



Risk assessment and spatial distribution of heavy metal in street dusts in the densely industrialized area

Kadir Ulutaş

Received: 5 August 2021 / Accepted: 7 January 2022 / Published online: 15 January 2022
© The Author(s), under exclusive licence to Springer Nature Switzerland AG 2022

Abstract Street dust samples can be used as an indicator for pollution monitoring especially in big cities. Various environmental problems have been experienced in Dilovasi, Turkey, and studies have been carried out in many different areas; however, no study has been conducted to examine the heavy metal content in street dusts. Therefore, in this study, 20 heavy metals, namely Si, Fe, Al, Zn, Mn, Ti, Cr, Ba, Pb, Ni, Sr, V, Co, Cd, Sb, As, Sn, Mo, Sc and Ag, in the street dusts of Dilovasi were investigated at 40 sampling points. Samples were analyzed with ICP–MS and ICP–OES. The concentrations were from 0.01 mg/kg for Ag to 42,645.48 mg/kg for Si. The Igeo values were in the range of 0.02 for Ag and 8.03 for V. The average EF value was 29.67, which indicates a very high pollution level. ERI was found as 300.74. This value being 300–600 indicates a considerable ecological risk level for the region. According to PCA, the predominant anthropogenic contribution of metal pollution in this area was due to traffic and vehicle-related activities and industrial activities and their waste. Metal pollution from residential areas and natural resources was relatively low, but it was another source of pollution.

Keywords Street dust · Heavy metals · Air quality · Risk assessment

Introduction

Urbanization is defined as the increase in population and the intense industrialization in a region due to the movement of people from rural areas to urban areas (Uttara et al., 2012). The heavy traffic potential caused by dense population and industrialization is one of the most important factors for urbanization. Urbanization and industrialization can be considered as development indicators for both cities and countries, as long as it is compatible with environmental factors such as sustainability and pollution. According to World Bank data, in 2018, the population living in urban areas was approximately 75% in Turkey, while it accounted for 74% in the EU-27 countries, a figure higher than average world rate of 55% (EU, 2020). The intensive urbanization and industrialization are considered as one of the most important factors for daily increasing release of toxic pollutants and heavy metals into the urban receiving environment (Nuhoglu et al., 2020). Moreover, heavy metals have higher potential environmental effects compared with other pollutants due to their non-biodegradable and persistent nature in the environment (Gabarron et al., 2017; Gao & Wang, 2018; Gunawardana et al., 2012; Karanasiou et al., 2014).

In urban and industrial areas, contaminations of heavy metal in street dust can be caused by different mobile sources (transportation) and fixed sources (industrial production) (Xiao et al., 2020). Heavy traffic causes generation of street dust in high amounts,

K. Ulutaş (✉)
Department of Environmental Engineering, Karabuk
University, Karabuk, Turkey
e-mail: kadirulutas@karabuk.edu.tr

which can act as a host and carrier of heavy metals and other toxic substances. In addition, street dust has different sources such as natural and anthropogenic activities (Nuhoglu et al., 2020). Geochemical processes are the examples for natural activities, and industrial operations, fossil fuel burning, vehicular emissions, tire wear and tear, mining, power plants and pesticides are the examples for anthropogenic activities (Abbasi et al., 2019; Choi et al., 2020; Wei et al., 2015; Xiao et al., 2020). For these reasons, street dust is seen as one of the most serious factors affecting atmospheric air quality.

Street dusts can be transported in the atmosphere with the meteorological factors causing pollution of water, land, atmosphere and ecosystems upon wet and dry deposition (Jeong et al., 2020). In addition, topography and land use are important factors that may affect not only heavy metal content and quantity, but also transport and accumulation in the atmosphere. Therefore, atmospheric transport and accumulation of natural and anthropogenic pollutants, especially in big cities, under the influence of meteorological and topographic factors, can be regarded as a natural process. As a result, it is possible to use street dust samples as an indicator for air quality monitoring.

Particulate matter and dusts with different size and chemical composition can be found everywhere due to their nature. Therefore, these pollutants receive potential interest among various air pollutants (Öztürk & Özgül, 2019). Many studies have focused on street dust due to its high toxicity, small size and ubiquity, bioaccumulation and effects on urban environmental quality and human health. These studies showed the pollution levels and the relationship between metal emission and specific activity. For example, Kara (2020) identified the source of Li, Co, K, Rb, Mn, As and Se came from coal and wood burning, while Cu, Sb, Mo and Zn originated from traffic emissions, and Zn, Pb, Cd, Sn and Tl were derived from industrial activities in İzmir, Turkey. Sadeghdoust et al. (2020) indicated that As, Co and V were associated with natural sources, and Pb, Zn, Cu, Cr, Cd and Ni were related to anthropogenic sources such as traffic, wear and tear of vehicle rings and tires, the use of gasoline and the combustion of fossil fuels in Dezful, Iran. Delibašić et al. (2020) in Bosnia and Herzegovina reported that the main emissions of As, Cd, Cu, Ni and Zn were industrial metallurgical processes (Ite et al., 2014) and Cd, Cr, Cu,

Fe, Ni, Pb and Zn came from automobiles, tear and wear on the car (Akhter & Madany, 1993). Taşpınar and Bozkurt (2018) in Düzce, Turkey, indicated that As, Cd, Cr, Pb, Sb, Sr, Mn, Sn and Ni were influenced by anthropogenic sources. In the study by Manasreh, (2010), Karak, Jordan, it was shown that Zn, Cu, Mn, Cd and Ni originated mainly from vehicles and industrial activities. In addition, the methods of enrichment factor (EF), geo-accumulation index (Igeo), ecological risk factor (ERF) and ecological risk index (ERI) were used to determine pollution levels of heavy metals in street dust. In order to classify source of heavy metals, principal component analysis (PCA) was used. The spatial distribution maps were used to visualize pollution levels in the study area (Castillo-Nava et al., 2020; Kara, 2020; Idris et al., 2020; Yusup & Alkarkhi, 2011).

According to the Circular no. 2013/37 (MEU, 2013) the city of Kocaeli has a high potential of air pollution. In addition, it was stated in the report (MEU, 2018) that air pollution is the top of environmental problems in Kocaeli, especially in the industrial region of Dilovasi. Turkish Parliament discussed environmental pollution problems in the study area and prepared a report on precautions to be taken in this area. Total concentrations of 20 heavy metals, namely Si, Fe, Al, Zn, Mn, Ti, Cr, Ba, Pb, Ni, Sr, V, Co, Cd, Sb, As, Sn, Mo, Sc and Ag, in the street dusts of Dilovasi were investigated at 40 sampling points. The main objectives of this study were: (i) to determine the concentration of heavy metals in street dust; (ii) to investigate the pollution levels of metals in street dusts by calculating EFs, Igeo, ERF and ERI; and (iii) to identify the possible anthropogenic and natural sources of metals in street dusts by principal component analysis (PCA). The findings can support plans to be made in the district of Dilovasi, particularly to improve air and environmental quality.

Methods and materials

Study area

Dilovasi, located very close to Istanbul, is an industrial district of Kocaeli where D-100, TEM highways and railway cross. Today, Dilovasi occupies an important position on the sea, road and rail networks that connect Anatolia, mainland Turkey, to Istanbul

and Europe. Especially since the 1980s, a significant population increase has been experienced in Dilovasi as a result of an increase in industrialization. While the population of the district was 10,600 in 1985, it has exceeded 50,000 today. A total of 6 Organized Industrial Zones in Dilovasi district cover an industrial area of approximately 2200 hectares (Hamzaoglu et al., 2011; Yılmaz et al., 2020). In the organized industrial zones, the predominant sector groups are metal, iron and steel (39%), chemistry (20%), storage (13%) and mining (7%) sectors. Food, weaving, textile, forestry, plastic, chemistry, petrochemical, glass, metal, hardware, electrical machinery, electronics, machinery manufacturing, wire rope manufacturing and metal heat processes are the main industrial activities in Dilovasi (Kanbak, 2011; MIT, 2019). For these reasons, Dilovasi has a high potential for air pollution from traffic, urban and industrial sources. In addition, the topography of the Dilovasi is rough and in the form of a bowl, which prevents air from mixing sufficiently in the region and causes inversion and intense air pollution. According to the average temperature data of the General Directorate of Meteorology between 1929 and 2019, the maximum temperature is observed during the month of August with 23.8 °C, and the lowest is observed in January with 6 °C (GDM, 2020). The monthly precipitation is 110.8 mm (the highest) and 44.0 mm (the lowest) in December and August, respectively. The prevailing wind direction was north and northeast.

Sample collection and preparation

The sampling points have been carefully selected to show the different characteristics of the district such as urban, industry and traffic. The street dust samples were collected from 40 sites dominating by residential, industrial, high density traffic areas in the center where traffic, residential and industrial areas are intertwined in the region. Sampling points were determined by considering sectoral differences, pollution sources and distances between them. The locations of the 40 sampling points are shown in Fig. 1. Street dust samples were collected once in September 2020. Samples consisted of about 1000 g street dusts were gently collected using polyethylene brush and hand shovels from the street surface, in an area of roughly 1–2 m². After polyethylene bags of all samples were individually labeled, they were transported

