Assessment of environmental pollution of heavy metals deposited on the leaves of trees at Yazd bus terminals

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Received: 31 August 2021 / Accepted: 18 December 2021 / Published online: 12 January 2022
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Abstract
There is a lack of information on the effect of urban transport activities in emitting heavy elements into the environment. This research assesses the concentrations of some heavy elements in the deposited atmospheric dust at Yazd bus terminals in Yazd, Iran. So, 34 falling dust samples were collected from the leaves of trees planted near the bus terminals. Following the digestion by nitric acid, the total concentrations of cadmium (Cd), cobalt (Co), copper (Cu), nickel (Ni), lead (Pb), zinc (Zn), chromium (Cr), and manganese (Mn) were determined in the dust by atomic absorption spectrometry. The map representing the spatial distribution of the metals was plotted, and their sources were identified using Pearson’s correlation coefficient, principal component analysis, and cluster analysis. The results indicated that the mean concentrations of the heavy metals in the dust deposited on the tree leaves were in the order of Cd < Co < Ni < Pb < Cu < Zn < Cr < Mn. The map representing the spatial distribution of the heavy metal concentrations illustrated that the abundance of metals in different stations varied with their location. Two main sources were detected for the heavy metals in the deposited dust. Co, Cd, Mn, and Ni had anthropogenic and lithogenic sources while Pb, Zn, Cr, and Cu were emitted by traffic and industrial activities. Enrichment factor, contamination factor, integrated pollution index, and risk index were estimated at low to extremely high levels of pollution in residential, commercial, green space, and environmental uses. Based on the results, the growth of industrialization and human activities contribute to the heavy metal contamination of the environment emitted into the atmosphere in Yazd.

Keywords Principal Component Analysis · Pollution index · Falling dust · Cluster Analysis

Introduction
Heavy metals severely impact local people’s health (Ahn et al. 2020). Prolonged exposure to various well-known environmental factors including heavy metals, air pollutants (particulates), metal-containing nanoparticles accelerates the progression of several diseases such as Alzheimer’s (Mir et al. 2020). Air pollution is becoming an increasingly essential environmental issue in today’s societies, particularly in developing countries, as it poses severe risks to the environment (Esfandiari et al. 2020a).

The leading cause of air pollution in growing large cities is the mass traffic of cars. In recent decades, increasing population density and economic and industrial activities in urban areas have increased traffic volume, which has, in turn, increased air pollution, fuel consumption, and energy use. Heavy traffic loads on urban streets are often rooted in such problems as poor traffic management and inappropriate traffic culture (Esfandiari et al. 2019).

Two of the significant contributors to urban air pollution are motor vehicles and road traffic (Bucko et al. 2011). Roads and roadsides in urban areas are usually polluted with fine particles emitted by traffic (Addo et al. 2012). Once emitted into the atmosphere, these particles may remain in the atmosphere for a long time and eventually deposit in the form of street dust on roadsides, buildings, and vegetation (Zhang et al. 2006). Most of these dust particles contain heavy metals. Environmentally, the metal contaminants are usually stable and can cause environmental damage through the food chain. Pollutants and particulates in the air, including metal particles, are harmful to the environment and plants (Sawidis et al. 2011).
Urban dust is currently used as an indicator of heavy metal pollution in the urban environment. Recently, due to the emissions of various environmental pollutants and their impacts on human health and other organisms, much attention has been paid to recognizing pollutants, how they are transported, their functions, and their availability.

Research shows that leaves are the most sensitive part of a plant and are useful in absorbing and retaining environmental dust that reaches their surface. Tree leaves are of low sampling costs, most useful, and most widely used as biocollectors for monitoring pollutants in urban and industrial environments (Kardel et al. 2010; Balasooriya et al. 2009). Recently, various investigations have been conducted on the concentrations of heavy metals in developed countries (Fu et al. 2020; Esfandiari et al. 2020a; Qadeer et al. 2020).

Qadeer et al. (2020) measured the concentrations and pollution indices of heavy metals in road dust in two urbanized cities of Pakistan (Lahore and Faisalabad). Their results showed that among sites, the heavy metal concentrations were the highest in dust obtained from the general bus stands in both cities. Alsbou and Al-Khashman (2018) collected samples of falling dust deposited on the palm leaves in Bosnia and Herzegovina and concluded that Fe, Mn, Zn, and Pb were the most abundant heavy metals in the dust, respectively, and Cd was the least. Cai and Li (2019) conducted a detailed investigation to determine levels and sources of heavy metal contamination in street dust from China. The results showed that the mixed group (traffic and industry) contributed the highest amount of heavy metals to the collected dust. Xiao et al. (2019) used an environmental index and assessed the heavy metal pollution risks in urban soils of the steel industrial city of Liaoning Anshan, China. The results indicated that urban soils were at moderate to high levels of Cd and Pb contamination.

