Source apportionment, ecological, and human health risks of toxic metals in road dust of densely populated capital and connected major highway of Bangladesh

Md. Morshedul Haque1,2 · Sajin Sultana1,3 · Nahin Mostofa Niloy1 · Shamshad B. Quraishi4 · Shafi M. Tareq1

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Abstract
This study investigates pollution levels, source apportionment, ecological, and human health risks associated with toxic metals (Pb, As, Hg, Cr, and Cd) in road dust from the most populated Dhaka city and a connected major highway in Bangladesh. The mean concentration of Pb, Hg, and Cd were 1.3, 29.3, and 13.2 times higher than their corresponding background values with spatially uneven distribution all over the study area. Metal pollution indices, the geo-accumulation index ($I_{geo}$), NIPI, and PI, indicated extreme contamination at many sites depending on local environmental factors. The potential ecological risk ($E_{ir}$) revealed that 84% and 54% of samples showed the extreme ecological risk for Hg and Cd pollution, respectively. On the other hand, the potential ecological risk index (PERI) and Nemerow integrated risk index (NIRI) showed that most sampling sites suffered high to extreme ecological risk. Source apportionment using positive matrix factorization (PMF) identified coal combustion, and gasoline (50.14%), traffic exhaust (35.26%), and industrial and agriculture activity (14.60%) were the main source of toxic metals of the study area. Non-carcinogenic health risk indicated that adults are more vulnerable than children, and hazard index (HI) of Hg for both age groups and Cd for adults were significantly higher than the safe level. The carcinogenic risk (CR) levels of toxic metals were acceptable ($10^{-6}$ to $10^{-4}$), although the maximum limit of Cr for children and As for adults was close to the unacceptable limit ($10^{-4}$). Continual exposure to toxic metals through road dust might develop lifetime cancer risk in local inhabitants.

Keyword Toxic metals · Road dust · Positive matrix factorization · Ecological risk · Human health risk

Introduction
Road dust is referred to as fine solid particles that exist in the environments through diverse processes and can accumulate outdoor, especially on cemented roads and hard pavement (Lu et al. 2014; Rahman et al. 2019). Road dust is accounted as hazardous materials due to its high transportability into environmental mediums and poses a potential threat to public health (Khademi et al. 2019; Yesilkanat and Kobya 2021). The dust acts as the sink and source of toxic metals to...
its corresponding environment (especially soil and air) (Men et al. 2020). The source of toxic metals in dust can be from the resuspension and erosion of surrounding natural environment (soil parent materials) as well as anthropogenic activities such as fossil fuel combustion, traffic activities (e.g., brake lining, tire, and asphalt wear), industrial activities, construction and demolition, waste dumping, and domestic emission (Ali et al. 2017; Hou et al. 2019; Wang et al. 2020). Toxic metal distribution and origin in road dust may depend upon different functional sites of an urban area because of types and intensities of anthropogenic activities (Wang et al. 2016; Li et al. 2017). Spatial analysis is a prerequisite to control and manage pollution through exploring the patterns, hotspots, and sources of toxic metals in road dust (Qin et al. 2020; Wang et al. 2020).

Many large cities in the world are seriously contaminated through toxic metal–polluted road dust (Lu et al. 2014; Dehghani et al. 2017; Wang et al. 2020; Yesilkkanat and Kobya 2021). Toxic metals are significant environmental contaminants that have harmful, concealed, persistent, bioaccumulation and non-biodegrade nature (Zhang et al. 2017; Haque et al. 2021b). Human health and the ecosystem have been affected significantly due to metal toxicity and abundance (Jayarathe et al. 2018). Long-term exposure to road dust through ingestion, inhalation, and dermal absorption may cause non-carcinogenic and carcinogenic effects on human health (USEPA 1996, 2011a). Recently, many studies were carried out to determine the source and assess the ecological and human health risk of trace elements exposed through road dust (Rahman et al. 2019; Wang et al. 2020; Jiang et al. 2020; Kolakkandi et al. 2020; Men et al. 2020, 2021; Moghtaderi et al. 2020; Al-Shidi et al. 2020; Aguilera et al. 2021; Yesilkkanat and Kobya 2021; Guo et al. 2021; Heidari et al. 2021). People have suffered different health-related complications through exposure to trace elements and other traffic-related pollutants who live near (< 50 m) or use urban roadways regularly (Duong and Lee 2011; Chen et al. 2017).

Trace elements related to risk are influenced by numerous factors such as toxicity, single, and multiple metal concentration (Wiesner et al. 2009). Different types of assessment methods have been used, such as geo-accumulation index (Igeo), potential ecological risk index (PERI), Nemerow integrated pollution index (NPI), and Nemerow integrated risk index (NIRI), to evaluate the pollution status and potential risks (Yang et al. 2011; Men et al. 2018, 2020). Multivariate statistical analysis has been widely used in grouping and identifying the source of pollution in different environmental mediums (Yang et al. 2011). Positive matrix factorization (PMF) is a multivariate statistical model which has been used for source apportionment, and recently many researchers applied it for environmental samples (Jiang et al. 2020; Kolakkandi et al. 2020; Men et al. 2020; Guo et al. 2021; Heidari et al. 2021; Zhu et al. 2021). PMF showed restriction to non-negative values to get more meaningful factors and provide numerical information regarding the contribution of every source types (Men et al. 2020).

In the last two decades, rapid industrialization and urbanization occur in Bangladesh, and trace element pollution in urban road dust has become a serious public health issue (Rahman et al. 2019). Dhaka is the capital and overpopulated region in Bangladesh, and 13% of the population lives in the capital (World population data, 2021). The number of vehicles in Dhaka City has been increased several times in the last decade and significantly pollutes the atmosphere and road dust (Ahmed and Ishiga 2006). Every day, several thousands of vehicles pass through one of the busiest highways named Dhaka-Aricha Highway. It has been supposed that significant augmentation of motor vehicles might impact on the environment in the city and around the highway, although there is growing interest in recent years in the road dust toxicity on public health. However, very limited attempts have been made to quantify the sources of toxic elements and its possible effect on human health of Bangladesh (Ahmed and Ishiga 2006; Rahman et al. 2019). To the best of our knowledge, this is the first comprehensive study on the toxic metal of the major highway to quantification with source identification and ecological and public health risk assessments. Therefore, this study aimed to (1) determine the toxic metal concentration and its distribution pattern within the Dhaka City and Dhaka-Aricha Highway; (2) assess the contamination levels and ecological risk due to toxic metals; (3) assess source apportionment and their contribution in road dust; and finally (4) assess human health risk due to exposure of toxic metals.