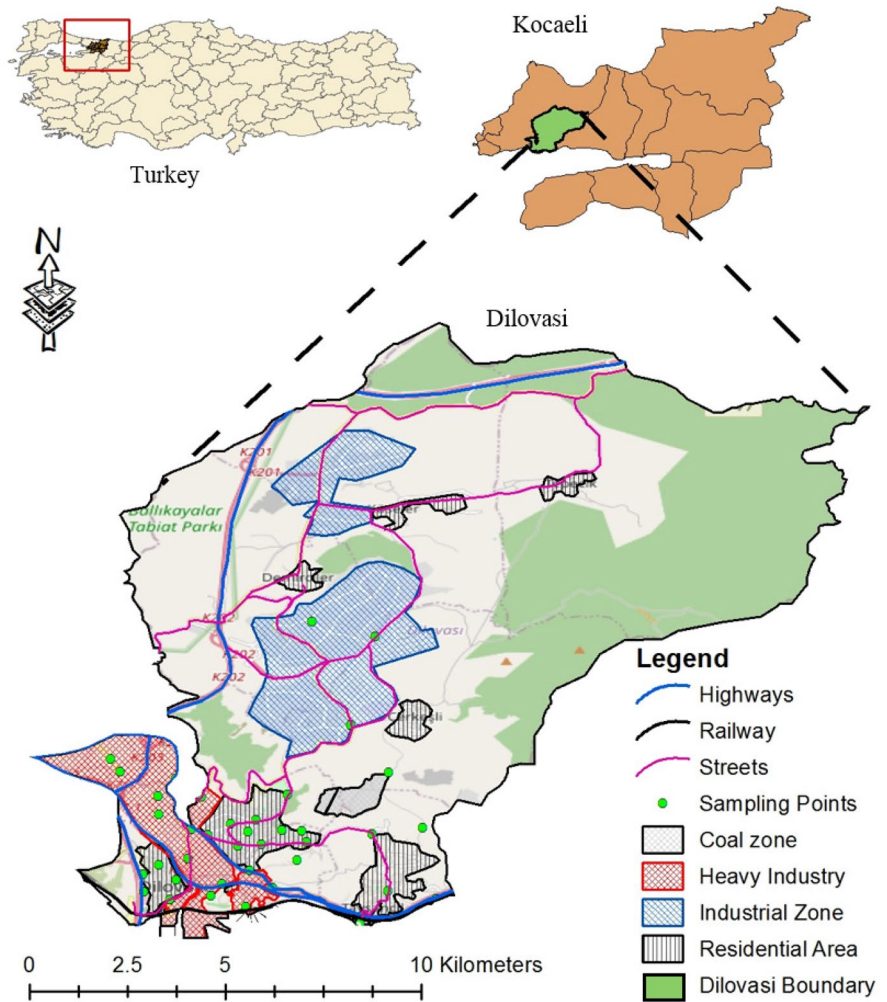
to the laboratory. Samples were dried at room temperature, and then refuse, small stones, plastics and other pieces of leaves and branches were removed. In the literature, there are many studies in which street dust samples were analyzed for various fractions (e.g., 220 mesh (Sadeghdoust et al., 2020), 150 mesh (Idris et al., 2020), 100 mesh (Lin et al., 2019), 90 mesh (Castillo-Nava et al., 2020) and 70 mesh (Xiao et al., 2020)). In this study, each sample was sieved through 100 mesh (154 micron) (Lin et al., 2019) to create homogenized sizes and pieces and stored in the laboratory until analysis.

Analytical procedures

Sieved street dust samples were dried at 105 °C overnight; then, the samples (0.25 g) were digested with a mixture of 2 ml of hydrofluoric acid (HF) (Merck suprapure), 2 ml of hydrogen peroxide (H₂O₂) (Merck Suprapure), 4 ml of nitric acid (HNO₃) (Merck Suprapure) and 1 ml of perchloric acid (HClO₄) (Merck Suprapure) in a microwave digestion system (Suryawanshi et al., 2016). The extraction process was carried out in 1200 W microwave oven (Milestone Microwave Digestion) for 20 min in 200 °C. The samples taken out from the microwave oven were cooled for 45 min and ultra-pure water (18.3 MΩ) was added until a volume of 50 ml. Lastly, the digested solution was analyzed for the concentrations of 20 elements mentioned before. Among these elements, Al, Fe, Ba, Mn, Zn, Sr, Si, Ti were analyzed by inductively coupled plasma (ICP) equipped optical emission spectrometer (ICP-OES, PerkinElmer Avio 200) and the others were analyzed by ICP equipped mass spectrometer (ICP-MS, Thermo Scientific, X Series 2). All extractions and analysis were performed with triplicate samples (n=3), and the mean values were reported. The analytical method was validated using serial dilution of standard stock solution of multi-elements having concentrations of 1000 mg/L (Merck, Cat. No. 111355).

A certified reference material (BCR-723 IRMM-JRC Road Dust, European Commission) was used to check the quality of the analytical method. The certified reference material (CRM) measurement was taken for 11 samples. Standard deviation, the limits of detection (LOD) and limit of quantification (LOQ) were calculated after the blank sample was read 21 times. The results of the CRM showed that the percentage of

Fig. 1 Study area (Dilovasi, Kocaeli, Turkey)



elemental recovery was obtained at 93.99–106.24% which assures the accuracy of the data, and LOD were defined as 0.044–0.975 ppb. Experimental analysis data, CRM values, percentage of the elemental recovery, LOD and other data are given Table 1.

Assessment of metal pollution

In this study, the concentration of heavy metals smaller than 154 μm in street dusts collected from the areas with different land use types are analyzed by descriptive statistics, e.g., minimum, maximum, mean, standard deviation (SD) and percentile. Geo-accumulation index (I_{geo}), enrichment factor (EF), ecological risk factor (ERF) and ecological risk index (ERI) analysis were used to investigate the pollution levels of metals in street dusts. In addition, principal

component analysis (PCA) was used to identify the possible anthropogenic and natural sources of metals in street dusts. Finally, the spatial distribution of metals was investigated by using ArcGIS.

Geo-accumulation index (I_{geo})

The geo-accumulation index (I_{geo}) is a widely used analysis in contamination estimation (Men et al., 2018; Muller, 1969; Odediran et al., 2021). I_{geo} analysis is based on comparison with background levels to assess the accumulation of pollutants (Tang et al., 2013) and is calculated by Eq. (1):

$$I_{geo} = \log_2 \left[\frac{C_i}{1.5C_{i,background}} \right] \quad (1)$$

Table 1 Quality control and quality assurance data

Elements	Analysis Data (ppm)	Certified Value (ppm)	Uncertainly	% Recovery	LOD (ppb)	LOQ (ppb)
Al	36,920	37,500	0.22	98.45	0.375	1.25
Ba	501	460	0.04	108.91	0.759	2.53
Cd	2.389	2.5	0.4	95.56	0.042	0.14
Co	28.01	29.8	1.6	93.99	0.075	0.25
Cr	442.36	440	18	100.54	0.054	0.18
Fe	31,890	32,900	0.2	96.93	0.294	0.98
Mn	1301	1280	0.04	101.64	0.0441	0.147
Mo	41.24	40	0.6	103.10	0.15	0.5
Ni	178.36	171	3	104.30	0.216	0.72
Pb	872.12	866	16	100.71	0.036	0.12
Sb	26.987	28.2	2.3	95.70	0.039	0.13

where C_i is the concentration of the examined element "i" in the street dust sample (mg/kg) and $C_{i,background}$ is the concentration of element "i" in the background. I_{geo} is evaluated in seven classes as follows: $I_{geo} \leq 0$: uncontaminated environment, $0 < I_{geo} \leq 1$: uncontaminated to moderately contaminated, $1 < I_{geo} \leq 2$: moderately contaminated, $2 < I_{geo} \leq 3$: moderately to heavily contaminated, $3 < I_{geo} \leq 4$: heavily contaminated, $4 < I_{geo} \leq 5$: heavily to extremely contaminated and $I_{geo} > 5$: extremely contaminated environment (Muller, 1969).

Enrichment factor (EF)

Enrichment factor (EF) is used to determine the level of contamination from anthropogenic sources. In the EF method, an examined element content in the street dust sample is standardized with a reference sample. In this study, Al was used as reference element for EF calculations. EF is calculated by Eq. (2):

$$EF = \frac{(C_i/C_{ref})_{Sample}}{(C_i/C_{ref})_{Crust}} \tag{2}$$

where $C_{i,Sample}$ is the concentration of the examined element "i" in the street dust sample. $C_{ref,Sample}$ is the concentration of reference element in the sample. $C_{i,Crust}$ is the concentration of the examined element "i" in the Earth's crust. $C_{ref,Crust}$ is the concentration of reference element in the Earth's crust. EF is categorized into five classifications as follows: $EF < 2$: deficiently to minimal enrichment, $2 \leq EF < 5$: moderate enrichment, $5 \leq EF < 20$: significant enrichment,

$20 \leq EF < 40$: very high enrichment and $EF \geq 40$: extremely high enrichment (Gope et al., 2017).

Ecological risk factor (ERF) and total potential ecological risk index (ERI)

The potential risk and contamination of elemental pollution is evaluated by calculating the potential ecological risk index (ERI) (Hakanson, 1980; Odediran et al., 2021). Firstly, single element contamination factor Cf is computed for toxic elements such as Ni, Cd, As, Pb, Cr and Zn by Eq. (3):

$$Cf = \frac{C_i}{C_{i,n}} \tag{3}$$

where C_i is the concentration of the examined element "i" in the street dust sample (mg/kg) and $C_{i,n}$ is the concentration of the examined element "i" in the Earth's crust. The Earth's crust reference values of Ni, Cd, As, Pb, Cr and Zn in soils are 18.6, 0.102, 2.0, 17, 35 and 52 mg/kg, respectively (Wedepohl, 1995). The ecological risk factor is used to determine the potential health risk in an ecosystem (Hakanson, 1980) and is calculated by Eq. (4):

$$ERF = T_i \times C_f \tag{4}$$

where Cf is the single element contamination factor and T_i is the toxic response factor and for Ni, Cd, As, Pb, Cr and Zn, it is 5, 30, 10, 5, 2 and 1, respectively (Ghosh et al., 2020; Hakanson, 1980). The following classifications are used to assess ecological risk factors: $ERF < 40$: low risk, $40 < ERF < 80$:

medium risk, $80 < \text{ERF} < 160$: medium to high risk, $160 < \text{ERF} < 320$: high potential risk and $\text{ERF} > 320$: very high risk (Hakanson, 1980). The ecological risk index (ERI) that shows the ecological risk of these elements is calculated Eq. (5):

$$\text{ERI} = \sum_{i=1}^n \text{ERF} \quad (5)$$

ERI is categorized as the following terminology: $\text{ERI} < 150$: low ecological risk, $150 < \text{ERI} < 300$: moderate ecological risk and $300 < \text{ERI} < 600$: considerable ecological risk (Hakanson, 1980; Kara, 2020).

PCA

The PCA technique, which has been applied in many studies before, was also used in this study to classify heavy metals in street dust (Idris et al., 2020; Kumari et al., 2021; Suryawanshi et al., 2016; Tang et al., 2017). PCA is a simplified data set technique in statistics processing and is used to reduce dimensions of the data set and arrange them as groups (Cai & Li, 2019). Thus, it allows determination of possible sources. PCA can provide a simpler and more understandable perspective on the relationships between heavy metals in street dust. These relationships between examined heavy metals point to their possible sources. PCA was performed in this study to determine the possible sources of heavy metals examined in the smaller than $154 \mu\text{m}$ street dust collected from the areas affected by industrial, traffic and residential activities in Dilovasi by using varimax rotation with Kaiser normalization.

