Temporal and spatial variations of deposition and elemental composition of dust fall and its source identification around Tabriz, Iran

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Abstract

Coarse particles are primarily deposited via sedimentation, commonly referred as dust fall (DF). This study presented the monthly and spatial variations of atmospheric DF and their elemental components (Al, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, Se, Sr, Ti, V, Si, and Hg). Dust samples were collected from four urban and suburban sampling sites around Tabriz, Iran, by using the ASTM method D-1739 during April to September 2017. Moreover, the ICP-OES was used to determine metal components of the DF. The obtained results showed that the DF amount ranged between 1.8–27.6 (7.4 ± 5.6) g/m².month. The elements of Fe (11863–13,906 mg/Kg and 85%–89%), Al (858–1205 mg/Kg and 4%–8%), and Si (274–386 mg/Kg) were the dominant elemental concentrations of the DF. The average value of enrichment factor (EF) for Hg, Pb, Cu, Sr, Co, Ni, Mn, and V was greater than 10 in all the samples, showing that anthropogenic sources emit a considerable amount of elements in DF rather than the soil or Urmia lake bed. The result of correlations between the concentration of dust fall with humidity, temperature, wind speed, and precipitation showed that there was a direct relationship between the amount of dust fall and wind speed while humidity, precipitation, and temperature were inversely proportional to the amount of dust fall. This study revealed that earth crust and anthropogenic activities such as vehicle traffic, combustion of fossil fuel, and different industrial activities were the main sources of the DF in the studied areas.

Keywords Dust fall · Elemental composition · Crustal enrichment factor · Principal component analysis · Tabriz

Introduction

Environmental pollution is a major problem that affects ecosystems and human health worldwide by contaminating ambient air, soil, and water. Air pollution can be more important due to the direct effect on the environment and human health [1]. On the other hand, chemical reactions between air pollutants and other atmospheric components result in the deposition of pollutants and their derivatives on the surface of the earth [2]. Atmospheric dust or dust fall (DF) is one of the serious environmental hazards, which can cause environmental pollution

and affect global geochemical cycles, ecosystems, atmospheric radiation transfer, and human health [3, 4]. Coarse particles, having an aerodynamic diameter between 2.5 and 10 μm , are primarily deposited via sedimentation, commonly referred as the DF [5, 6]. Some studies cleared that the deposition rate of the DF is affected by factors such as dust concentration in the ambient atmosphere, energy of winds, and characteristics of depositional environment. Moreover, type of emission sources as well as their distance, location of sampling sites, and certain meteorological conditions are some of the other factors involved [7].

In addition to the ambient air quality effects, the DF can influence human health with diseases such as tonsillitis, allergy, asthma, and eye irritation [8]. The DF has a broad range of chemical species including elemental, organic, and inorganic components. Among elemental components are heavy metals associated with the DF from a variety of natural and anthropogenic emission sources such as vehicular traffic, residential fossil fuel burning, industrial emissions, construction operations and non-ferrous metal production. For instance, fossil fuel combustion is the primary anthropogenic emission source

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of Co, Hg, Mn, Se, Ni, Cu, Sb, Zn, and V. Moreover, some quantities of Zn, Pb, Ni, Cu, and Cd are imparted from vehicular exhausts [9]. In addition, anthropogenic emissions of toxic trace metals have been reported to dominate natural processes such as local soils, weathered materials, and crustal minerals [10].

To improve air quality, it is necessary to differentiate various sources of the DF. The enrichment factor (EF) method proposed by Zoller et al. (1974) has been widely used as the first step to evaluate the potential strength of pollution emitting sources [9, 11]. To apportion the sources of aerosols, a factor analysis is usually required. The method has been used successfully by numerous researchers [10].