Materials and methods

Study area and sampling

Dhaka is the sixth most densely populated city in the world, with a population density of 47,700 citizens per square kilometer (World population data 2021). This enormous population has been considered a burden on the traffic, environment, and energy. The city is located mainly in the middle of Bangladesh and interconnected with all districts by roads. The Dhaka-Aricha National Highway connects the south and western part of the country to Dhaka with significant traffic. Day-by-day vehicles and industries are increasing rapidly and result in intensive air pollution (Rahman et al. 2019). On the other hand, the study sites have been surrounded by various industries such as the battery, textile, pharmaceutical, leather, brick kiln, and the agricultural field around the highway. The growing number of industries in Dhaka City and its surrounding has been shown to have a significant
impact on the onset of air pollution and also contamination of road dust (Rahman et al. 2022). The geology of this area is the Madhupur uplands covered by reddish brown, mottled, well-oxidized, ferruginous, and calcareous nodules, and compacted Madhupur clay (Rashid 2003). The iron oxides and kaolinite are produced during the weathering of mafic-rich sediments (Burgess et al. 2011). Lithological investigation revealed that the sediments in Dhaka are composed of clay, sand, and gravel beds (Bodrud-Doza et al. 2019).

This study covered the significant part of Dhaka City and Dhaka-Aricha National highway from where the total 52 samples were collected from thirteen important sites around the main streets from a sub-urban area Jahangirnagar University, Savar (23°52′47.44″N, 90°16′25.05″E) to the center of Dhaka metropolitan (23°43′28.44″N, 90°24′18.06″E) (Fig. 1), whereas 4 positional represented samples were collected around 500 m of 13 specific locations. Road dust samples were collected during the humid summer season (April). The sampling locations were uniformly distributed and represented the entire study area. More than 100 g of road dust samples from the impervious surface was collected using a polyethylene brush. The samples were stored in sealed zipper polyethylene bags with the appropriate labels and then transferred to the laboratory (Atomic Energy Centre, Dhaka) for further analysis. All the samples were air-dried for 2 weeks, then sieved with a 1.0-mm nylon mesh to remove all debris (Wang et al. 2009). Dust samples were also dried for 72 h at about 45 °C in an electric oven to remove moisture content and further sieved (74 µm) through a nylon mesh. This size was selected for elemental analysis as those particles with diameters below 100 µm are easily re-suspended (Schmel 1980; Nicholson 1988), and they can be inhaled through the nose or mouth during breathing (Ferreira-Baptista and De Miguel 2005). After being completely dried, the samples were crushed with an agate mortars and pestle to make fine grain and homogeneous mixer.

Sample preparation and analysis

The concentrations of Pb, As, Hg, Cr, and Cd in road dust samples were measured by flame atomic absorption spectrometry (FAAS; Model: AA240FS, Varian, Australia). The samples were prepared by wet digestion methods, according to Islam et al. (2017). All chemical reagents used in the analysis were analytical grade or Suprapure quality and purchased from E. Merck, Germany. For the preparation of all solutions, double deionized water (Milli-Q System, Millipore) was used for every step. The standard solutions were used for instrument calibration, which were prepared by diluting stock solutions of 1000 mg/l of the respective element. To prepare the sample for metal analysis, ~1 g of road dust samples and standards (IAEA-SL-1 and NIST-1633b) was digested in Teflon vessels with 7 ml HNO₃ (65%) in a microwave accelerator reaction system (MARS 5, CEM, USA) following standard procedure (USEPA, Method 3051A 2007; Islam et al. 2017). Then the digested solution was filtered by Whatman 41 paper after being chilled at room temperature and diluted to 20 ml double deionized water. Cold vapor atomic absorption spectrometry (CVAAS) (Analytik jena nova AA350) was used for Hg determination. Standard procedures were applied to monitor the instrument performance and data quality, such as replicating samples/standards, method blanks, and spike samples (Islam et al. 2017). Standard reference material (Coal Fly Ash; NIST-1633b) was used for determination of accuracy and precision of the method, and analytical results were found to be ±2% deviation of certified value. The spike recoveries were from 85 to 99%.

Metal pollution assessment

The method for pollution assessment of road dust is limited; researchers reported some methods which were used to interpret the pollution level of soil and sediment samples (Awadh 2015; Dehghani et al. 2017; Men et al. 2018). In this study, the geo-accumulation index ($I_{geo}$), Nemerow integrated pollution index (NIPI), and pollution load index (PLI) were used to calculate contamination levels.

Geo-accumulation index ($I_{geo}$) was determined by the following equation according to Müller (1979) to assess metals pollution level.

$$I_{geo} = \log_2 \left( \frac{C_i}{1.5B_i} \right)$$

(1)

where $C_i$ is the concentration of element $i$ examined in road dust (mg/kg), 1.5 is the background matrix correction factor due to lithospheric effects, and $B_i$ is the geochemical background value of element $i$ (mg/kg). Geochemical background of soil and sediment is unavailable for Bangladesh, and element concentrations in earth crust reported by Turekian and Wedepohl (1961), were taken for calculation.