Results and discussion

Heavy metal concentrations

In this study, the elemental composition of street dust in Dilovasi, where trace metal distribution is affected by topographic conditions as well as industrial facilities, traffic and residential heating, has been investigated in many ways. Descriptive statistics values such as mean values, standard deviations, minimum, maximum, skewness and kurtosis values of total concentrations element in street dusts are given

in Table 2 for 40 sampling points in Dilovasi. The measured mean concentrations were from 0.01 mg/kg for Ag to 42,645.48 mg/kg for Si. Table 2 shows that in the street dust samples, crustal-based elements such as Si, Fe, Al, Mn and Ti are dominant. These results are very similar to those found in the study by Kara (2020), as they are the most abundant elements in the Earth's crust. The average concentrations of these elements ranged from 809.30 to 42,645.48 mg/kg, and the concentrations except for Mn, were less than the reference concentration. In addition, while the average concentrations of some toxic elements such as Zn, Cr, Pb and Ni were higher than the reference concentrations, some of them such as Cd, As and Mo were lower than the reference concentrations. The average concentrations of other anthropogenic-based elements, namely Ba, Sr, V, Co, Sb, Sn, Sc and Ag, ranged from 0.01 to 235.93 mg/kg, and except for Co, the concentrations of all others are less than the reference concentration (Rudnick & Gao, 2003). The ratio of the average concentrations and the corresponding reference concentrations of Al, Fe, Ba, Mn, Zn, Sr, Co, Cr, Cd, Ni, Mo, Pb, V, Sb, As, Si, Sn, Sc, Ag and Ti in the samples were 0.13, 0.81, 0.38, 2.47, 34.83, 0.21, 1.01, 3.16, 7.04, 1.79, 0.03, 5.91, 0.22, 0.39, 3357.25, 0.03, 0.14, 0.03, 0.001, 0.19 and 0.21, respectively.

It can be concluded that the concentrations of all heavy metals except Cd, Sb, As, Sn, Mo, Sc, Ag in street dust samples have a wide variation due to large standard deviations. This indicates that for these elements, their amount varies significantly. The skewness values for Zn, Pb, Ni, Cd, Sn and Ag are above 2 indicating the presence of highly contaminated points. Table 2 shows that all heavy metals have positive skewness values. This means that the average concentrations for all heavy metals are higher than the median concentrations.

Differences in concentrations were observed depending on the metal type and sampling area. The highest concentrations were determined in traffic areas. However, many industrial facilities are located on the roadside, which might have played a role in achieving high value in traffic areas. The concentrations in industrial area were found to be higher than those found in residential regions. As mentioned before, the industrial, traffic and residential areas are very close to each other and could possibly be affected in study area (Fig. 2). The average total

Table 2 Descriptive statistics

Elements	Mean ± SD (mg/kg)	Minimum–Maximum (mg/kg)	Skewness	Kurtosis	Reference value
Si	42,645 ± 29,860	336 – 106,785	0.12	-0.79	311,395.97
Fe	31,633 ± 26,736	2,840. – 119,032	1.17	1.36	39,200.00
Al	7,323 ± 6,573	737 – 28,123	1.83	3.04	55,415.03
Zn	2,333 ± 3,249	98.54 – 14,188	2.19	4.45	67.00
Mn	1,916 ± 1,950	275 – 7,752	1.39	1.41	774.45
Ti	809 ± 388	174 – 1,836	0.49	-0.21	3,835.74
Cr	290 ± 264	31.14 – 984	1.08	0.33	92.00
Ba	235 ± 305	13.96 – 1,211	1.93	3.17	624.00
Pb	100 ± 86.45	6.97 – 421	2.06	5.48	17.00
Ni	84.17 ± 178	1.45 – 1,125	5.34	31.17	47.00
Sr	66.13 ± 42.03	12.57 – 178	0.86	0.31	320.00
V	21.57 ± 35.14	0.002 – 130	1.81	2.23	97.00
Co	17.46 ± 12.04	1.48 – 61.06	1.73	3.66	17.30
Cd	0.63 ± 1.22	0.001 – 5.93	2.66	8.29	0.09
Sb	0.16 ± 0.13	0.004 – 0.54	1.02	0.28	0.40
As	0.15 ± 0.10	0.004 – 0.48	1.06	1.38	4.80
Sn	0.06 ± 0.06	0.003 – 0.31	2.32	6.67	2.10
Mo	0.04 ± 0.03	0.001 – 0.14	1.07	0.48	1.10
Sc	0.01 ± 0.01	0.004 – 0.05	1.98	2.69	14.00
Ag	0.01 ± 0.00	0.01 – 0.04	5.10	29.57	0.05

concentrations of elements followed the order Si > Fe > Al > Mn > Zn > Ti > Co > V > Cd > As > Sb > Sn > Mo at all areas. However, the order is different for elements Sc, Ag, Ni, Sr, Pb, Ba, Cr. In areas where residential and traffic areas are dominant, the average total concentrations of the elements follow the order of Sc < Ag < Pb < Ba < Cr, while in industrial areas they follow the order of Sr Ba > Cr > Ni > Pb. The sequence was the similar for traffic and residential areas. Figure 2 shows the mean concentrations of elements in residential, traffic and industrial areas. The average concentrations of Ba, Zn, Sr, Co, Ni, V, Sb, Sn, Sc and Al proved to be higher in industrial areas compared with traffic and residential areas. In residential areas, average concentrations of V, Sc and Al were higher compared to traffic areas, and average concentrations of As and Si were higher compared to industrial areas. The average concentrations of Mn, Cr, Cd, As, Fe and Si were greater in traffic sites compared with other areas, while the average concentrations of Ag and Ti were the almost same for all areas.

Heavy metal concentrations in street dust of Dilovasi were evaluated comparing with concentrations in other cities in Turkey and other countries (Table 3).

In national and international perspective, heavy metal concentrations in street dust of Dilovasi were comparable to Düzce (Taşpınar & Bozkurt, 2018) and İzmir (Kara, 2020) in Turkey, Liaoning (Xiao et al., 2020) and Jinhua (Bartholomew et al., 2020) in China, Shiraz (Keshavarzi et al., 2015) in Iran, Khamis Mushait (Idris et al., 2020) in Saudi Arabia, Busan (Choi et al., 2020) in Korea. While the average concentration of Zn in the present study was lower than that in Jinhua, it was significantly higher than those in other cities. In addition, while the average Fe concentration in this study was lower than those in Liaoning and Khamis Mushait, it was higher than those in Düzce, Izmir and Shiraz. Although the average Al concentration in the street dust sampled in Dilovasi was lower than those in Düzce and İzmir, the average Si concentration in this study was higher than that in Izmir. Average concentrations of Mn, Cr, Ni in Dilovasi street dust were higher than those in other cities. In this study, the average concentrations of Ti and Ba were almost equal to those in Düzce and Izmir. In the present study, the average Pb concentration was higher than those in Düzce, Izmir and Liaoning, but lower than those in other provinces. The average Co

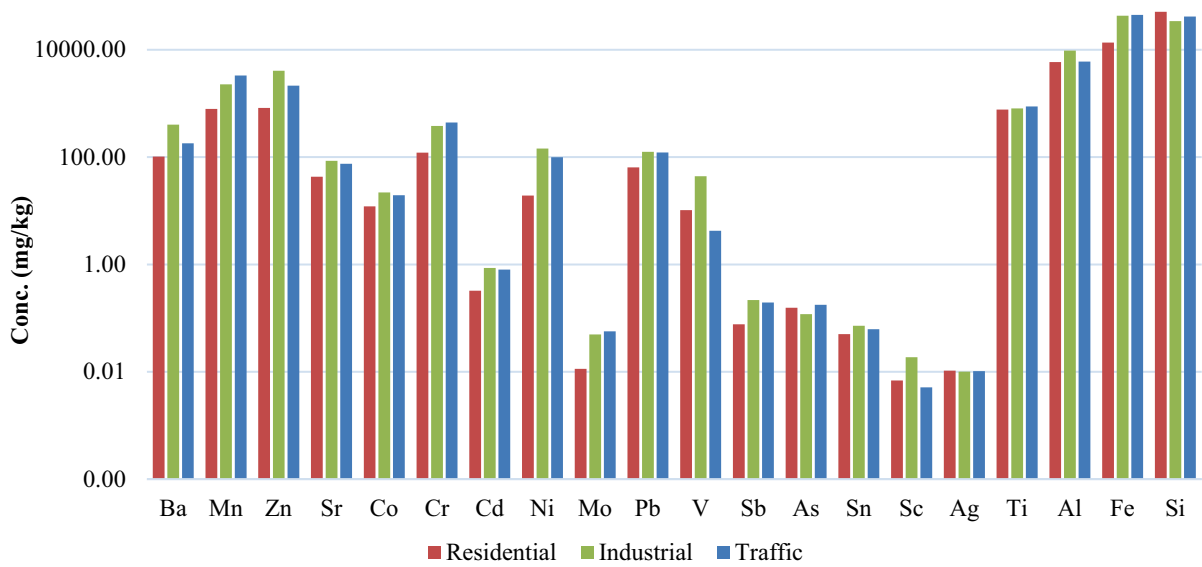


Fig. 2 Mean concentrations of elements in residential, traffic and industrial areas

concentration in Dilovasi street dusts was higher than those in Düzce and Izmir, lower than that in Khamis

Mushait. The average Cd concentration in Dilovasi street dusts was only higher than that in Izmir, lower

Table 3 Average metal concentrations in the street dust in different cities (mg/kg)

The average concentration (mg/kg)	Dilovasi, Kocaeli, Turkey	Düzce, Turkey	Izmir, Turkey	Liaoning, Northeast China	Shiraz, Iran	Khamis Mushait, Saudi Arabia	Busan, Korea	Jinhua, China
Si	42,645		24,637					
Fe	31,633	20,956	13,303	117,000	20,254	62,735		
Al	7,323	8,883	22,027					
Zn	2,333	335	61.60	325	403	117	1,090	8,430
Mn	1,916	650	274	1,170	438	802		451
Ti	809		862					
Cr	290	122	39.40	150	136	186	171	105
Ba	235	217	245					
Pb	100	59	26.90	63.01	115	126	199	110
Ni	84.17	31	19.40	29.59	77.52		19.49	76.32
Sr	66.13	333	119					
V	21.57	50	37.90					
Co	17.46	13	5.19			34.17		
Cd	0.63	2	0.15	1.17	0.50	1.16	1.70	4.90
Sb	0.16	28	4.11	4.56	4.78			
As	0.15	15	13.90		6.58		22.50	8.69
Sn	0.06	39	2.69	4.53				
Mo	0.04	28	0.90					
Sc	0.01	14	4.20					
Ag	0.01							

than those in other cities. Average concentrations of other heavy metals in street dust sampled in Dilovasi were lower than those in other cities. However, different results can be obtained in such studies since traffic density, local pollution sources, socioeconomic, topographic and meteorological conditions of the study area affect the composition of street dust (Taşpınar & Bozkurt, 2018).

Geo-accumulation index (I_{geo})

Background concentration values are required to calculate the geo-accumulation and to make comparisons at the pollution levels. However, different land uses, which alter the originality of the land structure, make it difficult to sample a background that reflects the actual land structure (Verma et al., 2020). Therefore, in the previous study by Chan et al. (2001), the minimum heavy metal concentrations were used as a background. In this study, we also used the minimum heavy metal concentrations as a background (Table 2).