Heavy metals are among the major components of the DF with adverse effects on human health and ecological quality, which might enter the human body through ingestion, inhalation or physical contact [12]. Most heavy metals can be harmful to human health even at low concentrations due to the formation of complex compounds within the cell [13, 14]. For example, lead may cause brain damage, kidney injury, seizures, and anemia [15, 16]. Therefore, the study of the DF amount as well as composition, distribution, and sources of heavy metals is important from the aspects of air pollution and health effect. Knowledge of temporal and spatial variability of the deposition rate of the DF provides a useful framework for evaluating dust characteristics in any given area [7].

The aims of this study were (1) to investigate the spatial and temporal variation of dust deposition rates at the selected sampling sites at urban and suburban regions; (2) to determine the monthly and spatial variability in the concentrations of the heavy metals (Al, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, Se, Sr, Ti, V, Si, and Hg) associated with the DF; and (3) to identify the likely natural or anthropogenic sources of heavy metals in the DF.

Material and methods

The studied area and sampling schedule

Four sampling sites, viz. Aq Gonbad (AG), Quri Gol (QG), and Amand Dam (AD) located in the suburban area as well as Tabriz sampling site (TAB) located in the urban area of Tabriz, Iran, were selected for this study. The TAB site represents urban and residential characteristics while the AD and QC sites represent suburban background characteristics and also effects of the DF on water resources. For investigating the amount of the DF affected by the Umiya lake bed, the AG site was selected. The geographical coordinates and location of the sampling sites are given in Table 1 and Fig. 1, respectively.

The DF samples containing wet and dry deposition were collected monthly (30 ± 2 days) during the spring and summer seasons at the four mentioned sampling sites during April to September 2017.

Table 1 Geographical coordinates of the sampling sites

Site	Site code	Location coordinates	
		Latitude	Longitude
Aq Gonbad	AG	37°49'9.80"N	45°25'15.57"E
Quri Gol	QG	37°54'33.49"N	46°42'12.47"E
Amand Dam	AD	38°12'28.07"N	46° 8'52.28"E
Tabriz	TAB	38° 3'49.73"N	46°19'19.09"E

Sampling protocol

In this study, the American Society for Testing and Materials Standard Method (ASTM Method D-1739) was used to collect the DF. According to this standard, polyethylene containers (20 cm in diameter) installed at a height of 2 m from the ground to prevent the accumulation of dust from soil and particulates were applied for the DF collection. These containers consisted of a windscreen fabricated according to Figs. 2 and 3.

In order to ensure that the obtained results of the DF measurements were not affected by any interference and to eliminate any contamination of the applied equipment, all the polyethylene bottles and glassware utilized for the DF and heavy metal analysis were treated using a 20% nitric acid (HNO_3) bath and then were rinsed using distilled water with an $18.2 \text{ M}\Omega\text{cm}$ resistivity. These containers were located at the mentioned sampling sites at the beginning of each month and after the predetermined time (30 days), the containers were closed and returned to the laboratory for analysis. The collected samples were kept at 4°C prior to analysis; and they have been extracted and analyzed immediately (up to two days after sampling)."

Determination of the dust fall (DF) concentration

The content of the sampled containers was rinsed using distilled water with an $18.2 \text{ M}\Omega\text{cm}$ resistivity and then filtered using Whatman 42 white filter-paper in the laboratory. The filter papers were weighted after drying at 105°C . The filter papers and their content were placed in an oven with temperature of $105 \pm 2^\circ\text{C}$ for at least 2 h. The drying procedure was continued until the filter papers achieved a constant weight. It should be mentioned that the filter papers were being weighted every 0.5 h after cooling in a desiccator. The following equation was used to determine undissolved solid concentration:

$$\text{Undissolved solid concentration (g/m}^2\text{.month)} = \frac{(F2-F1)}{A} \quad (1)$$

F1 The primary weight of the filter (g)

F2 The secondary weight of the filter (g)

A The area of the DF opening mouth of the container (m^2)

Fig. 1 The location of the sampling sites in the study area

Fig. 2 The wind shield of DF container (a) and its plan view (b) Handmade container (c)