The NIPI is used to assess the degree of trace element contamination at a particular sampling site. This index considers the mean and maximum values of a single-factor pollution index (PI), and also highlights different pollution degrees (Yang et al. 2011). The pollution load index (PLI) provides a comparative mean that indicates the level of metal pollution in the sample (Xiao et al. 2020; Yesilkcanat and Koby 2021). The NIPI, PI, and PLI can be calculated using following formula:

$$\text{NIPI} = \sqrt{\left( \frac{\text{PI}_{\text{ave}}^2 + \text{PI}_{\text{max}}^2}{2} \right)}$$

(2)

$$\text{PI} = \frac{C_i}{S_i}$$

(3)
where \( C_i \) (mg/kg) is the concentration of element \( i \) concentration and \( S_i \) (mg/kg) is the reference value of element \( i \) (Turekian and Wedepohl 1961). The \( \text{PI}_{\text{ave}} \) and \( \text{PI}_{\text{max}} \) are the mean and maximum value of PI, respectively. The classification of above pollution level assessment indexes are listed in Table S1.

\[
\text{PLI} = \sqrt[\text{PLI}_1 \times \text{PLI}_2 \times \cdots \times \text{PLI}_n}
\]  

\[
(4)
\]

Ecological risk assessment

The methods for assessing ecological risk of road dust is also limited; most of the researchers reported soil/sediment sample-based ecological risk assessment methods (Men et al. 2020; Mondal and Singh 2021; Yesilkanat and Koby 2021) to evaluate the conditions. The potential ecological risk index (PERI) is used to evaluate the potential ecological risk of trace elements (Jiang et al. 2014; Zhao et al. 2015). The formula of PERI determination is as follows:
PERI = \sum_{i=1}^{n} E_i^r  
\tag{5}
E_i^r = T_i^r \times C_i / S_i  
\tag{6}

where \( E_i^r \) is the potential ecological risk factor of element \( i \); \( T_i^r \) is the toxic response factor of element \( i \); \( r \) means risk and is not a variable; and \( C_i \) and \( S_i \) are the same as Formula (5). \( T_i^r \) of Pb, As, Hg, Cr, and Cd was 5, 10, 40, 2, and 30, respectively (Hakanson 1980; Men et al. 2020).

A new risk assessment method called Nemerow integrated risk index (NIRI) developed by Men et al. (2020) was established for integrated ecological risk quantification. The NIRI is the integration of NIPI and PERI, and provides more accurate evaluation of multiple trace elements effect on environment. The NIRI can be calculated by following formula:

\[ \text{NIRI} = \sqrt{\left( E_{\text{max}}^2 + E_{\text{ave}}^2 \right) / 2} \]  
\tag{7}

where \( E_{\text{max}}^i \) and \( E_{\text{ave}}^i \) are the maximum and average value of \( E_r^i \), respectively. \( E_r^i \) is calculated using Formula (6). The classification of above ecological risk indexes is listed in Table S1.

### Positive matrix factorization

Positive matrix factorization (PMF) is a very effective source identification tool among different multivariate models (Men et al. 2018). In the PMF model, the element concentration matrix decomposed into contribution matrix and profile matrix. Depending on this decomposition, the emission inventories and the profile information are evaluated, and the sources could be determined. Many researchers have described the detailed procedure of the PMF model (Kim and Hopke 2007; Yu et al. 2015). The formula is expressed as follow:

\[ x_{ij} = \sum_{k=1}^{p} g_{ik} f_{kj} + e_{ij} \]  
\tag{8}

where \( x_{ij} \) denotes the concentration of element \( j \) of sample \( i \), \( g_{ik} \) is the contribution of factor \( k \) to sample \( i \), \( f_{kj} \) is the concentration of element \( j \) in factor \( k \), \( e_{ij} \) is the concentration of residuals for the \( j \) element on the \( i \) sample, and \( p \) is the factor number. The factor contributions are constrained to be non-negative so that the meaning of operation could be interpreted easily (Bhuiyan et al. 2015).

In the PMF model, \( g_{ik} \) and \( f_{kj} \) are adjusted until the objective function, \( Q \), should be found minimum. The value of \( Q \) reflects the goodness of modeling (Men et al. 2020). \( Q \) is defined in the following formula:

\[ Q = \sum_{i=1}^{n} \sum_{j=1}^{m} \left( \frac{e_{ij}}{u_{ij}} \right)^2 \]  
\tag{9}

where \( u_{ij} \) is the uncertainly which was calculated according to Kim and Hopke (2007) and Men et al. (2020):

\[ u_{ij} = \begin{cases} \frac{5}{6} \times \text{MDL}, & x_{ij} \leq \text{MDL} \\ \sqrt{(\sigma_j \times x_{ij})^2 + (\text{MDL})^2}, & x_{ij} > \text{MDL} \end{cases} \]  
\tag{10}

where \( x_{ij} \) denotes the concentration of element \( j \) of sample \( i \) and \( \sigma_j \) is the relative standard deviation of the element \( j \) of sample \( i \).

This study used PMF software (Version 5.0, USEPA) for source identification. The source appointment through PMF model was determined on the basis of representative elements, literature, and the information from the study area.

### Human health risk assessment

The non-carcinogenic and carcinogenic risks to human health due to trace elements in road dust were assessed through a model developed by the US Environmental Protection Agency (US EPA, 1996; Men et al., 2018). Two groups of people, i.e., adult and children, have considered for risk assessment based on their physiological and behavioral differences. The people are exposed to trace elements through three main pathways: ingestion, inhalation, and dermal contact (Rahman et al. 2019). The average daily intake (ADI) of trace element through these three pathway was assessed using the following formula (USEPA 1989, 1996):

\[ \text{ADI}_{\text{ing}} = C \times \frac{\text{IngR} \times \text{EF} \times \text{ED}}{\text{BW} \times \text{AT}} \times 10^{-6} \]  
\tag{11}

\[ \text{ADI}_{\text{inh}} = C \times \frac{\text{InhR} \times \text{EF} \times \text{ED}}{\text{PEF} \times \text{BW} \times \text{AT}} \]  
\tag{12}

\[ \text{ADI}_{\text{dermal}} = C \times \frac{\text{SL} \times \text{SA} \times \text{ABS} \times \text{EF} \times \text{ED}}{\text{BW} \times \text{AT}} \times 10^{-6} \]  
\tag{13}

where \( \text{ADI}_{\text{ing}} \), \( \text{ADI}_{\text{inh}} \), and \( \text{ADI}_{\text{dermal}} \) (mg/kg) are the average daily element intakes through ingestion, inhalation, and dermal contact adsorption, respectively; \( C \) (mg/kg) is the concentration of trace element in road dust; \( \text{IngR} \) and \( \text{InhR} \) (mg/kg) are the ingestion and inhalation rate, respectively; \( \text{EF} \) (days/year) is the exposure frequency; \( \text{ED} \) (years) is the exposure duration; \( \text{BW} \) (kg) is the average body weight; \( \text{AT} \) (days) is the average time; \( \text{PEF} \) (m³/kg) is the particle emission factor; \( \text{SL} \) (mg/cm²/day) is the skin adherence factor;
SA (cm²) is the exposed skin area; and ABS (unitless) is the dermal absorption factor. The reference values for all the parameters in the above equations are listed in Table S2.