Rapid industrialization has made Yazd, a city in the center of Iran, face severe air, soil, and water pollutions, which can be a serious threat to the health of residents and employees working in the area. No information is available on the status of pollution caused by urban transportation in the atmospheric dust of Yazd. Identifying the source and amount of pollutants is useful and effective in managing air pollutants. Therefore, this research aims to determine the concentrations of some of the most critical heavy metals in the deposited atmospheric dust and evaluate air pollution that has come from urban transportation in this city.

**Materials and Methods**

**Study Area**

Yazd (31°N, 54°E) has a cold and dry climate located in the Pediment of the Yazd–Ardakan Plain. The region is at an average altitude of 1216 m above sea level. According to the 15-year data of Yazd Synoptic Station, the mean precipitation, average temperature, and relative humidity are 67.7 mm, 19.9 °C, and 27%, respectively (Fathizad et al. 2020b). Yazd covers an area of 6336 km2 and is home to 586,276 people. Yazd can be considered one of the cities with high traffic. There are seven bus terminals located for transportation inside and outside the city of Yazd including Emam Ali, Atiasi, Shohadaye Mehrab, Doulat Abad, Golzar Shohada, Quran Gate, and Ghadir (Esfandiari et al. 2020b). Figure 1 displays the location of the study area in Iran along with the sampling sites (the bus terminals and the control site).

**Sampling and Chemical Analysis**

In this study, trees in the green spaces of the bus terminals were used as a biological indicator and natural collector of falling dust. The deposited samples of falling dust were obtained from the leaves of trees that were 1.5–2 m tall. The collected leaf samples were transported in paper bags to the laboratory where they were rinsed with distilled water. To estimate the amount of deposited dust, the resulting solutions were centrifuged at 5000 rpm for 5 min. The water was then pipetted off the dust and the samples were placed in an oven at 55 °C for 24 h. Finally, the dry particles were weighed with a digital scale with an accuracy of 0.001 g (Sartorius Quintix, Germany), and acid digestion was performed on the dust samples using the ISO method (1995). According to the extraction procedure of trace elements, 7 mL of concentrated chloride acid plus 2.5 mL of concentrated nitric acid (1:3 ratio) (Merck, Germany) and then 5 mL of diluted nitric acid (0.5 M) were added to each sample drop by drop. The adsorption vessel and condenser were installed and rinsed with further 10 mL of nitric acid after reaction time. In the final step, after cooling the samples, 33.3 mL of diluted nitric acid was added, and the solution was completely filtered by Whatman 42 filter paper and reached the volume of 50 mL by adding deionized distilled water. The concentrations of heavy metals like Cd, Co, Cu, Ni, Pb, Zn, Cr, and Mn were estimated by an atomic absorption spectrophotometer (AAS, Analytik Jena-330, Germany) with an air–acetylene flame. Then, the readings were placed in Eq. (1) to calculate the concentrations of heavy metals in the falling dust in mg/kg (Lal et al. 2019).

\[
X = (a \times v \times b \times 100/m)
\]

(1)

in which X is the concentration of the element in mg/kg, a is the spectrophotometer reading, v is the volume of the extract used, b is the dilution factor, and m is the dust weight.
Statistical Analysis

All statistical analyses were conducted in the SPSS 16.0 statistical package. Pearson’s correlation coefficient, cluster analysis (CA), and principal component analysis (PCA) were used to show the relationship among the heavy metals and probability sources. The Kaiser–Meyer–Olkin measure of sampling adequacy was 0.54, so they were suitable for factor analysis. The results of Bartlett sphericity test were also significant ($p \leq 0.05$), which confirmed the opposite hypothesis, implying the existence of a significant correlation between the variables (Miller and Miller 2005). The interpretation of the principal components in PCA was done using Varimax rotation. The heavy metal concentrations were also standardized through the Z method, and Euclidean intervals were used to calculate similarities in variables. Then, hierarchical clustering was employed using the Ward method of the standardized data set (Möller et al. 2005).

Pollution Assessment

Due to the lack of specific background standards to assess the degree of pollution in Iran, the average concentrations of heavy metals in the earth’s crust were used as the background concentrations (Table 1). Contamination factor ($C_f$), modified contamination degree ($mCd$), integrated pollution index (IPI), enrichment factor (EF), and environmental risk index (RI) were used to check the contamination of commercial land use, residential area, green spaces, and environmental protection in the study area.