Fig. 3 The DF concentration at the sampling sites during the study period ($\text{g}/\text{m}^2\cdot\text{month}$)

The filtered samples (dissolved solids passed through the filter) were transferred to a beaker. The beaker was placed on a plate hot at a temperature below $100\text{ }^{\circ}\text{C}$ until the samples were concentrated to a volume less than 50 mL. The volumes were transferred to crucible porcelains that were weighted after drying at $105\text{ }^{\circ}\text{C}$. The used beakers were rinsed and added to the content in the crucible porcelains. The crucible porcelains were placed at $105\text{ }^{\circ}\text{C}$ until drying and reaching a constant weight and were kept for metal analysis in the next step. The following equation was used to determine dissolved solid concentration:

$$\text{Dissolved solid concentration } (\text{g}/\text{m}^2\cdot\text{month}) = \frac{(C2-C1)}{A} \quad (2)$$

C1 The primary weight of the crucible (g)

C2 The secondary weight of the crucible (g)

The following equation was used to determine the DF:

$$DF = \frac{(F2-F1) + (C2-C1)}{A} \text{ or} \quad (3)$$

DF = Undissolved solid concentration + dissolved solid concentration

DF Total DF concentration ($\text{g}/\text{m}^2\cdot\text{month}$)

Determination of the heavy metals in the DF

For analyzing the elements, the dried filters from the previous step were broken up into small pieces and digested at $170\text{ }^{\circ}\text{C}$ for 4 h in a high-pressure Teflon digestion vessel with 10 mL HNO_3 (69%), 3 mL HClO_4 (70%), and 1 mL HF (48%). The same procedures were also carried out on the new unused filter as a blank solution. After cooling of the digestion vessel at room temperature, the solutions were dried using a hot plate at temperature of $90\text{ }^{\circ}\text{C}$ – $100\text{ }^{\circ}\text{C}$. Afterwards, 1 mL concentrated HNO_3 and 5 mL deionized water were added for the dissolving metals. In addition, the solution was used to dissolve the metals in the crucible porcelains in the previous section. The crucible porcelains and digestion vessel were rinsed and diluted using 25 mL distilled-deionized water. The obtained

solutions were filtered through a micro-porous Whatman 42 filter with the pore size of $2.5\text{ }\mu\text{m}$ [17, 18].

All the elements (Al, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, Se, Sr, Ti, V, Si, and Hg) were measured by inductively coupled plasma-atomic emission spectroscopy (ICP-AES, model ULTIMA, JOBIN-YVON Company, France).

Quality control

Limits of detection (LODs) were calculated by adding three standard deviations of the blank readings to the average five replicates of the blank. The LODs were obtained in the range of 0.02 – $0.5\text{ }\mu\text{g L}^{-1}$ for the studied elements. The determined detection limits, method detection limit, and recovery efficiency for the measured elements are presented in Table 2.

Meteorological data

Wind speed, wind direction, ambient air temperature, precipitation, and relative humidity (RH) at the sampling sites were obtained from the National Climatic Data Center (NCDC) and East Azerbaijan Meteorological Organization. The obtained data were examined and processed for the missing values and used for investigation of the correlation between meteorological parameters with DF values.

Enrichment factor (EF)

The EF is one of the pollution indicators used to determine sources of detected elements, as anthropogenic or human activities. The EF is also used to assess the degree of anthropogenic influence [19], i.e. to assess the potential strength of pollution emitting sources [10], assess the effect of anthropogenic activities on the DF metal content, and measure the extent of non-crustal contributions to elemental concentration levels in the DF. The EF was calculated as follows [20]:

$$EF = \frac{(C_X/C_{Fe})_{\text{dust fall}}}{(C_X/C_{Fe})_{\text{crust}}} \quad (4)$$