The non-carcinogenic risk assessed by the following formula (Li et al. 2013):

\[ HQ = \frac{ADI_i}{RfD_i} \]

\[ CR = \sum HQ_i \times SF_0 \]

\[ HI = \sum HI_i \]

where HQ is the hazard quotient or non-carcinogenic risk of single pathway; RfD is the corresponding reference dose of that respective trace element; i indicates the specific pathway (Ferreira-Baptista and De Miguel 2005). HI is the non-carcinogenic risk of trace elements due to multiple exposure pathways. If HI < 1, it indicates no significant non-carcinogenic risk to people. Conversely, if HI > 1, it indicates the probability of significant non-carcinogenic effects (USEPA 2004). The values of SF0 are listed in Table S3.

The assessment of carcinogenic risk (CR) used the following formula (Dehghani et al. 2017):

\[ CR = \frac{ADI_i \times SF_0}{RfD_i} \]

\[ CR = \sum CR_i \]

\[ HI = \sum HQ_i \]

where SF0 (unitless) is the carcinogenic slope factor. If CR value is within \(10^{-6}\) to \(10^{-4}\), it indicates tolerable or acceptable cancer risk. If CR > \(10^{-4}\), it indicates unacceptable cancer risk and when CR < \(10^{-6}\), it indicates no significant cancer risk (USEPA 2011b; Haque et al. 2021b). The values of SF0 are listed in Table S3.

The exposure-point concentration (C) in Formulas (9)–(11) is considered to yield an estimate of the “reasonable maximum exposure” (USEPA 1989) which is the upper limit of the 95% confidence interval for the mean (95% UCL). Since the element concentration in the 52 samples approximate log-normal distributions, the 95% UCL was calculated by the following formula (USEPA 1996; Rahman et al. 2019):

\[ C_{95\%UCL} = \exp \left( \bar{X} + 0.5s^2 + \frac{z_{1-\alpha}}{\sqrt{n}} \right) \]

where \(\bar{X}\) is the average of log-transform data; \(s\) is the standard deviation of log-transform data, \(H\) is the H-statistic (Gilbert 1987), and \(n\) is the number of samples.

**Results and discussion**

**Toxic metal concentration in road dust**

The toxic metal concentration in 52 road dust samples was analyzed by a flame atomic absorption spectrometry. The statistical analysis for the studied toxic metals in the road dust samples is presented in Table 1. The mean and median values of some toxic metals exceeded their respective background values, and the inconsistency with the percentage of their relative standard deviation (%RSD) values indicating studied toxic metals was not varied significantly. (Table 1; Turekian and Wedepohl 1961). The mean concentrations of Pb, Hg, and Cd were 1.3, 29.3, and 13.2 times higher than those of the respective background concentration, indicating that anthropogenic activities strongly influence concentration in road dust (Men et al. 2018). However, the mean concentrations of As and Cr have not exceeded the background value. The mean As concentration for this study is also much lower than road dust from Dhaka City Bangladesh (Ahmed et al. 2006; Rahman et al. 2019, 2022). Contrastingly, the mean Cr concentration was found to be much higher than indoor dust sample at export processing zone (EPZ) area Dhaka, Bangladesh (Rahman et al. 2021).

Compared with other megacities, this study showed low Pb, As, and Cr concentrations (Table 1). In contrast, only Pb showed a higher value than one previous study on Dhaka City, Bangladesh (Rahman et al. 2019). Contrastingly, the concentration of Hg and Cd showed a significant level higher than other cities, except Cd in Dhaka, Bangladesh (Rahman et al. 2019), and Delhi, India (Banerjee 2003).

Among the toxic metals, most of them showed uneven distribution throughout the study area (Fig. 2). The concentrations of Pb, Hg, and Cr were found to a greater extent in high concentration ranges in Dhaka City (R6–R13). The population density and human activities in Dhaka City are also greater than those in other areas (Rahman et al. 2019). The sampling point R5 (Amin Bazar) in the Dhaka–Aricha Highway is the transition point between Savar Upazila and Dhaka City, which is one of the largest waste landfill sites in Bangladesh, and the site demonstrates relatively high toxic metal concentration.