Contamination Index and Mean Contamination

$C_f$ can be used to indicate the environmental contamination of a specific metal. This factor is calculated by Eq. (2) (Hakanson, 1980).

$$C_f = \frac{C_{i0-1}}{C_{in}}$$

Table 1: Basic statistical parameters and Earth’s crust values (Taylor and McLennan 1995)

| Elements (mg kg$^{-1}$) | Co  | Ni  | Cu  | Mn  | Zn  | Pb  | Cd  | Cr  |
|------------------------|-----|-----|-----|-----|-----|-----|-----|-----|
| Earth’s crust value    | 50  | 20  | 400 | 950 | 67  | 80  | 2   | 165 |
where \( C_i^f \) represents the contamination factor (mg kg\(^{-1}\)), \( C_{0-i} \) represents the average metal concentration (mg kg\(^{-1}\)), and \( C_{i}^n \) represents the concentration of the same metal in the reference sample (mg kg\(^{-1}\)).

\[
C_d = \sum_{i=1}^{n} C_i^f
\]

(3)

where \( C_d \) is used to evaluate the overall pollution of the environment. It is calculated by the sum of the total contamination factor for all metals as follows. Due to the limitations of the degree of contamination index, the mean contamination degree was used as Eq. (4) (Abrahim and Parker 2008).

\[
mC_d = \frac{\sum_{i=1}^{n} C_d}{n}
\]

(4)

where \( mC_d \) represents the mean contamination degree and \( n \) is the number of examined trace elements (mg kg\(^{-1}\)).

### Integrated Pollution Index

The pollution level was calculated using Eq. (6) in which \( PI \) represents the pollution index of the \( i \)th pollutant, \( C_i \) is the concentration of the \( i \)th pollutant (mg kg\(^{-1}\)), \( B_i \) represents the base concentration of the pollutant in soil parent materials (mg kg\(^{-1}\)), and \( n \) is the number of contaminants (Dolezalova Weissmannova et al. 2015). Table 2 shows the categories of the level of \( C_i^f \), \( mCd \), and IPI.

\[
PI_i = \frac{C_i}{B_i}
\]

(5)

\[
IPI = \left( \prod_{i=1}^{n} PI_i \right)^{1/n}
\]

(6)

In a recent study, the values of Iran’s standard soil trace elements were used to compare rangelands and environmental protection land use as shown in Table 3.

### Risk Index (RI)

The potential environmental risk factor was calculated to assess heavy metal contamination of soil and the ecological and environmental effects of heavy metals. \( RI \) is calculated by Eq. (7) and (8):

\[
E_i^r = T_r \times C_i
\]

(7)

\[
RI = \sum_{i=1}^{n} E_i^r
\]

(8)

where \( E_i^r \) represents the risk factor for each metal, \( T_r \) represents the toxicity response to heavy metals (Table 4), and \( RI \) represents the risk index. This index is calculated by the sum

### Table 2 Standard classification of mCd, \( C_i^f \), and IPI indexes (Estifanos and Degefa, 2012)

| mCd      | Class                  | \( C_i^f \) and IPI | Class |
|----------|------------------------|---------------------|-------|
| mCd < 1.5| Nil to very low degree | \( C_i^f < 1 \)     | Low   |
| 1.5 \leq mCd < 2 | Low degree | \( 1 \leq C_i^f < 3 \) | Moderate |
| 2 \leq mCd < 5 | Moderate degree | \( 3 \leq C_i^f < 6 \) | High |
| 5 \leq mCd < 8 | High degree | \( C_i^f \geq 6 \) | Very high |
| 8 \leq mCd < 16 | Very high degree | IPI < 1 | Low degree |
| 16 \leq mCd < 32 | Extremely high degree | \( 1 \leq IPI < 2 \) | Moderate degree |
| mCd \geq 32 | Ultra-high degree | IPI \geq 2 | High degree |

### Table 3 Standard reference values of some heavy metals of Iran for different functional areas (Fathizad et al. 2020a)

| Elements     | Land use                        | Residential area | Commercial area | Park and greenspace | Environmental protection |
|--------------|---------------------------------|------------------|-----------------|--------------------|-------------------------|
| Co mg kg\(^{-1}\) | 50                              | 100              | 50              | 20                 |
| Ni mg kg\(^{-1}\)  | 155                             | 600              | 530             | 50                 |
| Cu mg kg\(^{-1}\)  | 400                             | 1100             | 500             | 63                 |
| Mn mg kg\(^{-1}\)  | 950                             | 950              | 950             | 950                |
| Zn mg kg\(^{-1}\)  | 500                             | 5000             | 500             | 200                |
| Pb mg kg\(^{-1}\)  | 80                              | 700              | 290             | 300                |
| Cd mg kg\(^{-1}\)  | 2                               | 8                | 8               | 3.9                |
| Cr mg kg\(^{-1}\)  | 165                             | 500              | 535             | 64                 |

* The mean of earth’s crust was used as the reference standard of manganese (Mn)
of several metals or various pollution factors under investigation (Wan et al. 2016). Table 5 shows the classification of RI and potential environmental risk levels.