Table 2 The LODs, MDLs, and recovery efficiencies for the elements

Element	Detection limit* (ng/L)	Method detection limit (mg/Kg)	Recovery (%)	Element	Detection limit* (ng/L)	Method detection limit (mg/Kg)	Recovery (%)
Al	300	3.8	76–93	Pb	100	1.3	93–103
Cd	100	1.3	71–89	Se	20	0.25	80–84
Co	100	1.3	61–83	Sr	100	1.3	75–86
Cr	200	2.5	96–120	Ti	40	0.5	61–77
Cu	40	0.5	71–92	V	50	0.63	64–79
Fe	200	2.5	95–97	Si	300	3.75	87–95
Mn	40	0.5	79–88	Hg	100	0.25	52–68
Ni	500	6.3	88–93				

* Based on 3σ blank filters ($n = 5$)

Where C_x is the concentration of the element X and C_{Fe} is the concentration of Fe as the reference element. The subscripts of the DF and crust refer to the DF samples and crustal materials, respectively. Fe, Al, or Si is usually used as the reference element; based on Table 4, Fe had the highest elemental concentration in the DF among the determined elements and thus the EF were calculated using Fe as the reference element.

The EF values were classified into four categories. The EF values less than one indicate that the local crust and soil was the main source of elements; the EF values equal to 1–5 mean that these elements originated from sources other than the crustal soil; the EF values equal to 5–10 suggest that the anthropogenic emission was predominant; and finally, the EF values ≥ 10 show that a significant fraction of the elements was contributed from non-crust sources [20, 21].

Correlation matrixes were calculated to quantify the relation between the elemental concentrations based on Pearson's correlation coefficient.

Results and discussion

Temporal and spatial variation in the dust fall (DF) rate

The results of DF rate (concentrations) at the four different sampling sites and their variation during the study period are presented in Table 3 and Fig. 3, respectively. As is shown, the DF rate among all samples ranged between 1.77 and 27.63 g/m².month. The maximum monthly concentration of the DF belonged to May at the AG, AD, and TAB, and the highest amount of the DF equal to 27.63 g/m².month was observed in the AG. Based on one-way ANOVA analysis, there were statistically significant differences (p value < 0.05) between the DF values of May and other months (mean differences of May with April, June, July, August, and September were 8.4, 10.6, 8.6, 9.6, and 12.6, respectively). However, there were no statistically significant differences between the DF values at all

the sampling sites. On the other hand, the minimum monthly concentration of the DF belonged to September at all the sampling sites ranging between 1.77 and 5.00 g/m².month.

Comparison of the DF amounts with the standard of 1929:2011 SANS D < 18 <https://archive.org/details/za.sans.1929.2011> indicated that at all the sampling sites, except the AG sampling site in May, the measured DF rates were less than the determined standard level (18 g/m²/month) during the study period. Furthermore, comparisons of the measured concentration of the total DF in this study with other studies in different areas, such as the study of Malakootian et al. in an urban area (6.56–24.42 g/m²/month) [8], Kozak et al. in a rural and recreational area (5.94 g/m²/month) [22], Norela et al. in a residential area (7.6 g/m²/month) [23], and Momani et al. in an urban area (4.9 g/m²/month) [24] cleared that the measured DF rate in this study was almost equal to that in other studies. However, the measured DF rate in our study was lower than the results of the study of Yari et al. in Qom, Iran, in which the mean rate of the DF was measured as 27.088 and 15.685 g/m².month in April and May, respectively [25].

This demonstrates that the amount of the DF rate is the same in many urban and suburban areas around the world, unless affected by special metrological, geographical or other conditions.