**Metal pollution assessment**

Based on the pollution assessment results, the \(I_{geo}\) of Pb, As, and Cr revealed that most of the samples were not contaminated (Fig. 3a). According to classification (Table S1), 23%
of samples were showed moderately contaminated by Pb. The \( I_{\text{geo}} \) of Hg and Cd shows significant toxic metals that were the dominant and key factor of contamination throughout the study area. The \( I_{\text{geo}} \) for Hg ranges from −6.42 to 5.30 and indicating 23%, 31%, 23%, and 8% samples were extremely, heavily to extremely, heavily, and moderately contaminated by Hg, respectively. Similarly, the \( I_{\text{geo}} \) of Cd ranges from −1.58 to 4.26 and indicating 15%, 38%, 8%, and 8% samples were heavily to extremely, heavily, moderately, and uncontaminated to moderately contaminated, respectively. On the other hand, the 15% and 31% samples showed practically uncontaminated through Hg and Cd, respectively. The NIPI indicates how several toxic metals polluted road dust at specific sampling sites by assessing a single metal pollution index (Men et al. 2020). Based on pollution category, index values indicated the severe level of pollution throughout the study area (Yang et al., 2011), where the first quartile (12.11) of the NIPI at all sites was ~4 times higher than the maximum criterion (NIPI > 3) and the third quartile (33.27) was ~11 times greater than index maximum criterion (Fig. 3b). The majority of the sampling sites showed substantial pollution by toxic metals except for R8 (0.37) and R10 (2.51) (Fig. S1). The mean value of PI was observed highest in the study area for Hg (29.27) followed by Cd (13.21), Pb (1.32), Cr (0.12), and As (0.01) (Fig. 3c). Based on the PI index (Yang et al., 2011), among the studied samples, 23%, 85%, and 70% of sites were strongly polluted by Pb, Hg, and Cd, respectively. On the other hand, the PLI values showed that 38% of sites in the Dhaka-Aricha highway were polluted and exceeded the threshold level (PLI ≥ 1). In contrast, the majority of the samples in Dhaka City were unpolluted (PLI < 1) (Fig. S2). These toxic metals might come from traffic exhaust, tire wear, waste landfill, coal combustion, gasoline, and fertilizer and pesticides (Men et al. 2020; Wang et al. 2020; Guo et al. 2021; Mondal and Singh 2021).

### Ecological risk assessment

The assessment of potential ecological risk \( E_i^r \) of a single toxic metal shows all of the studied sites were at low ecological risk in the environment for Pb, As, and Cr \( (E_i^r \leq 40) \) (Fig. 4a). The \( E_i^r \) of Hg and Cd demonstrating similar patterns with \( I_{\text{geo}} \) and these toxic metals were key influence factors to cause the potential ecological risk. The \( E_i^r \) for Hg ranges from 1–2360 and indicating 77% and 8% sampling sites were extreme and high ecological risk by Hg, respectively. Similarly, the \( E_i^r \) for Cd ranges from 15–864 and indicating 54%, 8%, and 8% sampling sites were extreme, considerable, and moderate ecological risk by Cd, respectively. Conversely, 15% and 30% sites showed low ecological risk for Hg and Cd, respectively. The primary source of Cd in road dust could be lubricating oil, diesel fuel, and tire wear (Foti et al. 2017; Men et al. 2018). The study area was covered by the highway and the city; a significant number of vehicles continuously pass through the area and have a great possibility to contaminate through Cd by lubricating oil, diesel fuel, tire, and brake wear (Men et al. 2020; Heidari et al. 2021). Similarly, the Hg might be coming from coal combustion and gasoline (Wang et al. 2020), whereas both the processes are dominated throughout the study area. Among the sampling sites, 84% and 54% samples were at extreme ecological risk for Hg and Cd, respectively, where the values were a much higher than the \( E_i^r \) extreme risk category \( (E_i^r > 320) \).

### Table 1

|                | Pb (mg/kg) | As (mg/kg) | Hg (mg/kg) | Cr (mg/kg) | Cd (mg/kg) |
|----------------|------------|------------|------------|------------|------------|
| **Mean**       | 26.35      | 0.16       | 11.71      | 11.01      | 3.96       |
| **%RSD**       | 121.53     | 21.07      | 72.72      | 42.22      | 88.84      |
| **Median**     | 12.00      | 0.16       | 11.20      | 8.40       | 4.96       |
| **Minimum**    | 1.08       | 0.13       | 0.01       | 6.36       | 0.15       |
| **Maximum**    | 80.00      | 0.25       | 33.60      | 20.8       | 8.64       |
| **95% CI**     | 19.35      | 0.02       | 5.15       | 2.81       | 2.13       |
| **Background** |            |            | 90         | 0.3        |            |
| Dhaka (Bangladesh) | 18.9 | 8.1        | −          | 144.3      | 11.6       |
| Dhaka (Bangladesh) | 54.26 | −         | −          | 114.5      |            |
| Delhi (India)  | 597.9      | −          | −          | 481.9      | 18.9       |
| Beijing, China | 62.29      | 4.08       | 0.26       | 99.50      | 0.51       |
| Shanghai, China | 246       | 8.73       | 0.16       | 157        | 1.24       |
| Egypt          | 307        | 6.53       | 85.7       | 2.98       |            |
| Shiraz, Iran   | 115.71     | 6.58       | −          | 67.16      | 0.5        |
| Islamabad, Pakistan | 104 | 2.9        | −          | 125        | 5.0        |
| Toronto, Canada | 182.8     | −          | −          | 197.9      | 0.51       |
| Kuala Lumpur, Malaysia | 144.30 | −          | −          | 51.78      | 0.70       |

Rahman et al., 2019  
Ahmed and Ishiga, 2006  
Banerjee, 2003  
Men et al., 2020  
Wang et al., 2009  
Khairey et al., 2011  
Keshavarzi et al., 2015  
Faiz et al., 2012  
Nazzal et al., 2013  
Han et al., 2014  
Turekian and Wedepohl, 1961  
Rahman et al., 2019  
Ahmed and Ishiga, 2006  
Banerjee, 2003  
Men et al., 2020  
Wang et al., 2020  
Guo et al. 2021  
Mondal and Singh 2021
However, previous studies in different countries also found similar $I_{\text{geo}}$ and $E'_r$ results, such as Muscat (Oman), Beijing (China), Shijiazhuang (China), Baghdad (Iraq), and Egypt (Khairy et al. 2011; Awadh 2015; Men et al. 2018, 2020; Cai and Li 2019; Al-Shidi et al. 2020). Contrastingly, the first and third quartiles of PERI were 699 and 2303, respectively, which indicate most of the sites were high ecological risk due to toxic metal contamination (Fig. 4b). The PERI values range from 17 to 2878, demonstrating 77% of sampling sites were at high ecological risk ($\text{PERI} > 600$), and the values were a significance level higher than this risk index. Among the thirteen sites, one high public gathering site (Teacher-Student Center, Dhaka University, R12) shows considerable high ecological risk ($300 < \text{PERI} \leq 600$), and two other low anthropogenic activity sites (R8 and R10) show comparatively low ecological risk ($\text{PERI} \leq 150$) (Fig. S3). The potential ecological risk variation of different sites mostly depend on the localized anthropogenic and other effects.