The minimum, maximum and average values of I_{geo} for each heavy metal were visualized by box plot graph in Fig. 3. The average values of I_{geo} that ranged from 0.02 (Ag) to 8.03 (V) displayed the following decreasing trend: V > Cd > Si > Mo > Ni > As > Sb > Sn > Zn > Pb > Co > Ba > Fe > Al > Cr > Sr > Mn > Ti > Sc > Ag. The average I_{geo} values for Ag (0.02) and Sc (0.39) varied from 0 to 1, indicating that the study area was uncontaminated to moderately contaminated by these elements. Based on I_{geo}

values of Ag and Sc, 63% and 68% of the sampling points were uncontaminated ($0 < I_{geo} \leq 1$), respectively. The highest I_{geo} value of Ag was determined at the sampling point close to areas of residential, commercial, thermal insulation production, urban and intercity traffic. The highest I_{geo} value of Sc was determined at the sampling point close to traffic and iron–steel factories. The environment was moderately contaminated by the elements Ti (1.44), Mn (1.47), Sr (1.50) and Cr (1.97) with their I_{geo} values between 1 and 2. Considering the I_{geo} values of Ti and Sr, 45% and 33% of the sampling points were moderately contaminated ($1 < I_{geo} \leq 2$) and moderately to heavily contaminated ($2 < I_{geo} \leq 3$), respectively. According to the I_{geo} values of Mn and Cr, 28% (the highest rate) of the sampling points were uncontaminated to moderately contaminated ($0 < I_{geo} \leq 1$) and heavily contaminated ($3 < I_{geo} \leq 4$), respectively. The highest Ti, Mn, Sr and Cr values were obtained at sampling points close to the residence, iron–steel factories, shopping mall on the highway and casting factory, respectively. The average I_{geo} values of Al (2.27), Fe (2.30), Ba (2.39), Co (2.66), Pb (2.74) and Zn (2.84) suggest that these elements, which were in 2–3 range, contaminated the study area in moderate to heavy levels. 43% and 25% of sampling points were moderately contaminated ($1 < I_{geo} \leq 2$) by Al and Fe, respectively, while 21%, 43% and 25% of points were moderately to heavily contaminated ($2 < I_{geo} \leq 3$) by Ba, Co and Zn, respectively. However, 35% of points were heavily contaminated ($3 < I_{geo} \leq 4$) by Pb. The highest value was obtained at the sampling point near

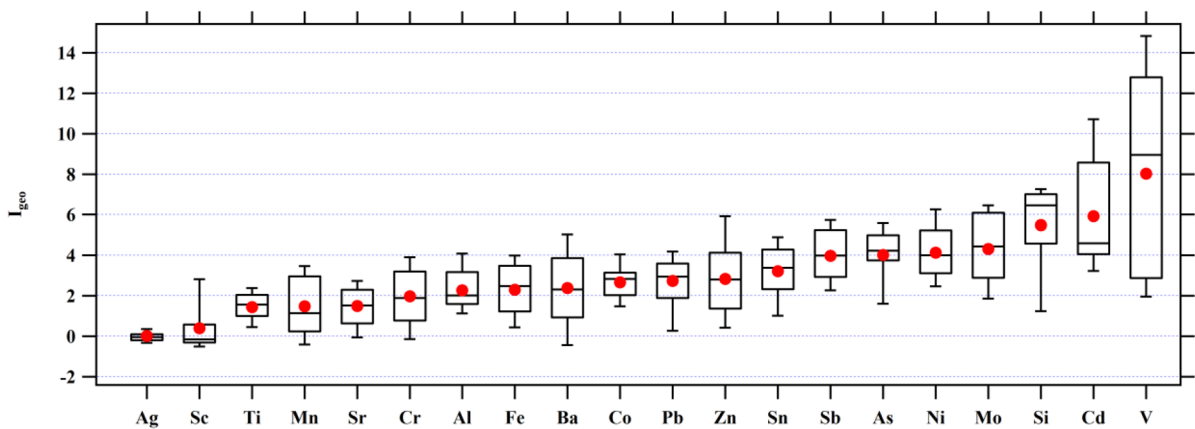


Fig. 3 I_{geo} values for elements in Dilovasi street dust samples (┐: upper extreme, ┘: lower extreme, ●: Mean, -: Median)

the residence for Al, while for Co it was obtained at the point close to truck scale and dyeing factory. Igeo values of Fe and Ba values were determined at the highest level at sampling points close to the iron–steel factory. Moreover, the highest Igeo values of Pb and Zn were at the same sampling points close to the traffic and iron–steel factory. The study area was also heavily contaminated by Sn (3.21) and Sb (3.97), both of which were in the range 3–4. 38% of sampling points were heavily contaminated ($3 < I_{geo} \leq 4$) by Sn, although 33% of points were extremely contaminated ($5 < I_{geo}$) by Sb. Igeo values of Sn and Sb values were determined at the highest level at the same sampling points close to the iron–steel factory. As (4.02), Ni (4.13) and Mo (4.32) with Igeo values of 4–5 caused a contamination ranging from heavy to extreme levels. 44% of sampling points were heavily to extremely contaminated ($4 < I_{geo} \leq 5$) by As, while 30% and 44% of points were extremely contaminated ($5 < I_{geo}$) by Ni and Mo, respectively. The highest Igeo values of As and Mo were found at the points close to residential and iron–steel factory, while Igeo value of Ni was obtained at the point close to truck scale and dyeing factory. Extreme contamination by the elements Si (5.48), Cd (5.92) and V (8.03) were also evidenced by their average Igeo values above 5. 73%, 43% and 55% of sampling points were extremely contaminated ($5 < I_{geo}$) by Si, Cd and V, respectively. The highest Igeo values of Si and Cd were found at the points close to commercial, traffic and iron–steel factory, while Igeo value of V was obtained at the point close to the iron–steel factory.

Enrichment factor (EF)

In this study, the Composition of the Upper Continental Crust (CUCC) (Rudnick & Gao, 2003) was used as the reference soil composition worldwide to determine EF values. In addition, since AI can be measured precisely with analytical method of inductively coupled plasma and its most important source soil (Öztürk & Keleş, 2016), AI was used as the reference element.

Calculated minimum, maximum and average values of EF for each heavy metal are shown in Fig. 4. From the results obtained, the average values of EF that ranged from 0.007 (Sc) to 295.8 (Zn) displayed the following decreasing trend: $Zn > Cd > Pb > Cr > Mn > Ni > Co > Fe > Sb > Ag > Ba > Ti > Sr > Si > V > Al > As > Mo > Sn > Sc$. The elements Si (1.98), V (1.31), As (0.49), Mo (0.36), Sn (0.33) and Sc (0.01) provided deficiently to minimal enrichment due to their EF values below 2. While the highest EF values of Sc, Sn and As were obtained at sampling points in industrial zone, the highest EF value for Mo was achieved at sampling points near the highway affecting coal and iron scrap site. Moreover, for V and Si the highest EF values were determined at the sampling points near the electrical generation facility and residential area, respectively. The average EF values of Sb (4.24), Ag (2.583), Ba (2.51), Ti (2.18) and Sr (2.02) were between 2 and 5, showing a moderate enrichment. Sr, Ba and Sb showed a deficiently to minimal enrichment at 60%, 60% and 38% of sampling points, whereas Ti and Ag exhibited a moderate

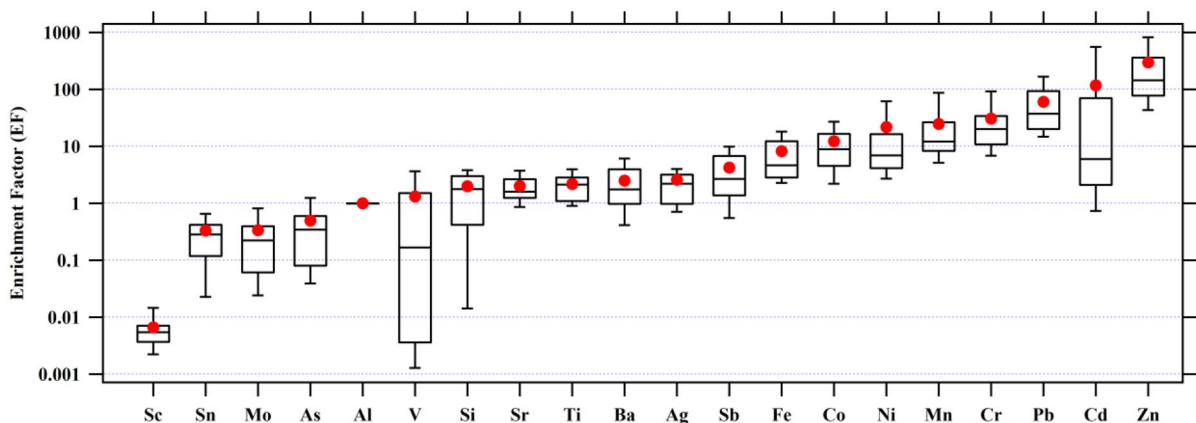


Fig. 4 Enrichment Factor for elements in Dilovasi street dust samples (└: upper extreme, ┘: lower extreme, ●: Mean, ─: Median)

enrichment at 53% and 50% sampling points, respectively. The highest EF values of Sr, Ti and Ba were found at the sampling points close to industrial zone, traffic and electrical generation facility, whereas for Ag it was determined at the sampling point close to areas of residential, commercial, thermal insulation production, urban and intercity traffic. Furthermore, the highest EF value of Sb was at sampling points near the highway affecting coal and iron scrap site. The average EF values of Fe (8.24) and Co (12.27) were between 5 and 20, meaning that the study area was significantly enriched by these elements. Fe showed moderate enrichment at 45% of the sampling points while Co demonstrated significant enrichment at 48%. The highest EF value of Fe was at sampling points near the highway affecting coal and iron scrap site, while for Co it was obtained at the point close to truck scale and dyeing factory. Ranging from 20 to 40, the average EF values of Ni (21.67), Mn (24.62) and Cr (30.75) indicate very high enrichment. Enrichment of Ni, Mn and Cr was significant at 45%, 58% and 45% of the sampling points. The highest EF value of Ni was obtained at the sampling point close to truck scale and dyeing factory, whereas it was found at sampling points near the highways for Mn and Cr. With average EF values above 40, Pb (60.54), Cd (116.96) and Zn (295.80) suggest that the study area was extremely rich. These elements indicated extremely high enrichment at 45%, 28% and 95% of sampling points, respectively. The highest EF values of Pb, Cd and Zn were found at sampling points very close the truck garage on highway, industrial zone and electrical generation facility. EF values (Zn, Cd, Pb, Cr, Mn, Ni, Co) greater than 10 are considered to be caused by human activities (Keshavarzi et al., 2015; Yongming et al., 2006). The average EF values of Fe, Sb, Ag, Ba, Ti, Sr, Si and V are caused by natural sources such as wind-blown soil minerals (Keshavarzi et al., 2015). There was a large difference between the minimum and maximum EF values for each heavy metal. Large difference may be due to a significant change in the material component and natural processes or anthropogenic contribution at various levels (Idris et al., 2020). If EF value is less than 1.5 or 2, it indicates that the metal is entirely caused by crustal materials or natural processes. However, if EF values are greater than 1.5 or 2, it indicates the increasing influence of anthropogenic sources (Remeikaitė-Nikienė et al., 2018). In this study, EF values of Si, V,

As, Mo, Sn and Sc were less than 2, and this means that they were usually affected by crustal materials or natural sources while the others (greater than 2) being affected by anthropogenic sources.