With respect to the climatic parameters of the study area during the sampling period and based on the correlation coefficients between the meteorological parameters and DF rates,

Table 3 The statistical data of DF concentration at sampling sites during studied months (g/m².month)

Location	Mean	Min	Max	Range	Std. Deviation
AG	9.01	2.60	27.63	25.03	9.51
TAB	8.29	2.96	16.93	13.97	4.94
QG	7.90	4.40	10.83	6.43	2.67
AD	4.32	1.77	8.96	7.19	2.56

i.e. wind speed, relative humidity, temperature, and precipitation, the meteorological parameters were identified as the major factors directly affecting on the DF rate in different months. The following results were obtained by calculating the correlation coefficient between the DF rate during six months and the meteorological parameters (temperature, wind speed, relative humidity, and precipitation).

The calculated correlation coefficient data revealed that in the AG sampling site, the DF had a significant correlation with all the meteorological parameters (with a correlation coefficient more than 0.5), especially with the precipitation (with a correlation coefficient equal to 0.928, p value <0.01). In addition, it was shown that the DF had a significant correlation only with the precipitation (0.600) in the QG sampling site while it had a significant correlation with the wind speed (0.546) in the TAB sampling site. The results of Malakootian et al. showed that the DF rate and precipitation had a significant and direct correlation (with a correlation coefficient equal to 0.771, p value = 0.023) [8], which is in agreement with the results of the QG and AG sampling sites obtained in this study. Other studies conducted in Yazd, Iran, in 2006 [26] as well as in the industrial city of Lukavac, Bosnia, in 2011 [27] showed a direct correlation between the DF concentration and wind speed, which is similar to the results of our study in the QG and TAB sites. The prevailing wind in the study area blew east to west and west to east during the spring and summer seasons. As shown in Fig. 1, the study area was located around the Urmia lake bed and had no vegetation cover in the west of the TAB and AM sites as well as in the east of the QG site from the mid spring to the end of summer. Therefore, the prevailing eastern and western wind carried dust from the mentioned dry and barren areas.

Furthermore, the calculated correlation coefficient showed that the correlation between the DF rate and temperature was indirect. This finding is in contrast to the results of Norouzi et al. who stated a positive and statistically significant correlation between the monthly DF and monthly maximum temperature and also between the monthly DF and monthly minimum temperature [3]. This can be due to the effect of the above mentioned region wind speed, which is higher in spring than in summer.

Heavy metal concentrations in dust fall (DF)

The mean, standard, maximum and minimum contents of elements in the DF at the four sampling sites during the study period (based on ppb and percentage) are summarized in Table 4 and Fig. 4. The sum of the concentrations of the analyzed elements in the DF among all the samples ranged from 10,700 to 21,800 mg kg^{-3} . It was demonstrated that Fe (11863–13,906 mg/Kg and 85%–89%) and Al (858–1205 mg/Kg and 4%–8%) were respectively the most abundant detected metals among the other elements in all the samples. Additionally, the dust-borne elemental content of the DF

followed the order $\text{Si} > \text{Mn} > \text{Sr} > \text{Cu} > \text{V} > \text{Pb} > \text{Ni} > \text{Co} > \text{Hg}$. It should be mentioned that the Se, Cd, and Ti concentrations were zero or lower than the detection limit in all the samples.

Many researches have been conducted to investigate the metal concentration in the DF around the world. For comparison of the current study with some other studies, the mean concentrations of some elements associated with the DF, which were detected in other studies, are presented in Table 5.

With respect to the variation of the elemental concentrations of the DF in different cities around the world in Table 5, it can be concluded that the concentration of the heavy metals in the DF strongly depended on the study and sampling location and sampling time, and also on the sampling method.