The NIRI is the new technique for ecological risk assessment, where the integration of NIPI and PERI took place for intensive assessment of study sites. There are basic differences among NIRI, NIPI, and PERI reported in different studies (Men et al. 2020; Heidari et al. 2021). The NIRI values for all samples in the study area ranged from 10.86 to 1702.25. The value for 85% of samples was higher than 320, indicating extreme ecological risk related to studied toxic metals. The first and third quartiles of NIRI were 375 and 1329, respectively, indicating sites suffered extreme ecological risk (Fig. 4c). Spatially, the NIRI was higher around Dhaka-Aricha Highway and some locations in Dhaka City (Fig. 4d). Only one site out of 13 was at low risk ($\text{NIRI} < 40$), and another one showed moderate risk ($40 < \text{NIRI} \leq 80$). The difference between NIRI levels and NIPI/PERI levels was significant for all the studied sites. The spatial distribution of risk was systematically related to the spatial intensities of the sources (Fig. 4d, S1 and S3;
Based on NIRI and PERI, most of the sites (81%) may pose significantly high risk on the local ecology due to the toxic metal pollution by road dust. This study revealed surrounding environments of the majority of the sampling sites under stress due to the high risk of Pb, Hg, and Cd toxicity. Different indexes showed significant variations in pollution and risk status, although the spatial distribution showed a similar pattern. Among the study area, some sites of Dhaka City and the major portion of Dhaka-Aricha Highway showed significant pollution and ecological risk.

Source analysis

The EPA PMF 5.0 model was extensively used to assess the pollution sources (Men et al. 2020; Xiao et al. 2020; Guo et al. 2021; Heidari et al. 2021; Zhu et al. 2021). In this study, the PMF model shows three main factors that...
contribute to the accumulation of toxic metal in the road dust. As shown in Fig. 5a, factor 1 contributed 73.05%, 53.51%, and 37.31% to the concentration of Pb, As, and Cr, respectively. Pb in the road dust might be accumulated from traffic emission (Men et al. 2018; Xiao et al. 2020). The high concentration of Pb might be associated with industrial activity (Bhuiyan et al. 2015) and As pollution from the agricultural activity (such as use of arsenical pesticides, herbicides, and crop desiccants) and geogenic process (Rahman et al. 2022). A previous study reported that these metals might have been released in Dhaka City road dust from the industries of motor vehicle and metal smelting (Rahman et al. 2019). The major portion around Dhaka-Aricha Highway is the agricultural field, where the farmer uses extensive amount of pesticide and fertilizer for crop growth (Ahmed et al., 2006). The Cr could release from lather tanning and basification in tannery industries (Bhuiyan et al. 2011). Several lather industries are located near the Dhaka-Aricha Highway and the Dhaka city. Moreover, factor 1 represents industrial and agricultural activity.

Factor 2 mainly contributed to 85.37% of the total concentration of Cd. The major source of Cd in road dust might be lubricating oil, diesel fuel, tire, and brake wear (Foti et al. 2017; Men et al. 2020; Heidari et al. 2021). The Cd could be released in the environment easily due to the friction between road and tire of vehicles. Similarly, lubricating oil

**Fig. 5** Positive matrix factorization (PMF) results; a contributions of factors to each toxic metal and b total contributions of factors to the toxic metals in road dust.
and diesel fuel leakage can contribute Cd in road dust (Men et al. 2018). Therefore, factor 2 indicates traffic emissions. Based on the analysis of $I_{\text{geo}}$ and $E_i$, Cd is a significant contributor to road dust pollution and ecological risk.

Factor 3 accounts for 95.43% of the total concentration of Hg with negligible contributions of other toxic metals. The source of Hg might be gasoline and coal combustion (Lu et al. 2009; Wang et al. 2020). Fly ash in the atmosphere with metals might come from coal combustion and be deposited in the road dust (Raja et al. 2014). Many brick kilns and other industries (battery, leather, textile, etc.) are located along the highway and near Dhaka city (Guttikunda et al. 2013; Rahman et al. 2019). On the other hand, gasoline pollution was abundant in Dhaka City (Ahmed and Ishiga 2006), and it could be the significant source of Hg pollution (Lu et al. 2009). The brick kilns have used coal (~ 80%) as a fuel that might pollute the atmosphere and road dust (Guttikunda et al. 2013). Similarly, day-by-day, the battery electric vehicles are increasing in Bangladesh, especially in urban and suburban areas (Hasan 2020). It could be released a significant amount of Hg in the environment through battery disposing of the local environment (Hwang et al. 2016). According to the analysis of $I_{\text{geo}}$ and $E_i$, Hg demonstrates the highest contributor among other metals and caused substantial pollution and ecological risk. So factor 3 most likely represents coal combustion and gasoline as the considerable source.

Among the three contributing factors, coal combustion and gasoline contribute (50.14%) (factor 3) significant content of metals, although traffic exhaust also contributes the most (Fig. 5b). Most of the part of this study covered a highway where brick kilns and different industries are dominated, and in the city along the road, we found extensive urbanization. However, the traffic emission (35.26%) (factor 2) is the second contributor of metals and evenly releases pollutants throughout the study area. The previous study on Dhaka City also speculated the same sources as this study (Ahmed and Ishiga 2006; Rahman et al. 2019). Although factor 1 (14.60%) showed low content, it is also alarming for the people in Dhaka City, especially those who lived along the highway, indicating time to pay attention to the potential exposure to toxic metal content road dust and consequent health risk.