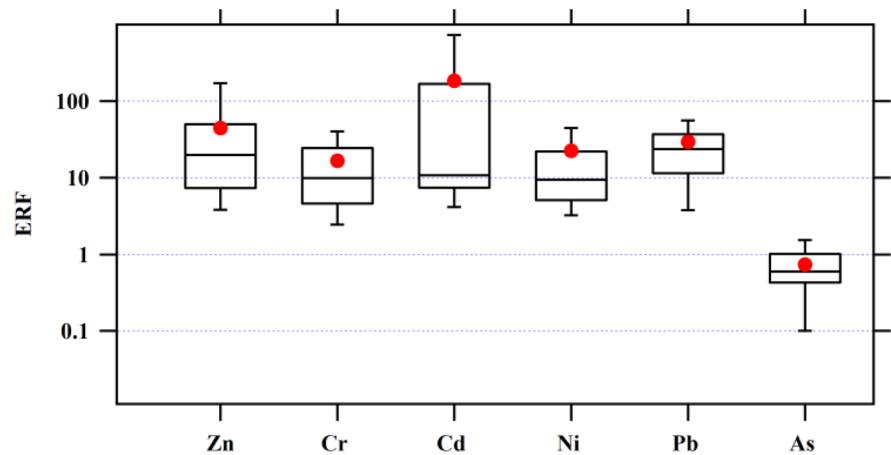
It was also found that crustal materials or natural sources usually had an effect on the study area as evidenced by EF values of Si, V, As, Mo, Sn and Sc which were less than 2. However, other elements with EF values were greater than 2 were affected by anthropogenic sources. The average EF value in this study was 29.67, which is considered a very high amount of pollution. Sampling points with the highest total EF value are as follows: Electricity generating facility, truck garage on highway, industrial zone, the region where heavy industrial facilities are located, cultural center on highway and district center (residential area). However, it is clear that these areas affect each other. As can be understood from this result, in general the pollution level in the region can be listed as industry, traffic and residential area.

Ecological risk factor (ERF) and total potential ecological risk index (ERI)

The ecological risk (Er) and total potential ecological risk index (ERI) developed by Hakanson's were used to understand the environmental effects of elemental pollution. From the results obtained, the average values of Er, which ranged from 0.07 (As) to 44.87 (Zn), displayed the following decreasing trend: Zn > Cr > Cd > Pb > Ni > As and they were in the ranges of 1.89–272.85, 0.89–28.12, 0.01–58.12, 0.41–24.81, 0.08–60.53 and 0.002–0.24, respectively.

Calculated average values of ecological risk factor (ERF), ranging from 0.74 (As) to 186.35 (Cd), displayed the following decreasing trend: Cd > Zn > Pb > Ni > Cr > As, and they were in the ranges of 1.89–272.85, 1.78–56.23, 0.29–1743.73, 2.05–124.06, 0.39–302.67 and 0.02–2.38, respectively. Figure 5 shows the statistical results, as box plot graph, of ERF values of Cd, Zn, Pb, Ni, Cr and As in Dilovasi street dust samples. Being below 40, the average ERF values of As (0.74), Cr (16.62), Ni (22.63) and Pb (29.53) indicated the low risk level. ERF values of As were below 40 at 100% of sampling points and the maximum value was obtained at the sampling point in the residential area. ERF values of Cr were below 40 at 90% of sampling points and between 40 and 80 at 10% of sampling points. The maximum value was obtained at the sampling point close to

Fig. 5 ERF values for elements in Dilovasi street dust samples (└: upper extreme, └: lower extreme, ●: Mean, -: Median)



casting industry. ERF values of Ni were below 40 at 88% sampling points, between 40 and 80 at 10% of sampling points and between 160 and 320 at 3% of sampling point. The maximum value was obtained at the sampling point close to truck scale and dyeing factory. ERF values of Pb were below 40 at 78% of sampling points, between 40 and 80 at 18% of sampling points and between 80 and 160 at 5% of sampling points. The average ERF values of Zn (44.87) were between 40 and 80 suggesting the medium risk level. ERF values of Zn were below 40 at 68% of sampling points, between 40 and 80 at 18% of sampling points, between 80 and 160 at 3% of sampling point and between 160 and 320 at 13% of sampling points. The average ERF values of Cd (186.35) between 160 and 320 show high potential risk level. ERF values of Cd were below 40 at 68% of sampling points, between 80 and 160 at 8% of sampling points, and between 160 and 320 at 5% of sampling points and above 320 at 20% sampling points. The maximum value of Pb, Zn and Cd were obtained at the same sampling point close to traffic and iron–steel factories. ERF indicated a change in the toxicity of heavy metals in street dust as in the Er for each sampling point. The results showed the low ecological risk level for Pb, Ni, Cr, As; the medium ecological risk level for Zn and the high ecological risk level for Cd.

In this study area, the contamination level was also evaluated with total potential ecological risk index (ERI) that was calculated with ERF values. The total potential ERI was from 29.46 to 2201.24. ERI with a value of below 150 indicates low ecological risk level at 55% of sampling points, while between 150 and 300 it means a moderate ecological risk level at 15% of sampling points. ERI below 150 indicates

a low ecological risk level in 55% of the sampling points, and between 150 and 300 indicates a moderate ecological risk level at 15% of the sampling points. Moreover, ERI between 300 and 600 indicates considerable ecological risk level at 13% of sampling points, and above 600, it indicates very high ecological risk at 18% of sampling points. The maximum value of ERI was obtained at the sampling point close to traffic and iron–steel factories. ERI was found as 300.74, this value was between 300 and 600 and indicates a considerable ecological risk level for the region.

PCA

Principal component analysis (PCA) was performed in this study to determine the sources of pollution according to the spatial distribution of metals. Useful qualitative information about the sources of heavy metal pollution in street dust was obtained with the PCA. In this study, PCA was carried out using JMP Pro 15.1.0 program. In order to interpret between the heavy metals in each group, variables with a factor load greater than 0.30 as a result of varimax rotation were selected.

The results of PCA demonstrated that there were five eigenvalues higher than 1, and five principal components illustrated 81.116% of the total variance (Table 4). Principal component 1 (PC1) specified 26.481% of the total data variance. PC1 was heavily loaded with Al, Ba, Zn, V, Sc and Ti, and was moderately loaded with Fe, Sr, Co, Pb and Sb (Table 4). According to Igeo values, Sc was uncontaminated to

moderately contaminated, others were moderately and more contaminated. In addition, the highest concentrations in PC1 were found in industrial, residential and traffic area in this study. Al can be found in high amounts in the residential area affected by natural factors while Sb and Sr may originate from anthropogenic sources such as vehicle emissions, combustion and other nearby sources. Fe and Ba are related to traffic pollution and the steel producing industries (Taşpınar & Bozkurt, 2018). However, Co and V are probably caused by natural sources (local soil) (Shi & Lu, 2018). Fe, Pb and Zn heavy metals may be caused by non-exhaust emissions and resuspension of street dust from vehicle traffic (Kumari et al., 2021). These results revealed that the principal component PC1 had a mixed source such as traffic, industry and residential. Principal component 2 (PC2) accounted for 26.095% of the total data variance. PC2 was heavily loaded with Fe, Mn, Cr, Mo, Pb and Sb, and moderately loaded with Ba, Zn, Sr, Sn and Ti (Table 4). The heavy metals in this group were moderate and more contaminated

based on Igeo values. In addition, the highest concentrations in PC2 reflected the impact of industrial, residential and traffic in the study area. While Pb, Zn and Sr were highest in areas close to traffic, the others except Ti in PC2 were highest near casting, iron–steel facilities. It can be also said that Ti was affected by domestic or natural factors for this study due to its maximum concentration in the residential area. Other studies (Kumari et al., 2021; Hou et al., 2018; Thorpe & Harrison, 2008; Davy et al., 2012) have showed that Pb was used in vehicle paint and Zn was emitted from wear and tear of vulcanized rubber tires, coal and/or wood combustion was one of the most important sources of Mo, Co, Mn and Ti. Besides industrial and residential activities, vehicle-related activities substantially contributed to metal contamination in dust. Principal component 3 (PC3) constituted 12.597% of the total data variance. PC3 was heavily loaded with Si and was moderately loaded with Zn, Pb and As (Table 4). According to Igeo values, heavy metals in this group were found to be moderately to heavily and more contaminated.