The results of some studies showed that Fe is the most abundant element among others [31, 33]; however, some other studies revealed that the Al concentration is highest [34]. The results of the study by Huang et al. (2013) on heavy metal contamination of the DF in northern China showed that the Fe concentration in the DF samples was extremely higher than the Al concentration [31]. Moreover, the research of Balasubramanian et al. (2009) on the concentration of 13 elements (Al, As, Co, Cd, Cr, Cu, Fe, Mn, Ni, Pb, Ti, V, and Zn) in street dust [33] revealed that the portion of elements in the DF ranged from mg kg^{-1} for many elements (e.g., As, Cd, V) to g kg^{-1} for Al and Fe. The average elemental concentrations in their studied areas followed the order of $\text{Fe} > \text{Al} > \text{Mn} > \text{Zn} > \text{Cu} > \text{Ti} > \text{Pb} > \text{Cr} > \text{V} > \text{As} > \text{Ni} > \text{Co} > \text{Cd}$. These results are very close to those in our study; our results indicated that the concentration of the measured elements ranged from $\mu\text{g kg}^{-1}$ for many elements (e.g., Bb, Ni, Co, Hg etc.) to mg kg^{-1} for Fe.

Several researches reported that the presence of Fe, Al, and Si is mainly the result of regional soil re-suspension [35, 36]. Chew et al. (2013) reported that industrial areas tend to discharge more Al to the atmosphere in comparison with the semi-urban or residential area [5]. As seen in Table 4, the concentration of the Al element was higher in the AD sampling site compared to the other studied areas, which can be due to the proximity of the AD sampling site to the industrial area in the region.

With respect to the elemental concentrations of heavy metals such as Mn, Cr, Ni, As, Cu, Co, and Hg contributing to the DF, no statistically significant differences were observed among the samples collected in the different months during the study period.

Enrichment factor (EF) for the studied elements

As mentioned previously, the EF was used to determine sources of the elements, assess the degree of anthropogenic influence, and measure the extent of crustal and non-crustal contributions of the elements in the DF.

Table 4 The spatial variation of the heavy metals (mg kg^{-1}) in the dust-fall samples (Mean $\pm$ SD (min-max))

	AG	QG	AD	TAB
Fe	13,906.69 $\pm$ 3212.08 (9648.44–17,462.91)	11,790.76 $\pm$ 1332.59 (9589.99–13,336.35)	13,113.86 $\pm$ 1930.24 (11,326.80–16,571.06)	11,863.96 $\pm$ 530.51 (11,199.37–12,677.82)
Al	858.31 $\pm$ 986.84 (27.10–2561.04)	580.26 $\pm$ 585.08 (38.47–1644.11)	1205.77 $\pm$ 1420.92 (42.69–3927.46)	728.12 $\pm$ 781.90 (99.91–2178.87)
Si	379.51 $\pm$ 172.94 (188.28–615.63)	273.84 $\pm$ 138.80 (140.34–474.99)	386.01 $\pm$ 194.37 (171.05–626.94)	366.25 $\pm$ 248.28 (118.89–845.97)
Mn	329.38 $\pm$ 62.83 (216.82–399.08)	278.39 $\pm$ 38.96 (215.53–322.52)	270.07 $\pm$ 63.52 (179.15–362.65)	240.54 $\pm$ 33.05 (174.36–261.96)
Sr	217.75 $\pm$ 81.01 (67.66–286.63)	192.07 $\pm$ 16.16 (172.71–220.55)	208.93 $\pm$ 28.25 (182.51–258.64)	182.71 $\pm$ 39.95 (114.79–219.04)
Cr	73.75 $\pm$ 15.38 (52.01–96.10)	43.28 $\pm$ 9.06 (34.42–59.71)	74.16 $\pm$ 39.02 (23.41–135.58)	64.09 $\pm$ 14.53 (51.70–91.16)
Cu	54.51 $\pm$ 3.69 (47.78–57.88)	54.11 $\pm$ 25.91 (33.02–93.63)	56.15 $\pm$ 43.37 (9.83–137.86)	67.44 $\pm$ 26.90 (43.45–108.92)
V	42.29 $\pm$ 6.30 (30.62–47.04)	30.97 $\pm$ 3.63 (25.28–35.45)	34.10 $\pm$ 4.77 (27.81–41.52)	28.71 $\pm$ 5.69 (17.47–33.55)
Pb	38.77 $\pm$ 10.70 (21.87–50.41)	40.38 $\pm$ 6.42 (32.22–51.15)	41.21 $\pm$ 9.38 (30.85–56.71)	3.44 $\pm$ 15.43 (28.59–73.32)
Ni	27.37 $\pm$ 8.41 (15.32–39.43)	20.75 $\pm$ 3.27 (16.70–25.52)	43.55 $\pm$ 8.78 (34.36–60.25)	25.84 $\pm$ 2.38 (22.79–28.56)
Co	11.93 $\pm$ 1.95 (8.30–13.97)	8.22 $\pm$ 0.99 (6.83–9.86)	8.49 $\pm$ 3.92 (1.00–12.53)	8.01 $\pm$ 0.32 (7.56–8.42)
Hg	2.88 $\pm$ 1.96 (0.39–6.13)	2.06 $\pm$ 0.88 (1.02–3.13)	3.25 $\pm$ 1.32 (1.95–4.97)	2.40 $\pm$ 1.61 (0.79–4.98)