**Health risk assessment**

Human health risk assessment of toxic metals in the road dust through three exposure pathways (ingestion, inhalation, and dermal contact) was analyzed for children and adults (Table 2). For non-carcinogenic risk, this study revealed that the ingestion of road dust appeared to be the primary exposure route for toxic metals to both age groups, followed by dermal contact and inhalation, respectively (Table 2). Similar results were also reported in many other scientific works (Dehghani et al. 2017; Rahman et al. 2019; Heidari et al. 2021; Yesilkakanat and Kobya 2021). Both age groups showed the highest $\text{ADI}_{\text{ing}}$, $\text{ADI}_{\text{inh}}$, and $\text{ADI}_{\text{dermal}}$ for Pb, and lowest $\text{ADI}_{\text{ing}}$ and $\text{ADI}_{\text{inh}}$ for As, although the lowest $\text{ADI}_{\text{dermal}}$ was found for Cd. The hazard quotient (HQ), also known as non-carcinogenic risk for children and adults, was calculated based on reference dose ($\text{RfD}$) and average daily intake (ADI) of every metal. The HQ values for children and adults were found in the order of $\text{HQ}_{\text{ing}} > \text{HQ}_{\text{dermal}} > \text{HQ}_{\text{inh}}$ and $\text{HQ}_{\text{dermal}} > \text{HQ}_{\text{ing}} > \text{HQ}_{\text{inh}}$, respectively. Therefore, the result suggested that inhalation of road dust is almost negligible compared to ingestion and dermal contact. The HQ order suggested that adults are more susceptible to dermal contact of road dust than children; a previous study in Dhaka City also reported similar findings (Rahman et al. 2019). This study found $\text{HQ}_{\text{dermal}} > 1$ in adult groups for Hg indicating potential non-carcinogenic effects for dermal contact of road dust (USEPA 2004). On the other hand, the HI for all analyzed toxic metals of road dust for both age groups showed the descending order of Hg $>$ Cd $>$ Cr $>$ Pb $>$ As. Based on non-carcinogenic effects, it was found that Hg showed a high HI (1.06) at the maximum limit than the safe level (HI $<$ 1) for children. Similarly, Hg and Cd showed higher HI values at maximum, mean, and 95% upper confidence limit than the safe level (1) for adults. This study finding suggested that if children lived around the Dhaka-Aricha Highway and contacted with the road dust at a significant level, then the children might suffer from impairment of the developing central nervous system, as well as pulmonary and nephrotic damage due to mercury contamination (Counter and Buchanan 2004). Similarly, adults who live close to the study area might be significantly exposed to road dust and suffer from various diseases of the brain, heart, lungs, kidneys, immune system disorder (e.g., neurological, immunological, nephrological), reproductive, cardiac, motor, and even genetic problems due to Hg poisoning (Kim et al. 2016), and also skeletal damage (osteoporosis), severe kidney damage, and chronic renal failure due to Cd pollution (Haque et al. 2021b). This study also demonstrated that the maximum HI values for Pb, As, and Cr are close to the safe limit (1) (USEPA 2004), indicating that these metals might have contributed to non-cancer risk in both age groups.

Since Pb, As, Cr, and Cd are classified as class I cancer-causing agents (IARC 2011), carcinogenic risk (CR) is evaluated based on the concentration of these toxic metals. Lifetime exposure to carcinogenic agents can develop any type of cancer in an individual (Haque et al. 2021a). This study could not consider Hg, Cd (dermal), and Cr (dermal) for risk assessment due to the unavailable of cancer slope factor (SF0) values. The results of cancer risk for possible exposure pathways are shown in Table 2. The average CR values of three exposure routes have been suggested that
### Table 2: Non-carcinogenic and carcinogenic health risk assessment results

| Element | Non-carcinogenic risks | | Carcinogenic risks | |
|---------|------------------------|---|-------------------|---|
|         | Child                  | Adult | HI              | HI | CR           | CR          | CR          | CR           |
|         | Dng       | Dnhd   | Dnk             | Dnk           | Crng         | Crh         | Crd          | Crng         | Crh         | Crd          |
| Pb Max  | 6.72E-04  | 2.82E-04 | 2.82E-04 | 1.92E-04 | 8.00E-05  | 5.38E-01 | 2.40E-01 | 7.20E-05 | 7.11E-08 | 2.4E-10 |
| Min     | 8.40E-06  | 3.52E-06 | 3.59E-07 | 2.40E-06 | 1.00E-06 | 6.72E-04  | 3.07E-03 | 9.00E-07 | 7.14E-08 | 1.4E-10 |
| mean    | 2.21E-04  | 9.28E-04 | 9.30E-07 | 6.33E-04 | 2.64E-01 | 1.77E-01 | 8.10E-02 | 2.37E-05 | 1.33E-08 | 7.1E-11 |
| 95% UCL | 2.30E-04  | 9.63E-04 | 9.65E-07 | 6.57E-04 | 2.74E-01 | 1.84E-01 | 8.41E-02 | 2.46E-05 | 1.31E-08 | 7.0E-12 |
| As Max  | 6.10E-06  | 4.80E-06 | 2.82E-07 | 1.92E-06 | 7.00E-04 | 2.31E-01 | 2.82E-02 | 2.25E-07 | 7.5E-02 | 3.5E-04 |
| Min     | 1.09E-06  | 4.58E-06 | 3.64E-06 | 1.55E-06 | 1.12E-06 | 1.09E-06 | 1.44E-02 | 1.17E-07 | 9.8E-02 | 4.0E-04 |
| mean    | 1.39E-06  | 5.77E-06 | 4.59E-06 | 1.92E-06 | 1.41E-06 | 1.87E-06 | 1.45E-04 | 1.47E-09 | 8.4E-02 | 2.1E-04 |
| 95% UCL | 1.55E-06  | 6.50E-06 | 5.17E-06 | 2.16E-06 | 1.58E-06 | 2.11E-06 | 1.66E-01 | 1.71E-05 | 9.5E-02 | 2.3E-05 |
| Hg Max  | 1.98E-08  | 8.31E-08 | 8.31E-08 | 6.61E-08 | 9.38E-07 | 5.37E-02 | 1.00E+00 | 2.12E-05 | 5.9E-02 | 2.5E-02 |
| Min     | 8.40E-11  | 3.52E-11 | 3.59E-07 | 2.40E-07 | 4.11E-07 | 6.59E-03 | 4.49E-04 | 9.00E-11 | 2.51E-07 | 1.0E-02 |
| mean    | 9.84E-08  | 4.12E-08 | 3.82E-08 | 4.81E-08 | 1.97E-07 | 5.25E-01 | 1.05E-02 | 1.09E-11 | 2.94E-07 | 3.51E-02 |
| 95% UCL | 9.55E-08  | 4.16E-08 | 3.80E-08 | 4.82E-08 | 1.97E-07 | 5.26E-01 | 1.05E-02 | 1.09E-11 | 2.95E-07 | 3.52E-02 |
| Cr Max  | 1.69E-06  | 7.07E-06 | 7.00E-06 | 5.62E-06 | 2.47E-06 | 1.18E-06 | 1.77E-01 | 1.81E-06 | 5.05E-06 | 6.30E-06 |
| Min     | 5.34E-08  | 2.24E-08 | 2.24E-08 | 1.78E-08 | 7.83E-08 | 3.74E-07 | 5.00E-02 | 5.73E-08 | 1.60E-06 | 1.91E-06 |
| mean    | 9.29E-08  | 3.88E-08 | 3.80E-08 | 1.35E-08 | 6.47E-08 | 9.69E-02 | 9.91E-02 | 1.02E-07 | 2.77E-06 | 3.30E-07 |
| 95% UCL | 1.16E-07  | 4.87E-08 | 3.87E-08 | 1.70E-07 | 8.13E-08 | 1.22E-01 | 1.24E-01 | 1.28E-07 | 4.18E-07 | 5.79E-08 |
| Cd Max  | 7.26E-05  | 3.04E-05 | 3.05E-05 | 2.76E-05 | 3.01E-05 | 3.78E-06 | 3.78E-06 | 8.01E-05 | 1.7E-05 | 2.18E-05 |
| Min     | 1.26E-05  | 5.28E-05 | 5.29E-05 | 5.28E-05 | 5.39E-05 | 6.53E-05 | 1.35E-05 | 1.39E-05 | 3.77E-05 | 1.38E-05 |
| mean    | 3.33E-05  | 1.40E-05 | 1.40E-05 | 3.33E-05 | 1.40E-05 | 1.73E-05 | 3.87E-06 | 3.67E-06 | 9.96E-06 | 3.57E-06 |