### Enrichment Factor (EF)

The enrichment factor (EF) is an important factor that indicates the degree of human intervention in the natural environment. The passive element is used to calculate this factor. The reference element for calculating the enrichment coefficient is an element that has a strictly geological basis. The reference element, which is necessary to calculate the enrichment factor, has a purely geological origin. In environmental research, Al, Fe, Sc, Ti, and Zr are most often used as the reference (Abrahim and Parker 2008). Iron (Fe) was selected as the reference element since it presented the lowest level variation in concentration. This indicator can be calculated by Eq. (9):

\[
EF = \frac{\left(\frac{C_i}{C_{Fe}}\right)_{\text{sample}}}{\left(\frac{C_i}{C_{Fe}}\right)_{\text{background}}}
\]  

(9)

where \(\left(\frac{C_i}{C_{Fe}}\right)_{\text{sample}}\) is the ratio of the concentration of C_i to the concentration of Fe in the topsoil sample and \(\left(\frac{C_i}{C_{Fe}}\right)_{\text{background}}\) is the ratio of the concentration of C_i to the concentration of Fe in the reference value (Ergin et al. 1991). Table 6 indicates the severity of heavy metal contamination using the EF coefficient.

### Distribution Map of Pollution

Plotting a map representing the distribution of heavy metals to identify geographical patterns is important for understanding the distribution behavior of elements (Tang et al. 2013). The spatial variations of heavy metals in the studied urbanized area were described by the geographical information system (GIS) software version 10.2. Distribution maps can show the risk of contamination by dividing the site into different levels of metal concentrations and using the color separation method. Kriging is a method of estimation based on a weighted moving average. It is the best nonlinear estimator. One of the most important features of Kriging is that it can calculate the errors associated with estimation (Hakimzadeh and Esfandiari 2016).

### Results

#### Comparison of Means

The mean concentrations of heavy metals in the falling dust of the study area are compared in Fig. 2. Mn and Cd were the most and least abundant heavy metals in the falling dust, respectively. The highest amount of Cd was associated with the Ghadir bus terminal. There was, however, no statistically significant difference between the Ghadir and the other terminals. The trend of changes in the concentrations of Co and Ni was similar in all sampling stations, and there was no significant difference between them. The highest amount of Cu was observed in the Emam Ali and Golzar Shohada bus terminals, which did not differ significantly from that in the Quran Gate and Ghadir bus terminals. The lowest amount of Cu was associated with the control site, which was not significantly different from that of the Doulat Abad and Shohadaye Mehrab bus terminals. Mn was most abundant in the Doulat Abad and Emam Ali bus terminals and least abundant in the Atlasi bus terminal. No significant differences were observed between the Shohadaye Mehraj, the Golzar Shohada, and the control site. The highest value of Pb was associated with the Quran Gate bus terminal and the lowest with the control site. The highest value of Cr was related to the Ghadir and Emam Ali bus terminals and the lowest value to the control site. The highest

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**Table 4** Toxic response factor (Wan et al. 2016)

| Elements | Co | Ni | Cu | Mn | Zn | Pb | Cd | Cr |
|----------|----|----|----|----|----|----|----|----|
| Toxic response factor | 5  | 5  | 5  | 1  | 1  | 5  | 30 | 2  |

**Table 5** Potential ecological risk factor (Hakanson, 1980)

| RI   | Ecological risk degree | \(E_i^r\) | Risk degree |
|------|------------------------|----------|-------------|
| RI \(\leq 150\) | Low | \(E_i^r < 40\) | Low |
| 150 \(\leq RI \leq 300\) | Moderate | 40 \(\leq E_i^r < 80\) | Moderate |
| 300 \(\leq RI < 600\) | Considerable | 80 \(\leq E_i^r < 160\) | Considerable |
| RI \(\geq 600\) | Very high | 160 \(\leq E_i^r < 320\) | High |
|       |            | \(E_i^r \geq 320\) | Very high |

**Table 6** Classification of heavy metal contamination intensity using the enrichment factor (Ergin et al. 1991)

| Contamination level | Extremely severe enrichment | Very severe enrichment | Severe enrichment | Moderate enrichment | No enrichment | Contamination level |
|---------------------|-----------------------------|------------------------|------------------|---------------------|--------------|---------------------|
| EF Value            | \(EF \geq 40\)              | 20 \(\leq EF < 40\)     | 5 \(\leq EF < 20\) | 2 \(\leq EF < 5\)   | \(EF < 1\)   | EF                  |
Fig. 2  Mean values and ranges of heavy metal concentrations in the dust deposited in the bus terminals. (The same letters in the deposited dust indicate that the means were not statistically significant at the 0.05% level)
amount of Zn was obtained from the Ghadir bus terminal and the lowest from the control site. It was not significantly different from that of the Atiasli and the Shohadaye Mehrab bus terminals. Table 7 presents a comparison of our results with some same studies in the world.

