attributed to Brake lining, fuel Additives and Combustion of heavy oil (Banerjee et al. 2015, Pant and Harrison. 2012). In India vehicular emissions is the key source of Cu, Ni, Pb, Zn and Mn (Kulshrestha et al. 2009; Deshmukh et al. 2013) GLA site can be attributed to higher rate of brake abrasion and high traffic flow rate. Cd, Fe, Al, Ca were higher at Iradatnagar sites followed by GLA. These are the crustal element which probable sources are resuspended road dust, metal smelter, incinerators and vehicular emission (Chueinta et al. 2000). Al, Ca and Fe are elements linked with crustal sources (Begum et al. 2004) probably un-paved road at rural traffic site is the main source of these tracer comparison to other site. Al, Ca is also emitted from Brick Klin (Begam et al. 2014) which is situated 9 km. far away from rural site (Iradatnagar) and the key contributors of metal sources. Results showed the similar trend for size fraction $PM_{1.0-0.5}$ excepting Ba and Mn which were higher at Iradatnagar. Iradatnagar is occupied with residential colonies and people generally use two stroke engine (bikes and scooters) comparatively four stroke engine (cars) to go offices, market and schools. Two stroke engine and fuel additives in two stroke engines are the main sources of Zn and Ba (Pant and Harrison 2012; Mansha et al. 2012). Elevated concentration of Ni, Mn, Cr, Cu, Mg, Pb and Cd may be affected by industrial activities (Kulshrestha et al. 2009; Das et al. 2014; Banerjee et al. 2015). The average value of Ca, Cd, Cu, Fe, Mg, Ni, Zn was found higher for $PM_{2.5-1.0}$ fraction while Al, Ba, Cr, Mn, and Pb was higher for $PM_{1.0-0.5}$ fraction. Light metal group (atomic number < 20 and lower) like Ca, Mg and Al was found higher at all sampling sites whereas Heavy metals (atomic number > 20) group viz. Cd, Cu, Fe, Ni, Zn, Ba, Cr, Mn, Pb were found in low concentration compared to light metal group. 52.46% light metal found in $PM_{2.5-1.0}$ and 56.68% in $PM_{1.0-0.5}$ size fraction whereas heavy metals were 47.53% in $PM_{2.5-1.0}$ and 43.31% was in $PM_{1.0-0.5}$ size fraction.

3.3 Bioavailability Index (BI)

In the current study eleven metals revealed soluble mass concentration except Ni and Mn which were below the detection limits for Iradatnagar site. Metals are associated in the form of silicate, cement and doxidades in soluble fraction and that ought's to be extracted under hard acid conditions (Feng et al. 2009). The soluble fraction of metals is readily absorbed in respiratory system which possesses maximum risk to human health (Friberg et al. 1986). Bioavailability is the fraction of the total amount of a metal; which indicated overall physiological and toxic effects of a metal on biological systems (Olaniran et al. 2013). Mn causes various psychiatric and movement disorder. Long term exposure of Al associated with pulmonary fibrosis and pulmonary injury. Inflammation has been caused by transition

metal. Cu, Zn is associated as vomiting, diarrhea, liver and kidney failure and anemia. Long time exposure of Pb is associated with heme-biosynthesis, nervous system and kidney failure. The calculated values of BI for metal are shown in **Fig. (5)** for size fraction $PM_{2.5-1.0}$ and **Fig. (6)** for size fraction $PM_{1.0-0.5}$. Results reveals that bigger particles showed the higher bioavailability in comparison with smaller size fraction. In this study it was found that $PM_{2.5-1.0}$ size fraction has more mobile and bio-accessible chemical species compare to $PM_{1.0-0.5}$. Average bioavailability results for both size fractions was found higher for Iradatnagar while it was least for GLA. The BI of metals in $PM_{2.5-1.0}$ and $PM_{1.0-0.5}$ ranged between 5.12–6.46% and 4.56–7.055% respectively at both sites. On the basis of BI values metals can be categorized as less bioavailability when $BI < 30\%$; medium bioavailability when $30\% < BI < 50\%$ and high bioavailability when $BI > 50\%$ (**Sah et al. 2017**). The calculated BI values are present in Fig. 6, 7. Higher BIs are considered to be physiologically active and pose more risks to individuals. In the present study at both size fraction all metals were found Low bioavailable except Al (33.01%), Ca (34.23%) and Fe (35.00%) which was found medium Bioavailability for $PM_{2.5-1.0}$. Results of Cr, Ca, Mn Matched with **Jiang et al. 2015** whereas for Cd BI showed similarity with study of **Espinosa et al. 2002** conducted in Spain. Result of Pb and Zn was found similar with **Rohra et al. 2018** However the results of Al, Ba, Cu, Mn and Fe was contradicts with earlier studies found contradict with study results of **Jiang et al. 2015; Rohra et al. 2018**. This is probably because the different methods were used for extraction and acid digestion (i.e. the concentration and matrix of acid) among the studies, which create differences in the recovery capacity for metals with different chemical states. (**Espinosa et al. 2002**).