Table 4 PCA of heavy metals in this study

Heavy metals	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
Al	0.756				
Fe	0.335	0.867			
Ba	0.837	0.441			
Mn		0.887			
Zn	0.754	0.410	0.340		
Sr	0.528	0.477			
Co	0.326			0.801	
Cr		0.822			
Cd				0.470	
Ni				0.861	
Mo		0.909			
Pb	0.493	0.661	0.315		
V	0.908				
Sb	0.424	0.797			
As			0.436		
Si			0.905		
Sn		0.315			
Sc	0.922				
Ag					0.811
Ti	0.725	0.318			
Variance	5.296	5.219	2.519	1.941	1.247
Percentage of Variance, %	26.481	26.095	12.597	9.707	6.236
Cumulative, %	26.481	52.577	65.173	74.880	81.116

In this study, the highest concentrations of Si, Zn and Pb were seen at the same sampling point, which were affected by the highest traffic and iron and steel plants, and As was seen in the residential area. Previous studies (Hou et al., 2018; Kara, 2020) argued that industrial activities had an effect on Zn and Pb, while coal burning had an effect on As. In addition, in the study conducted by Zararsiz and Öztürk (2020), it was stated that the amount of arsenic detected indoor dust was three times higher than the amount reported for an industrial area in the literature. This could suggest that industrial and residential activities contributed to metal contamination in street dust. Principal component 4 (PC4) explained 9.707% of the total data variance. PC4 was heavily loaded with Co and Ni and was moderately loaded with Cd (Table 4). The heavy metals in this group were moderately to heavily and more contaminated according to Igeo values. The highest concentrations of Co and Ni were found at the same sampling point, which were affected by the highest traffic due to truck scale and dyeing factory. The highest Cd concentration was obtained at the sampling point, close to traffic and iron–steel factories in this study. Previous studies (Nuhoglu et al., 2020; Kumari et al., 2021; Tasdemir et al., 2006; Xu et al., 2017) reported that combustion of fuel, engine wear and industrial activities such as alloying or welding activities are the main source of Ni. While Co is used in carbide alloys, magnets, ceramics and glass production as well as in protection of alloy surfaces, vehicle materials one of the most important uses of Cd (Tang et al., 2017; Yıldırım & Tokalioğlu, 2016) are associated with industrial activities (Kara, 2020). Traffic and industry were the major sources which can be defined as mixed source for PC4. This result also indicates that the lubricating oil is burning. Principal component 5 (PC5) explained 26.095% of the total data variance with heavily loaded with Ag (Table 4). Ag was uncontaminated to moderately contaminated according to Igeo values. The maximum Ag concentration was obtained in the area with residential, commercial, thermal insulation production, urban and intercity traffic. This result also shows the effect of the crustal material. According

to PCA, the predominant anthropogenic contribution of metal pollution in this area was created by traffic and vehicle-related activities and industrial activities and their waste. Metal pollution from residential areas and natural resources was relatively low, but it was another contribution of pollution.

Spatial distribution of heavy metals in Dilovasi

ArcGIS software were used to map the spatial distributions of Si, Fe, Al, Zn, Mn, Ti, Cr, Ba, Pb, Ni, Sr, V, Co, Cd, Sb, As, Sn, Mo, Sc and Ag in street dust samples of the heavily industrialized district of Dilovasi. The concentration of each heavy metal is graphed in Fig. 6 to be able to visualize its levels spatially. The spatial distributions show that the heavy metal concentrations except Sn, Si As and Cd were higher in the western and southwestern parts of district than in other parts. The concentrations appear to be lower in the center of Dilovasi. Sn was higher in the eastern and western parts of the district, while Si was higher in the western part and in the center of Dilovasi. Cd was higher in the southern and eastern part of the district, while Co was higher in the southern part of the district. The highest concentrations of As and Ag were found in the center of district, while the highest concentration of Al and Ti were determined in the residential area in the southeastern part of the district. The highest concentrations of Si, Zn, Pb, Cd and Sc were in the western part of the district where traffic and iron and steel activities were located. Fe, Mn, Sb, Sn and Mo were at the highest level in the northwest part of the district where metal and iron and steel activities were carried out. On the other hand, the highest concentration of Ba and V were found in the southern of the district where iron and steel businesses operate, while the highest concentration of Ni and Co were observed in the southwest of district, where truck scales and painting production are active. Finally, Cr was highest in the northwestern part of the district, while Sr was highest at the sampling point in the shopping mall near the highway in the southwestern of the district.

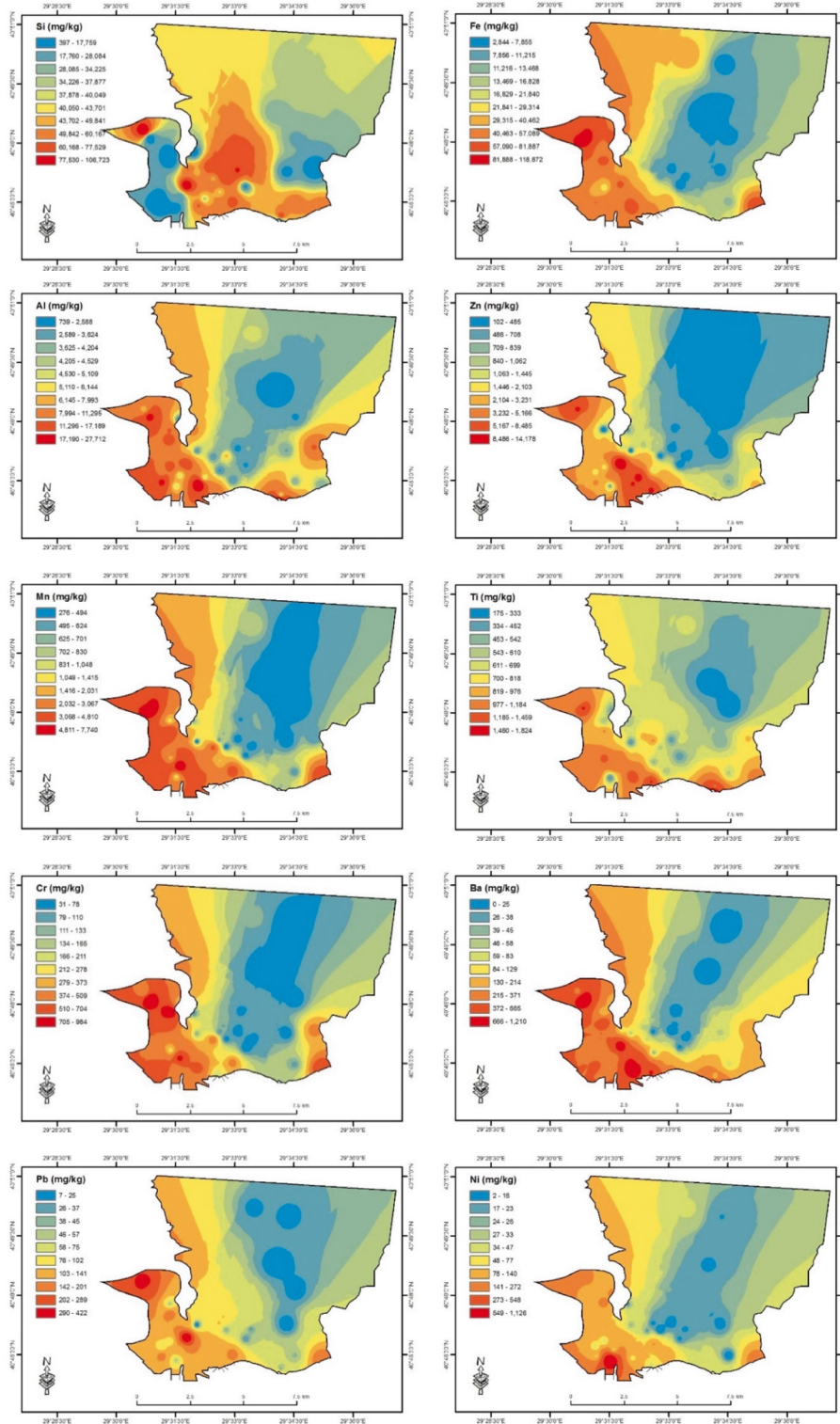


Fig. 6 Spatial distribution of Si, Fe, Al, Zn, Mn, Ti, Cr, Ba, Pb, Ni, Sr, V, Co, Cd, Sb, As, Sn, Mo, Sc and Ag concentration in street dust samples of Dilovasi

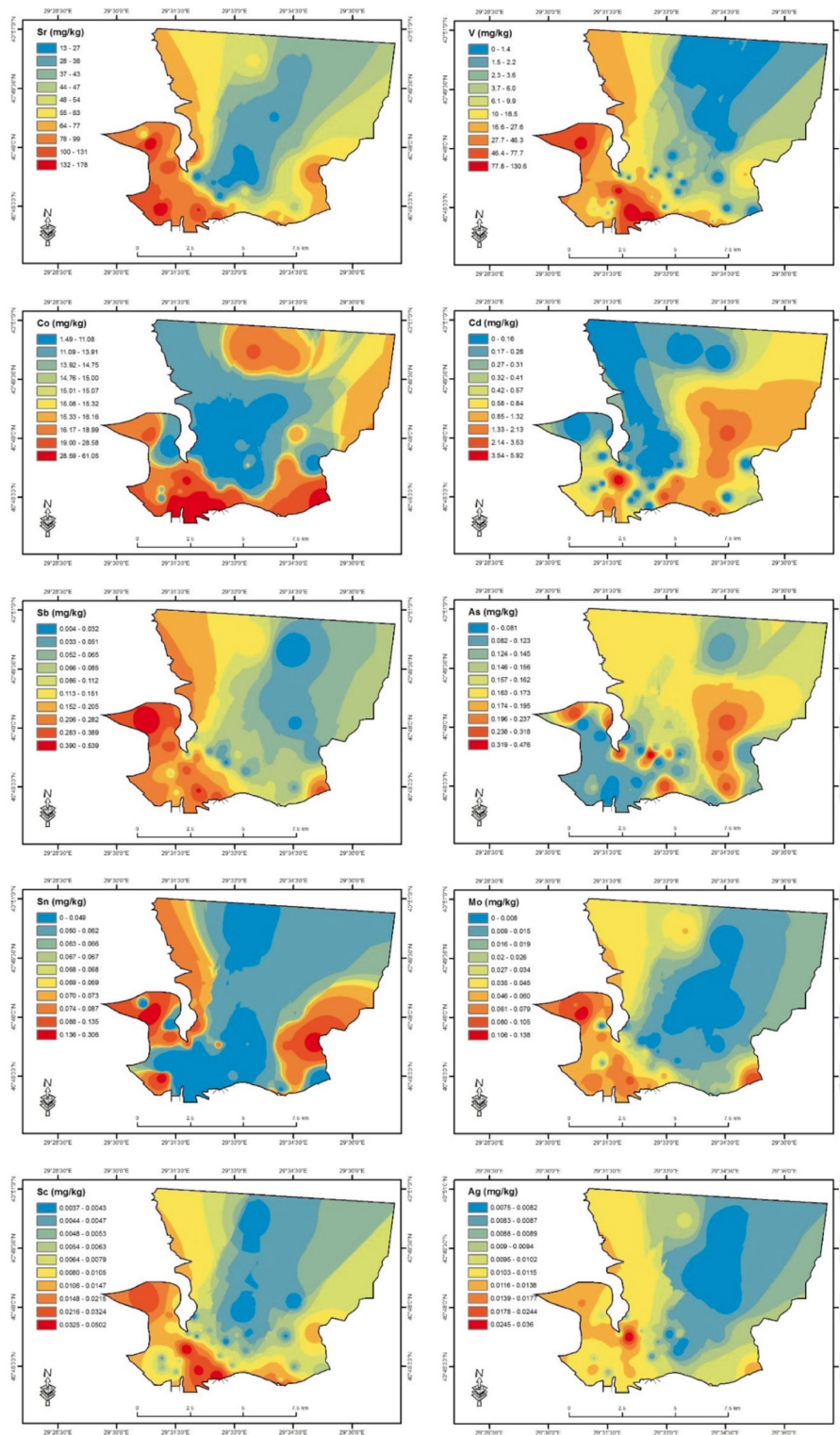


Fig. 6 (continued)