**Distribution Map of Pollution**

The kriging method was used to show the spatial distribution of the concentration of different elements. Among the types of kriging (ordinary, simple, universal, indicator, probability, disjunctive), the model with a lower root mean square (RMS) was selected, and the map for each metal was presented based on the low and high range (Fig. 3). The maps indicated that the abundance of heavy metals in different bus terminals varies with their geographical location.

In general, according to the element maps presented in Fig. 3, the Ghadir and Quran Gate bus terminals had the highest amount of heavy elements because Yazd is predominantly subject to winds flowing from the west and northwest. In addition to transportation factors and urban and human activities, industrial factors have also been very effective in increasing the concentrations of these elements. The location of Meybod City in the Yazd–Ardakan plain, which is actually a topographic valley surrounded by mountains, contributes to channeling strong winds from the north and northwest across Meybod to the west of Yazd and creating winds that carry dust contaminated with hazardous materials. Since Yazd city is located in the center of the Iranian Plateau, it is one of the arid and desert areas with low annual precipitation, high evapotranspiration, low humidity, and strong eroding winds carrying dust contaminated with heavy metals to the area.

Fengjin et al. (2008) examined the relationship between dust storms and climatic factors in northern China. They found a negative correlation between the amount of fine dust and relative humidity in the region. They also state that precipitation, which is one of the factors influencing dust storm phenomena, has a significant negative correlation with the number of days of dust storms at the p ≤ 0.01 level.

**Sources of Heavy Metals in Deposited Dust**

The relationships between heavy metals in the falling dust were investigated using Pearson’s correlation matrix (Table 8). The relationships between elements could provide information on sources and pathways of heavy metals in the environment (Dragović et al. 2008). Lu and Baim (2010) state that the correlation coefficients between metals can provide valuable information on the sources of heavy metals. Based on our results, Ni did not have a significant correlation with other metals and in some cases had a negative correlation coefficient with other pollutants. As a result, the potential sources of its emissions were different from other pollutants (Table 8). According to the results in Table 8, there is a significant correlation between Cr/Cu, Zn/Cu, Mn/Co, Cd/Co, and Cd/Pb in the falling dust at the p ≤ 0.01 level. The highest correlation coefficient was associated with Co/Cd and Zn/Cu metals with correlation coefficients of 0.71 and 0.62, respectively. These significant correlations showed that these metals came mainly from common sources.

Other research studies have also confirmed the direct relationship between contamination of heavy metals and traffic (Addo et al. 2012; Werkenthin, et al. 2014). Nan et al. (2002) also found that Zn was closely correlated with Cu and Pb in wheat grown in contaminated soils in China. Rodriguez Martin (2006) obtained similar results for the correlation between heavy metals.

The CA method is often combined with PCA to examine the results and group individual parameters and variables (Lu and Baim 2010). Figure 4, which is derived from the CA method, also confirms this finding. In general, emission sources can be divided into two groups: Co, Cd, Mn, and Ni in one collection, and Pb, Zn, Cr, and Cu in another. So, they probably have a common emission source. Thus, Cr, Cu, Pb, and Zn were raised by industrial and anthropogenic pollution resulting from traffic. Cd, Mn, Co, and Ni came from lithogenic and anthropogenic sources. The results are in line with the findings obtained by Koshiravi et al. (2018) and Lu et al. (2007).

Table 9 presents the results of PCA in which a Varimax rotation was applied to determine the sources of heavy metals in the falling dust. The results for the first to eighth main components are given in this table. Also, the factor loading of each variable before and after the rotation is presented in Table 10. According to the results, the total variance of two of the specific amounts was greater than one, and these two factors accounted for 57.93% of the total variance (Table 9). The first factor captured 33.83% of the total variance. It included the elements of Zn, Cu, Pb, and Cr. The second factor accounted for 24.10% of the total variance, and it included Cd, Co, Mn, and Ni.

Proshad et al. (2018) used PCA and analyzed the soil of industrial areas in Bangladesh. They divided the measured metals into three separate clusters: 1) Ni, Pb, and Cu, 2) Ar and Cd, and 3) Cr. Ungureanu et al. (2017) state that Cr and Cd might be affected by both lithogenic and anthropogenic sources, even if they do not exceed the alert threshold values. Xiao et al. (2019) used PAC and CA to classify the sources of heavy metals into three groups, i.e., traffic emission, natural source, and both natural and anthropogenic sources.