3.4 Health Risk Estimation

Present study makes novel tactics to assess health risk impersonated by different size fraction of PM in term of different types of traffic junction. For both receptor (adult and child) carcinogenic (ELCR) and non-carcinogenic risk (HQ), is calculated in term of different traffic sites. When $HQ \leq 1$ indicates no adverse health effects and $HQ \geq 1$ indicates likely adverse health effects. The average value of HQs for $PM_{2.5-1.0}$ and $PM_{1.0-0.5}$ size fraction was found higher for GLA (7.95, 9.50) comparison to Iradatnagar (1.74, 3.90). The results are found to accord with (**Prakash et al., 2018**) (Fig. 7a, Fig. 7b) values for smaller size fraction was found slightly higher. Mn and Ni was below the limit at Iradatnagar site for $PM_{2.5-1.0}$ size fraction while Ni for $PM_{1.0-0.5}$ size. Results of the present study were found similar with **Liu et al., 2015** in Changsha. HQs trend in term of metals for $PM_{2.5-1.0}$ and $PM_{1.0-0.5}$ were followed as $Cr > Ni > Al > Mn$ our results found similar with (**Khan et al., 2016**). Ni found higher than Mn for $PM_{2.5-1.0}$ size fraction but it contradicts with $PM_{1.0-0.5}$. Cr was found higher than Al (**Rohra et al., 2018**), (**Niu et al., 2015**). It should be noted that long-term exposure to vehicle exhaust, emissions from wear and tear and re-suspended road dust threat to commuters, pedestrian and People working in commercial establishments near road.

3.5 Excess Life Cancer Risk Values (ELCR)

Carcinogenic risk for metals was calculated in both size fractions ($PM_{2.5-1.0}$ and $PM_{1.0-0.5}$). Cr posed highest non-carcinogenic risk as well as cancerous risk; result was found higher for Cr (VI) comparison to other metals. It was found that result was higher than the acceptable limit (**USEPA 2009**) for both adult and children. The trend of metal for carcinogenicity followed as $Cr(VI) > Pb > Ni$ for both size fractions. Cr(VI) value for ELCR was found similar with earlier study (**Hieu and Lee et al. 2010; Massey et al. 2013 and Sah et al. 2017**). Highest values for carcinogenicity were found higher for GLA to Iradatnagar site. This study conducted to find out the existing link between size fraction and its effect on human health. It was observed that overall non-carcinogenic risk (Fig. 7a,b) and ELCR (Fig. 8a, b, c, d) differ by different size fraction. Values of HQ and ELCR was found higher at smaller size fraction ($PM_{1.0-0.5} > PM_{2.5-1.0}$) for both sampling sites. The trend of average value of carcinogenic risk factor was found two times higher than prescribed limit (1×10^6) given by USEPA which infers higher risk posed to the locales in our study report furthermore, values of ELCR was found higher for adults (2 times) comparison to children (1.5 times).

3.6 Principal Component Analysis

PCA, an extension of the correlation analysis, is used to distinguish and validate the major sources of potential pollution in the study area. PCA results are shown in Table 1 and Table 2 for Iradatnagar and GLA sampling sites, which they are within Factor 1 with the highest eigenvalue of 7.13. Factor loads of **0.30–0.50** show weak, **0.50–0.75** medium and **0.75 >** strong relationship.

Table 1
PCA for Iradatnagar Site.

Iradatnagar Rotated Component Matrix				
	Component			
	Factor 1	Factor 2	Factor 3	Factor 4
Al	-.85	-.01	.12	-.21
Ba	.09	.04	.06	.89
Ca	.64	.19	-.08	.01
Cd	.39	.60	.03	.30
Cr	-.88	-.01	.03	-.07
Cu	.90	-.02	.03	.11
Fe	.66	.04	-.27	.03
Mg	.00	.06	.86	.00
Mn	-.29	-.09	.65	.01
Ni	.76	-.09	-.10	-.05
Pb	.06	-.83	.13	-.00
Zn	-.08	.60	.23	-.47
Eigen Value	4.29	1.51	1.25	1.02
Cumulative	33.60	46.04	57.49	67.38
%Variance	33.60	12.43	11.45	9.89

Table 2
PCA for For GLA Site.