Conclusion

The street dust samples from heavily industrialized district of Dilovasi area were collected to analyze heavy metals and to assess their levels and sources for this study. The heavy metal concentrations were determined in different sites dominating by industrial, residential and traffic areas. In the street dust samples, crustal-based elements such as Si, Fe, Al, Mn and Ti were dominant. After crustal elements, Zn, Cr, Ba, Pb, Ni, Sr, V and Co were found in higher concentrations than others. The mean concentrations of Zn, Mn, Cr, Pb, Ni, Co and Cd were much higher than their reference values, suggesting that these metals in road dust were influenced by anthropogenic sources. In addition, Igeo, EF, ERF and ERI values were calculated and assessed based on the concentrations of heavy metals. The average Igeo value was 3.05, which is between 3 and 4, indicating heavily contaminated environment in the study area. In this study, the Igeo values were in the range of 0.02 for Ag and 8.03 for V. In this study, the average EF value was 29.67 and indicated very high pollution level. The fact that the average EF values of Pb, Cd and Zn were above 40 revealed that the study area was extremely enriched by these elements. Sampling points with the highest total EF value were as follows: electricity generating facility, truck garage on highway, industrial zone, the region where heavy industrial facilities are located, cultural center on highway and in district center (residential area). ERF indicated a change in the toxicity of heavy metals in street dust samples for each sampling point. The results showed the low ecological risk level for Pb, Ni, Cr and As; the medium ecological risk level for Zn; and the high ecological risk level for Cd. In addition, ERI was found as 300.74. This value was between 300 and 600 and indicated a considerable ecological risk level for the region. Igeo, EF and ERI analyses were selected for the determination and classification of pollution levels and used in their evaluations. Although these analyses gave an idea of the pollution level and ecological risk situation in the study area, they did not provide sufficient information in terms of health risk assessment. According to PCA, the predominant anthropogenic contribution of metal pollution in this area was created by traffic and vehicle-related activities and industrial activities and their waste. Metal pollution from residential areas and natural resources was relatively low, but it was

another contribution of pollution. These results show that in order to reduce the level of anthropogenic pollution, local governments should take measures to protect environmental health, especially in places where the pollution level is high. In this context, it is important to increase the efforts to prevent dust formation at the source. The spatial distributions show that the heavy metal concentrations except Sn, Si, As and Cd were higher in the western and southwestern parts of district than in other parts. The concentrations appeared to be lower in the center of Dilovasi. In total, the highest concentration at the sampling points was observed in the western, southwestern and southern parts of the district dominated by industry and also in the east of the district, which reflects the traffic effect. Individual measures are necessary to ensure favorable conditions for a better quality of life. Especially by sensitive groups such as those with heart and lung diseases, the elderly, children and diabetics, places with high pollution should not be preferred for daily activities. It is thought that focusing on the implementation of ecological city standards such as energy efficient buildings, renewable energy, green transportation and protection of environmental values in city planning at national and local level will contribute to the reduction of pollution in the future.

Funding Not funded.

Availability of data and material Not applicable.

Code availability Not applicable.

Declarations

Conflicts of interest The authors declare that they have no conflict of interest.

References

- Abbasi, S., Keshavarzi, B., Moore, F., Turner, A., Kelly, F. J., Dominguez, A. O., & Jaafarzadeh, N. (2019). Distribution and potential health impacts of microplastics and micro-rubbers in air and street dusts from Asaluyeh County, Iran. *Environmental Pollution*, 244, 153–164. <https://doi.org/10.1016/j.envpol.2018.10.039>
- Akhter, M. S., & Madany, I. M. (1993). Heavy metals in street and house dust in Bahrain. *Water, Air, and Soil Pollution*, 66(1–2), 111–119. <https://doi.org/10.1007/BF00477063>
- Bartholomew, C. J., Li, N., Li, Y., Dai, W., Nibagwire, D., & Guo, T. (2020). Characteristics and health risk assessment

- of heavy metals in street dust for children in Jinhua, China. *Environmental Science and Pollution Research*, 27(5), 5042–5055. <https://doi.org/10.1007/s11356-019-07144-0>
- Cai, K., & Li, C. (2019). Street dust heavy metal pollution source apportionment and sustainable management in a typical city-Shijiazhuang, China. *International Journal of Environmental Research and Public Health*, 16(14), 2625. <https://doi.org/10.3390/ijerph16142625>
- Castillo-Nava, D., Elias-Santos, M., López-Chuken, U. J., Valdés-González, A., de la Riva-Solís, L. G., Vargas-Pérez, M. P., Galán-Wong, L. J., & Luna-Olvera, H. A. (2020). Heavy metals (lead, cadmium and zinc) from street dust in Monterrey, Mexico: ecological risk index. *International Journal of Environmental Science and Technology*, 1–10. <https://doi.org/10.1007/s13762-020-02649-5>
- Chan, L. S., Ng, S. L., Davis, A. M., Yim, W. W. S., & Yeung, C. H. (2001). Magnetic properties and heavy-metal contents of contaminated seabed sediments of Penny's Bay, Hong Kong. *Marine Pollution Bulletin*, 42(7), 569–583. [https://doi.org/10.1016/S0025-326X\(00\)00203-4](https://doi.org/10.1016/S0025-326X(00)00203-4)
- Choi, J. Y., Jeong, H., Choi, K. Y., Hong, G. H., Yang, D. B., Kim, K., & Ra, K. (2020). Source identification and implications of heavy metals in urban roads for the coastal pollution in a beach town, Busan, Korea. *Marine Pollution Bulletin*, 161, 111724. <https://doi.org/10.1016/j.marpolbul.2020.111724>
- Davy, P. K., Ancelet, T., Trompeter, W. J., Markwitz, A., & Weatherburn, D. C. (2012). Composition and source contributions of air particulate matter pollution in a New Zealand suburban town. *Atmospheric Pollution Research*, 3(1), 143–147. <https://doi.org/10.5094/APR.2012.014>
- Delibašić, Š., Dokić-Kahvedžić, N., Karić, M., Keskin, I., Velispahić, A., Huremović, J., Herceg, K., Selimović, A., Silajdžić, S., Žero, S., Gojak-Salimović, S., Partić, A., & Pašalić, A. (2020). Health risk assessment of heavy metal contamination in street dust of federation of Bosnia and Herzegovina. *Human and Ecological Risk Assessment: An International Journal*, 1–13. <https://doi.org/10.1080/10807039.2020.1826290>
- EU. (2020). Urban population. Accessed November 29, 2020. [https://ec.europa.eu/eurostat/statistics-explained/index.php?title=File:Urban_population,_2018_\(%25_of_total_population\)_world20.png](https://ec.europa.eu/eurostat/statistics-explained/index.php?title=File:Urban_population,_2018_(%25_of_total_population)_world20.png)
- Gabarron, M., Faz, A., & Acosta, J. A. (2017). Effect of different industrial activities on heavy metal concentrations and chemical distribution in topsoil and road dust. *Environment and Earth Science*, 76, 129. <https://doi.org/10.1007/s12665-017-6449-4>
- Gao, J., & Wang, L. (2018). Ecological and human health risk assessments in the context of soil heavy metal pollution in a typical industrial area of Shanghai, China. *Environmental Science and Pollution Research*, 25(27), 090–105. <https://doi.org/10.1007/s11356-018-2705-8>
- GDM. (2020). Official Statistics. Accessed March 17, 2021. <https://mgm.gov.tr/veridegerlendirme/il-ve-ilceler-istatistik.aspx?k=A&m=KOCAELI>
- Ghosh, S. P., Raj, D., & Maiti, S. K. (2020). Risks Assessment of heavy metal pollution in roadside soil and vegetation of national highway crossing through industrial area. *Environmental Processes*, 7(4), 1197–1220. <https://doi.org/10.1007/s40710-020-00463-2>
- Gope, M., Masto, R. E., George, J., Hoque, R. R., & Balachandran, S. (2017). Bioavailability and health risk of some potentially toxic elements (Cd, Cu, Pb and Zn) in street dust of Asansol, India. *Ecotoxicology and Environmental Safety*, 138, 231–241. <https://doi.org/10.1016/j.ecoenv.2017.01.008>
- Gunawardana, C., Goonetilleke, A., Egodawatta, P., Dawes, L., & Kokot, S. (2012). Source characterisation of road dust based on chemical and mineralogical composition. *Chemosphere*, 87, 163–170. <https://doi.org/10.1016/j.chemosphere.2011.12.012>
- Hakanson, L. (1980). An ecological risk index for aquatic pollution control. A sedimentological approach. *Water Research*, 14(8), 975–1001. [https://doi.org/10.1016/0043-1354\(80\)90143-8](https://doi.org/10.1016/0043-1354(80)90143-8)
- Hamzaoglu, O., Etiler, N., Yavuz, C. I., & Çağlayan, Ç. (2011). The causes of deaths in an industry-dense area: Example of Dilovası (Kocaeli). *Turkish Journal of Medical Sciences*, 41(3), 369–375. <https://doi.org/10.3906/sag-1007-943>
- Hou, C., Shao, L., Zhao, C., Wang, J., Liu, J., & Geng, C. (2018). Characterization of coal burning-derived individual particles emitted from an experimental domestic stove. *Journal of Environmental Sciences*, 71, 45–55. <https://doi.org/10.1016/j.jes.2018.04.011>
- Idris, A. M., Alqahtani, F. M., Said, T. O., & Fawy, K. F. (2020). Contamination level and risk assessment of heavy metal deposited in street dusts in Khamees-Mushait city, Saudi Arabia. *Human and Ecological Risk Assessment: An International Journal*, 26(2), 495–511. <https://doi.org/10.1080/10807039.2018.1520596>
- Ite, A. E., Udousoro, I. I., & Ibok, U. J. (2014). Distribution of some atmospheric heavy metals in lichen and moss samples collected from Eket and Ibeno Local Government Areas of Akwa Ibom State, Nigeria. *American Journal of Environmental protection*, 2(1), 22–31. <https://doi.org/10.12691/env-2-1-5>
- Jeong, H., Choi, J. Y., Lee, J., Lim, J., & Ra, K. (2020). Heavy metal pollution by road-deposited sediments and its contribution to total suspended solids in rainfall runoff from intensive industrial areas. *Environmental Pollution*, 265, 115028. <https://doi.org/10.1016/j.envpol.2020.115028>
- Kanbak, A. (2011). The position of organized industrial zones in urban development: Dilovasi case. Ph.D Thesis, Istanbul University, Istanbul.
- Kara, M. (2020). Assessment of sources and pollution state of trace and toxic elements in street dust in a metropolitan city. *Environmental Geochemistry and Health*, 42(10), 3213–3229. <https://doi.org/10.1007/s10653-020-00560-z>
- Karanasiou, A., Amato, F., Moreno, T., Lumberras, J., Borge, R., Linares, C., Boldo, E., Alastuey, A., & Querol, X. (2014). Road dust emission sources and assessment of street washing effect. *Aerosol and Air Quality Research*, 14(3), 734–743. <https://doi.org/10.4209/aaqr.2013.03.0074>
- Keshavarzi, B., Tazarvi, Z., Rajabzadeh, M. A., & Najmeddin, A. (2015). Chemical speciation, human health risk assessment and pollution level of selected heavy metals in urban street dust of Shiraz, Iran. *Atmospheric Environment*, 119, 1–10. <https://doi.org/10.1016/j.atmosenv.2015.08.001>
- Kumari, S., Jain, M. K., & Elumalai, S. P. (2021). Assessment of pollution and health risks of heavy metals in particulate