The three different analyses used to identify the sources of pollutant emissions produced almost the same results. The source of these pollutants is most likely human activities. According to the studies, the most prominent source of Pb emissions in the street dust is fuel additives from
automobiles (De Miguel et al. 1997). Cr, Cu, and Zn are originated from the erosion of alloys used in vehicles and other surfaces and metal materials (Wei et al. 2010). Industrial activities or the erosion of parts used in vehicles may also be sources for the conversion of these elements into street dust (Al-Khashman 2007; Charlesworth et al. 2003). The combustion of fossil fuels and oils used in automobiles is the source of Ni (Wei et al. 2010). Other studies have confirmed the direct relationship between the amount of roadside pollution with heavy metals and the volume of traffic (Duong and Lee 2011; Wu et al. 2015a, 2015b; McKenzie et al. 2009).

**Pollution Assessment**

In this study, geochemical indicators were used to grade the levels of dust pollution in the air. The results are shown in Figs. 5, 6, 7, and 8 for the residential, commercial, park, and green space and environmental protection land uses, respectively. According to Fig. 5 and based on the EF index, the highest amount of dust enrichment was associated with Mn and Cr. According to the classification, except for Mn that exhibited very high enrichment in all four land uses, the other metals had no enrichment unless Cr, which was at the moderate level of enrichment in environmental protection land use.

Proshad et al. (2018) used enrichment indices to calculate contamination load in the Tangail ground located in Bangladesh. The results showed that agricultural soils were heavily contaminated with hazardous elements. In terms of pollution load, the amounts of soil index were less than one in all selected sites, which indicated relative soil pollution. In terms of the enrichment index, it had a potential environmental risk.

The results of the contamination factor (CF) for heavy metals in the air showed that Co, Ni, Cu, Zn, and Cr were in the low pollution range for all four residential, commercial, green space, and environmental protection land uses. In the case of Pb, the level of pollution was in the range of moderate pollution for the residential area. As is shown in Fig. 6, the highest contamination was associated with Mn in Yazd so that it was classified in the very high pollution range for all four uses.

A study by Zhuang et al. (2018) showed that the concentrations of Pb, Fe, Ni, and Cr in the soil of industrial towns were significantly higher than the permitted standard, which is in line with the present study regarding the concentration of Pb in agricultural lands. Wan et al. (2018) argue that the high degree of contamination of heavy metals indicates severe metal pollution and the anthropogenic source of these metals. Doung and Lee (2011) discovered considerable contamination of Zn and Cu in road dust samples collected from the asphalt highway in the city of Ulsan, South Korea. Wong et al. (2003) state that the high concentration of heavy metals in the environment is indicative of the anthropogenic source of these metals, resulting from the rapid growth of industrialization and urbanization.

**Table 7** Mean concentrations of heavy metals in dust samples reported by some similar studies as compared to the results of the present study

| City/region              | Mean elemental concentrations (mg/kg) | References                         |
|--------------------------|---------------------------------------|------------------------------------|
|                          | Cd | Co | Cr | Cu | Mn | Ni | Pb | Zn |                                        |
| Zhengzhou (China)        | 1.57 | - | 53.96 | 33.64 | - | 18.07 | 74.59 | 356.5 | Wang et al. (2021)                     |
| Huangshi (China)         | 9.54 | - | - | 1628.54 | 5316.07 | - | 401.52 | 593.16 | Zhong et al. (2020)                    |
| Lahore (Pakistan)        | 6.9 | - | - | 40.4 | - | 20 | 56.8 | 95.5 | Qadeer et al. (2020)                   |
| Beijing (China)          | 0.074 | - | 99.50 | 97.36 | 536.29 | 40.76 | 62.29 | 255.90 | Men et al. (2020)                      |
| Tianshan (China)         | 3.42 | - | 132.35 | 69.86 | - | 40.71 | 121.48 | 815.42 | Cui et al. (2020)                      |
| Anshan (China)           | 1.17 | - | 150.36 | 57.41 | 117,000 | 29.59 | 4.56 | 325.26 | Xiao et al. (2019)                     |
| Shihwa (Korea)           | 2.22 | - | 498 | 992 | - | 164 | 612 | 1824 | Jeong et al. (2019)                    |
| Shijiazhuang (China)     | 1.86 | - | 131.70 | 91.06 | - | 40.99 | 154.78 | 496.17 | Cai and Li (2019)                      |
| Zanjan (Iran)            | 5.79 | 4.16 | - | 18.31 | - | 26.38 | 119.59 | 684.11 | Khosravi et al. (2018)                 |
| Petra (Jordan)           | 1.0 | - | - | 19.1 | - | - | 177.0 | 129.0 | Alsobou and Al-Khashman (2018)         |
| Jalalabad (Afghanistan)  | 0.69 | 4.02 | 25.43 | 29.56 | 189.94 | 31.03 | 33.10 | 95.76 | Jadoon et al. (2018)                   |
| Kabul (Afghanistan)      | 1.16 | 1.16 | 38.40 | 43.63 | 252.93 | 66.41 | 28.69 | 122.51 | Jadoon et al. (2018)                   |
| Beijing (China)          | 2.29 | 10.6 | 86.0 | 138.4 | 607.1 | 45.2 | 167.9 | 727.7 | Wan et al. (2018)                      |
| Thessaloniki (Greece)    | - | - | 526.2 | 529.1 | - | 191 | 671 |                                       | Bourliva et al. (2016)                 |
| Delhi (India)            | 2.56 | - | 148.8 | 191.7 | - | 36.4 | 120.7 | 284.5 | Suryawanshi et al. (2016)              |
| Guangzhou (China)        | 0.32 | - | 35.8 | 218 | - | 18.7 | 87.6 | 107 | Lu et al. (2016)                       |
| Toronto (Canada)         | 0.51 | - | - | 162 | 1407.2 | - | 182.8 | 232.8 | (Nazzal et al. (2013)                  |
| Massachusetts (American) | - | - | - | 105 | 456 | - | 73 | 240 | Apeagyei et al. (2011)                 |
Fig. 3  Distribution of heavy metals in the deposited dust by the kriging method
Evaluating the general status of ecological risk (ER) of atmospheric heavy metals in the urban atmosphere of the urbanized area showed that the region ranged from non-polluted to safe in different functional areas (Fig. 7). Examining the general status of pollution in the study area using the integration of indices (IPI, mCd, and RI) showed that the level of pollution in the urban atmosphere was from low to extremely high (Fig. 8).