GLA Rotated Component Matrix			
	Component		
	Factor 1	Factor 2	Factor 3
Al	– .81	– .08	.04
Ba	– .15	– .20	.86
Ca	.96	.06	– .09
Cd	.14	.63	– .08
Cr	– .63	– .27	– .40
Cu	.85	.03	– .15
Fe	.95	.00	– .16
Mg	.90	.01	.14
Mn	– .81	– .10	.23
Ni	.43	– .49	– .26
Pb	.09	.77	– .13
Zn	– .89	– .07	.06
Eigen Value	6.27	1.36	1.07
Cumulative	51.34	62.94	72.59
%Variance	51.34	11.59	9.65

For Iradatnagar KMO value for the study was found to be 0.78 which is sufficient to apply PCA. As a result of PCA test, 4 factors with eigen value > 1 were calculated which explained 67.38 % of total variance. The first factor constitutes 33.6 % of the total variance. In this factor Cu and Ni Showed Strong Load while Ca and Fe showed Moderate load. Al and Cr were found to be in Negative loadings. Thus the 1 component with metal loading of Al, Ca, Cr, Cu, Fe and Ni was influenced by vehicular as well as industrial emission (**Karar et al., 2006; Kulshrestha et al., 2009**). The second factor constitutes of a total of 12.43% of the total variance where Cd and Zn showed moderate load and Pb were found to be in Negative load. Thus the 2 components having metal loadings of Cd, Zn, and Pb possible source of these metals could be abrasion of brake pad and engine parts (**Karar et al., 2006**). The third factor constitutes of total 11.45% of the total variance. In this factor, Mg showed high loadings while Mn showed moderate loadings. Thus the 3 components having metal loadings of Mg and Mn were influenced by sources like industries, re-suspended road dust and long-range transported dust (**Lee & Von Lehmden, 1973; Sun et al., 2004**). The fourth factor constitutes of total 9.89% of the total variance where Ba showed high loading indicating,

Vehicular tailpipe emission, brake and tyre wear are primary sources of Ba in atmosphere (Monachi & Bargagli, 1997; Goddard et al., 2019). For the site GLA KMO value for the study was found to be 0.888 which is sufficient to apply PCA. As a result of PCA test, 3 factors with eigen value > 1 were calculated which explained 72.59 % of total variance. The first factor constitutes 51.34 % of the total variance. In this factor Ca, Cu, Fe, and Mg Showed Strong Load while Al, Cr, Mn and Zn were found to be in Negative loadings. Thus the 1 component with metal loading of Ca, Cu, Fe, Mg, Al, Cr, Mn and Zn was influenced by re-suspension of road dust including tailpipe emission from vehicle as well as non-exhaust emission from vehicular activities (Daun et al., 2013; Hjortenkrans et al., 2007; Lin et al 2020). The second factor constitutes of a total of 11.59% of the total variance where Pb showed High loading and Cd with moderate load. Thus the 2 components having metal loadings of Pb and Cd were influenced by brake pad and engine parts (Karar et al., 2006). The third factor constitutes of total 9.65% of the total variance. In this factor, only Ba was found in high loadings which indicates that it might be influenced by vehicular tailpipe emission, brake and tyre wear are primary sources of Ba in atmosphere (Monachi & Bargagli, 1997; Goddard et al., 2019).

4. Conclusion

Results of the present study reveals a very high average concentration of PM found at traffic sites crossing posing high risk of particulate pollution. In term of metals anthropogenic sources (vehicular emissions, oil combustion, coal combustion, Incineration) have stronger contribution to metals emission. The study showed that health risk through inhalation of PM is not negligible to commuters, pedestrian and people living near road side. Higher average percentage of bioavailability was found for Bigger (PM_{2.5-1.0}) size fraction comparison to smaller size (PM_{1.0-0.5}). Metal toxicity has proven to be major threats and associated with several health risks. Metal toxicity is harmful for the human body and its proper functioning. The calculated values of HQ was found higher for all metals (Ni, Mn, Cr and Al) which has adverse health effect, it was observed that high traffic intensity have greater influences on these metals, the trend obtained was GLA > Iradatnagar. It shows that traffic emission has higher impact on air quality which is deteriorating the health of human being. Highest value of ELCR was found for Cr (VI) the trend of average value of carcinogenic risk factor was found ~ 2 times higher than prescribed limit (1×10^{-6}) for adult and child respectively.

Declarations

Acknowledgements

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Conflict of Interest

There is no conflict of interest by authors

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Figures

Figure 1

Map of India showing sampling sites.

Figure 2

Comparison of Average Mass concentration of PM in different sampling site. (Values in $\mu\text{g}/\text{m}^3$)

Figure 3

Comparison of Average concentration of metals in PM_{2.5-1.0} at different sampling site. (Values in $\mu\text{g}/\text{m}^3$)

Figure 4

Comparison of Average concentration of metals in PM1.0-0.5 at different sampling site.(Values in $\mu\text{g}/\text{m}^3$)

Figure 5

Bioavailability Index of metals in PM2.5-1.0 at different sampling site. (Values in %)

Figure 6

Bioavailability Index of metals in PM_{1.0-0.5} at different sampling site. (Values in %)

(a)

(b)

Figure 7

(a) HQ value For PM_{2.5-1.0}. (b) HQ value For PM_{1.0-0.5}.

(a)

(b)

(c)

(d)

Figure 8

(a) ELCR values of PM_{2.5-1.0} for Adult. (b) ELCR values of PM_{2.5-1.0} for Child. (c) ELCR values of PM_{1.0-0.5} for Adult. (d) ELCR values of PM_{1.0-0.5} for Child.

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