- matter and road dust along the road network of Dhanbad, India. *Journal of Health and Pollution*, 11(29). <https://doi.org/10.5696/2156-9614-11.29.210305>
- Lin, H., Zhu, X., Feng, Q., Guo, J., Sun, X., & Liang, Y. (2019). Pollution, sources, and bonding mechanism of mercury in street dust of a subtropical city, southern China. *Human and Ecological Risk Assessment: An International Journal*, 25(1–2), 393–409.
- Manasreh, W. A. (2010). Assessment of trace metals in street dust of Mutah city, Karak, Jordan. *Carpathian Journal of Earth and Environmental Sciences*, 5(1), 5–12. Accessed November 2, 2020. https://hero.epa.gov/hero/index.cfm/reference/details/reference_id/2622287
- Men, C., Liu, R., Xu, F., Wang, Q., Guo, L., & Shen, Z. (2018). Pollution characteristics, risk assessment, and source apportionment of heavy metals in road dust in Beijing, China. *Science of the Total Environment*, 612, 138–147. <https://doi.org/10.1016/j.scitotenv.2017.08.123>
- MEU. (2013). Circular, dated 09.09.2013 and numbered 88462725–010–31677. Accessed November 29, 2020. <https://webdosya.csb.gov.tr/db/cygm/edotordosya/GNG2013-37HavaKalitesiDeger.pdf>
- MEU. (2018). Turkey environmental issues and priorities evaluation report, Publication No:40. Accessed November 29, 2020. https://webdosya.csb.gov.tr/db/ced/icerikler/cevre_sorun_2018-20180702151156.pdf
- MIT. (2019). Kocaeli provincial industry status report. Accessed February 13, 2021. <https://www.sanayi.gov.tr/plan-program-raporlar-ve-yayinlar/81-il-sanayi-durum-raporlari/mu2603011652>
- Muller, G. (1969). Index of geo-accumulation in sediments of the Rhine River. *Geology Journal*, 2(3), 108–118.
- Nuhoglu, Y., Yazıcı, M., Nuhoglu, C., Kuzu, S. L., Osmanlıoğlu, A. E., & Kam, E. (2020). Distribution of trace metals in street dusts and tree leaves and their source identification in a mid-populated Anatolian City. *Bulletin of Environmental Contamination and Toxicology*, 105, 103–110. <https://doi.org/10.1007/s00128-020-02882-1>
- Odediran, E. T., Adeniran, J. A., Yusuf, R. O., Abdulaheem, K. A., Adesina, O. A., Sonibare, J. A., & Du, M. (2021). Contamination levels, health risks and source apportionment of potentially toxic elements in road dusts of a densely populated African City. *Environmental Nanotechnology, Monitoring & Management*, 15, 100445. <https://doi.org/10.1016/j.enmm.2021.100445>
- Öztürk, F., & Keleş, M. (2016). Wintertime chemical compositions of coarse and fine fractions of particulate matter in Bolu, Turkey. *Environmental Science and Pollution Research*, 23(14), 14157–14172. <https://doi.org/10.1007/s11356-016-6584-6>
- Öztürk, F., Özgül, M. K. (2019). Assessing long term trends of air pollutants and associated health risks imposed on residents in Bolu (Turkey) during winter. *Türkiye Halk Sağlığı Dergisi*, 17(2), 102–122. <https://doi.org/10.20518/tjph.427342>
- Remeikaitė-Nikienė, N., Garnaga-Budrė, G., Lujanienė, G., Jokšas, K., Stankevičius, A., Malejevas, V., & Barisevičiūtė, R. (2018). Distribution of metals and extent of contamination in sediments from the south-eastern Baltic Sea (Lithuanian zone). *Oceanologia*, 60(2), 193–206. <https://doi.org/10.1016/j.oceano.2017.11.001>
- Rudnick, R. L., & Gao, S. (2003). Composition of the continental crust. *Treatise Geochem*, 3, 1–64.
- Sadeghdoust, F., Ghanavati, N., Nazarpour, A., Babaenejad, T., & Watts, M. J. (2020). Hazard, ecological, and human health risk assessment of heavy metals in street dust in Dezful, Iran. *Arabian Journal of Geosciences*, 13(17), 1–14. <https://doi.org/10.1007/s12517-020-05915-5>
- Shi, D., & Lu, X. (2018). Accumulation degree and source apportionment of trace metals in smaller than 63 µm road dust from the areas with different land uses: A case study of Xi'an, China. *Science of the Total Environment*, 636, 1211–1218. <https://doi.org/10.1016/j.scitotenv.2018.04.385>
- Suryawanshi, P. V., Rajaram, B. S., Bhanarkar, A. D., & Rao, C. C. (2016). Determining heavy metal contamination of road dust in Delhi, India. *Atmósfera*, 29(3), 221–234. <https://doi.org/10.20937/ATM.2016.29.03.04>
- Tang, R., Ma, K., Zhang, Y., & Mao, Q. (2013). The spatial characteristics and pollution levels of metals in urban street dust of Beijing, China. *Applied Geochemistry*, 35, 88–98. <https://doi.org/10.1016/j.apgeochem.2013.03.016>
- Tang, Z., Chai, M., Cheng, J., Jin, J., Yang, Y., Nie, Z., Huang, Q., & Li, Y. (2017). Contamination and health risks of heavy metals in street dust from a coal-mining city in eastern China. *Ecotoxicology and Environmental Safety*, 138, 83–91. <https://doi.org/10.1016/j.ecoenv.2016.11.003>
- Tasdemir, Y., Kural, C., Cindoruk, S. S., & Vardar, N. (2006). Assessment of trace element concentrations and their estimated dry deposition fluxes in an urban atmosphere. *Atmospheric Research*, 81(1), 17–35. <https://doi.org/10.1016/j.atmosres.2005.10.003>
- Taşpınar, F., & Bozkurt, Z. (2018). Heavy metal pollution and health risk assessment of road dust on selected highways in Düzce, Turkey. *Environmental Forensics*, 19(4), 298–314. <https://doi.org/10.1080/15275922.2018.1519736>
- Thorpe, A., & Harrison, R. M. (2008). Sources and properties of non-exhaust particulate matter from road traffic: A review. *Science of the Total Environment*, 400(1–3), 270–282. <https://doi.org/10.1016/j.scitotenv.2008.06.007>
- Uttara, S., Bhuvandas, N., & Aggarwal, V. (2012). Impacts of urbanization on environment. *International Journal of Research in Engineering and Applied Sciences*, 2(2), 1637–1645.
- Verma, A., Kumar, R., & Yadav, S. (2020). Distribution, pollution levels, toxicity, and health risk assessment of metals in surface dust from Bhiwadi industrial area in North India. *Human and Ecological Risk Assessment: An International Journal*, 26(8), 2091–2111. <https://doi.org/10.1080/10807039.2019.1650328>
- Wedepohl, K. H. (1995). The composition of the continental crust. *Geochimica Et Cosmochimica Acta*, 59(7), 1217–1232. [https://doi.org/10.1016/0016-7037\(95\)00038-2](https://doi.org/10.1016/0016-7037(95)00038-2)
- Wei, X., Gao, B., Wang, P., Zhou, H., & Lu, J. (2015). Pollution characteristics and health risk assessment of heavy metals in street dusts from different functional areas in Beijing, China. *Ecotoxicology and Environmental Safety*, 112, 186–192. <https://doi.org/10.1016/j.ecoenv.2014.11.005>
- Xiao, Q., Zong, Y., Malik, Z., & Lu, S. (2020). Source identification and risk assessment of heavy metals in road dust of steel industrial city (Anshan), Liaoning, Northeast China. *Human and Ecological Risk Assessment: An International Journal*,

- 26(5), 1359–1378. <https://doi.org/10.1080/10807039.2019.1578946>
- Xu, H., Ho, S. S. H., Cao, J., Guinot, B., Kan, H., Shen, Z., Ho, K. F., Liu, S., Zhao, Z., Li, J., Zhang, N., Zhu, C., Zhang, Q., & Huang, R. (2017). A 10-year observation of PM 2.5-bound nickel in Xi'an, China: Effects of source control on its trend and associated health risks. *Scientific reports*, 7(1), 1–10. <https://doi.org/10.1038/srep41132>
- Yıldırım, G., & Tokaloğlu, Ş. (2016). Heavy metal speciation in various grain sizes of industrially contaminated street dust using multivariate statistical analysis. *Ecotoxicology and Environmental Safety*, 124, 369–376. <https://doi.org/10.1016/j.ecoenv.2015.11.006>
- Yılmaz, M., Toros, H., İncecik, S., Öztürk, Z., Kirkil, G., Öztaş, D., Akçay, M., Dinç, U., Gültekin, M., Emanet, H., & Arslantaş, A. O. (2020). Evaluation of Dilovası air pollution in terms of traffic emission. *Ulusal Çevre Bilimleri Araştırma Dergisi*, 3(1), 43–51.
- Yongming, H., Peixuan, D., Junji, C., & Posmentier, E. S. (2006). Multivariate analysis of heavy metal contamination in urban dusts of Xi'an, Central China. *Science of the Total Environment*, 355(1–3), 176–186. <https://doi.org/10.1016/j.scitotenv.2005.02.026>
- Yusup, Y., & Alkarkhi, A. F. (2011). Cluster analysis of inorganic elements in particulate matter in the air environment of an equatorial urban coastal location. *Chemistry and Ecology*, 27(3), 273–286. <https://doi.org/10.1080/02757540.2010.547491>
- Zararsız, A., Öztürk, F. (2020). Estimation of Health Risks Associated with Household Dust Contamination in Bolu (Turkey). *Düzce Üniversitesi Bilim ve Teknoloji Dergisi*, 8(4), 2245–2265. <https://doi.org/10.29130/dubited.706362>

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.