Similarly, Lafta et al. (2013) concluded that their study area in Iraq was contaminated with Co, Cd, and Ni, but it was not contaminated with other metals. Ogunkunle and Fatoba (2014) assessed the concentrations and ecological risks of heavy metals (Pb, Cu, Zn, Cd, and Cr) in the soils in southwestern Nigeria. The results showed that in terms of geo-accumulative index RI, the study area was at a very high risk, which was not in line with the results of this research. Ogunkunle (2014) showed that the

### Table 8: Correlation coefficients of heavy metals in the deposited dust

| Metal | Cr | Cu | Zn | Mn | Ni | Co | Cd | Pb |
|-------|----|----|----|----|----|----|----|----|
| Cr    | 1  |    |    |    |    |    |    |    |
| Cu    | 0.58** | 1  |    |    |    |    |    |    |
| Zn    | 0.38 | 0.62** | 1  |    |    |    |    |    |
| Mn    | 0.18 | 0.17 | 0.19 | 1  |    |    |    |    |
| Ni    | -0.08 | -0.09 | -0.18 | 0.08 | 1  |    |    |    |
| Co    | 0.19 | 0.06 | 0.14 | 0.55** | 0.21 | 1  |    |    |
| Cd    | 0.41 | 0.27 | 0.39 | 0.18 | 0.05 | 0.71** | 1  |    |
| Pb    | 0.33 | 0.49* | 0.28 | -0.04 | 0.007 | 0.04 | 0.53** | 1  |

Significance at 0.05, **Significance at 0.01

### Table 9: PCA values for the heavy metals in the deposited dust

| Component | Initial eigenvalues | Extraction sums of squared loadings | Rotation sums of squared loadings |
|-----------|---------------------|-------------------------------------|----------------------------------|
|           | Total | Variance (%) | Cumulative (%) | Total | Variance (%) | Cumulative (%) | Total | Variance (%) | Cumulative (%) |
| 1         | 2.958 | 36.975 | 36.975 | 2.958 | 36.975 | 36.975 | 2.706 | 33.831 | 33.831 |
| 2         | 1.677 | 20.959 | 57.934 | 1.677 | 20.959 | 57.934 | 1.928 | 24.103 | 57.934 |
| 3         | 1.040 | 13.003 | 70.937 |        |        |       | 1.293 | 15.869 | 70.937 |
| 4         | .849  | 10.613 | 81.550 |        |        |       |        |        |       |
| 5         | .626  | 7.829  | 89.379 |        |        |       |        |        |       |
| 6         | .554  | 6.923  | 96.301 |        |        |       |        |        |       |
| 7         | .229  | 2.862  | 99.164 |        |        |       |        |        |       |
| 8         | .067  | .836   | 100.000|        |        |       |        |        |       |

Evaluating the general status of ecological risk (ER) of atmospheric heavy metals in the urban atmosphere of the urbanized area showed that the region ranged from non-polluted to safe in different functional areas (Fig. 7). Examining the general status of pollution in the study area using the integration of indices (IPI, mCd, and RI) showed that the level of pollution in the urban atmosphere was from low to extremely high (Fig. 8).
contamination of Pb and Cu in a study area at a mega cement factory was high to moderate. The investigation conducted by Olowoyo et al. (2015) showed that the concentrations of Pb, Ni, Zn, Cr, Cu, and Cd were moderate in terms of IPI. The pollution index indicated that Anshan City's road dust was environmentally (RI index) moderate to highly polluted by heavy metals (Xiao et al. 2019).