Note: Dng, Dnhd, Dnk, Crng, Crh, and Crd refer to the different risk assessment methods for non-carcinogenic and carcinogenic risks, respectively.
Ingestion for children and dermal contact for adults is the most significant routes for cancer risk. The average CR values for children and adults were found in the order of Cr (4.79E-05) > Cd (1.27E-05) > As (8.42E-06) > Pb (1.89E-06) and As (4.55E-05) > Cr (9.24E-06) > Cd (1.59E-06) > Pb (2.12E-07), respectively. This study revealed that the average CR values of all toxic metals (except Pb for adults) in road dust fell within the range of acceptable or tolerable cancer risk (10^{-6} to 10^{-4}) (USEPA 2011b). The CR of Pb for adults was (range: 8.06E-09–6.45E-07) lower than no cancer risk value (< 10^{-6}), which indicates the adults would pose negligible cancer risk due to Pb pollution. Regarding the cancer risk, this study observed that the maximum CR level of Cr for children and As for adults was very close to unacceptable cancer risk (10^{-4}) which suggested that local inhabitants might pose significant cancer risk if they expose continuously to road dust. A previous study on road dust in Dhaka City also focused on Cr- and As-induced cancer risk for inhabitants (Rahman et al. 2019). Therefore, it could be suggested that As, Cr, and Cd in road dust of Dhaka City and Dhaka-Aricha Highway pose a detrimental threat of cancer risk.

**Conclusion**

The mean concentration of toxic metals, except As and Cd, was significantly higher than the corresponding background values. Spatial distribution of toxic metals revealed that Pb, Hg, and Cr mostly dominated in suburban areas of the highway. The I_{geo} indicated low to extreme contamination of toxic metals of the sampling sites. Similarly, the NIPI, PI, and PLI demonstrated that road dusts were unpolluted to strongly polluted by toxic metals depending on local environmental factors. The ecological risk indices, E_i, PERI, and NIRI, showed low to extreme ecological risk throughout the study area, and the highway was the most vulnerable than the city. The Hg, Cd, and Pb were the influential toxic metals among studied metals to calculate the above indices. The PMF analysis showed three main factors that influence metal accumulation. Factor 1 (Pb, As, and Cr) indicates industrial and agriculture activity (14.60%), factor 2 (Cd) indicates traffic exhaust (35.26%), and factor 3 (Hg) indicates coal combustion and gasoline (50.14%). Among the sources, coal combustion and gasoline were the dominant factors because of abundant brick kiln and gasoline engine throughout the study area. Health risk assessment suggested that inhalation of road dust mostly negligible compare to ingesting and dermal contact, and adults are more susceptible than children. The HI value for Hg was higher than the safe limit for both age groups, whereas HI for Cd showed higher than 1 for adults only. Therefore, the inhabitants of the study area might suffer from non-carcinogenic health risks due to Hg and Cd. The cancer risk level for all the studied toxic metals, except Pb for adults, were within the acceptable range (10^{-6} to 10^{-4}). In comparison, the CR of Pb for adults showed negligible risk (< 10^{-6}). However, continual lifetime exposure to toxic metals by road dust might develop cancer in the local inhabitants. Finally, the results of this work highlight source identification and environmental implications for toxic metals in road dusts that would facilitate the local inhabitants and regularity authorities to take effective mitigation measures for reducing pollution load on nearby agriculture field and potential public health risk.

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**Author contribution** Md. Morschedul Haque: writing—original draft; formal analysis; visualization.
Sajin Sultana: investigation and data curation.
Shamshad B. Quraishi: resources.
Shaif M. Tareq: conceptualization, review and editing, supervision.

**Data Availability** All data sources described in this study are directed at the corresponding authors.

**Declarations**

**Ethics approval and consent to participate** Not applicable.

**Consent for publication** Not applicable.

**Competing interests** The authors declare no competing interests.

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