**Conclusion**

This study aimed to evaluate the role of transportation in the production of some heavy metals like Cd, Co, Cu, Ni, Pb, Zn, Cr, and Mn in the falling dust. The results suggest

### Table 10  Factor loadings of heavy metals in the deposited dust in the study area for factors with an eigenvalue > 1

| Metals | Before rotation | After rotation |
|--------|----------------|---------------|
|        | Factor 1 | Factor 2 | Factor 1 | Factor 2 |
| Cr     | .710    | -.193   | -.722   | -.141   |
| Cu     | .746    | -.411   | .851    | .038    |
| Zn     | .679    | -.343   | .761    | .007    |
| Mn     | .370    | .590    | .070    | .693    |
| Ni     | .030    | .495    | -.246   | .430    |
| Co     | .543    | .767    | .147    | .928    |
| Pb     | .624    | -.286   | .686    | .020    |
| Cd     | .784    | .300    | .570    | .616    |

**Fig. 5** Enrichment factor value of heavy metals for the assessment of different functional areas

**Fig. 6** Contamination factor value of heavy metals for the assessment of different functional areas
that the mean concentrations of heavy metals in the deposited dust in natural sediment traps (leaves of trees in the bus terminals) have increased in the following order from low to high: Cd < Co < Ni < Pb < Cu < Zn < Cr < Mn.

The highest concentration of heavy metals was associated with the Qadir and Quran Gate bus terminals because these two terminals were more exposed to winds blowing to Yazd city from the west. In addition to the traffic-related pollution, other pollutants came from brick-making furnaces, mines, industrial centers, and industrial towns adjacent to or located along the winds entering Yazd, power plants and glass, steel, pelletizing, ceramic, and tile factories, and other plants built in Ardakan and Meybod where the pollutants were carried by multi-directional winds toward the city of Yazd.

In this study, in addition to office and residential buildings located in the city, the canopies constructed in stations that are made of metal can produce heavy metals. The main sources of heavy metals are the wear and tear of the tires and various vehicle parts, car batteries, and building materials. Human activities determined the severity of these contaminants. The results showed that Cr, Zn, Pb, and Cu originate from other emission sources in addition to the combustion of fossil fuels.
The second major cluster included Cd, Ni, Mn, and Co among which Ni exists in heavy fossil fuels and gas oil. It was also likely that some elements of this cluster might have originated from the combination of heavier fuels and other heavy hydrocarbon sources such as bitumen used to cover roadsides. However, since the average concentration of Mn was higher than that of the amount existing in the earth's crust, it may have human sources in addition to natural sources and local soils. The elements of Mn and Co had a positive and significant correlation with each other at the 1% level. Due to the relatively high level of Mn in the dust, it may have natural and anthropogenic sources, differing from the sources of other metals.

The indices studied separately and integratively for the metals in the falling dust collected from the bus stations of Yazd categorized them into the range of low or non-polluted to extremely high pollution. Most concerns are related to Mn and Cr whose variations can be considered the result of the lack of urban spaces, open space areas, and the difference of urban surface roughness in terms of buildings' height and urban operations.

According to the results, though currently the average concentrations of Ni, Co, Cd, and Cu in the samples of dry atmospheric deposition in Yazd are lower than the permitted limit, the lack of continuous monitoring of heavy metal concentrations in the dust and particles suspended in the air can lead to the emission of harmful pollutants such as heavy metals into the atmosphere. Public health is affected by heavy metals through inhalation, ingestion, skin contact, and absorption of toxic metals. To this end and to support public health, it is suggested to study the radioactive substances and bacteria fungi in the dust and particles suspended in the air.

**Funding**

This work is extracted from a postdoctoral research project supported by Yazd university (No. 1398.50.720). The authors would like to gratefully acknowledge all people who contributed to this study.

**Authors Contributions** Motahareh Esfandiariparticipated in conceptualization, investigation, formal analysis, data curation, resources, and writing the original draft. Mohammad Ali Hakimzadeh was involved in conceptualization, formal analysis, writing, reviewing, and editing, and supervision.

**Declarations**

**Ethical Approval** The authors have thoroughly observed ethical issues, and no data from the study have been or will be published separately elsewhere.

**Competing Interests** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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