Fig. 4 The proportion and percentage distribution of the elemental constituents in the DF at the sampling sites

Table 5 Comparison of the heavy metal concentrations (mg kg^{-1}) in the DF between the current study and other similar studies

Study location	Study area	Elements											ref
		Al	Fe	Mn	Sr	Cr	Cu	V	Pb	Ni	Co	Hg	
Jordan	Petroleum refinery	NR	12–14	NR	NR	60–72	65–111	NR	55–66	NR	NR	NR	[28]
India	Coal mining	NR	NR	NR	54–110	23–78	22–111	41–54	43–104	15–63	11–21	NR	[29]
China	Urban area	NR	NR	NR	NR	167.3	94.9	NR	230.5	NR	NR	0.64	[30]
China	Urban area	NR	15,330	538	NR	29.7	19.7	35.3	38.3	18.4	9.22	NR	[31]
Canada	Street dust	47,540	18,948	431.5	459	43.3	65.8	34	39.1	15.2	8.31	0.03	[32]
Canada	House dust	25,948	14,135	269.3	255	86.7	206.1	24.8	405.6	62.9	8.92	3.63	[32]
Iran	Urban and rural area	NR	NR	NR	NR	37.2	67.00	NR	96.3	53.4	8.53	0.67	[3]
Current study	Urban area	881	12,940	291.1	206.2	51.3	67.3	37.0	42.1	27.4	9.5	2.7	
Current study	Suburban area	728	11,860	240.5	182.7	64.1	67.4	28.7	43.4	25.2	7.5	2.3	

NR Not reported

The calculated EF values for elements at the four studied sites have been separately presented in Fig. 5. As shown in Fig. 5, the average value of the EF for Hg, Pb, Cu, Sr, Co, Ni, Mn, and V was more than 10 at all the studied sites. The highest value of the EF for Hg, Pb, and Cu represented the anthropogenic and non-crustal sources of these elements. Anthropogenic activities such as combustion of fossil fuels and activities of different factories like cement factory lead to higher EFs [37, 38]. This may indicate that a great fraction of the dust-borne heavy metals in the study area originated from the anthropogenic sources. The lowest values of the elemental EF for Al, Si, and Fe showed the crustal sources of

these elements and revealed that the mentioned elements were not enriched with heavy metals from the anthropogenic sources. The average EF value for Cr was between 1 and 5, showing that human factors such as construction and demolition activities, road dust, and industrial activities (factories, etc.) have slight effect on the Cr concentration in the DF.

Correlation coefficient (R^2)

The correlation coefficient between the metal concentrations in the DF at the four selected sites was studied in order to predict

Fig. 5 The EF values for the elements at the four studied sites

Table 6 The correlation between the heavy metals in the DF at the selected sites

		Fe	Al	Si	Mn	Sr	Cr	Cu	V	Pb	Ni	Co
AG	Al	0.706										
	Si	−0.338	−0.220									
	Mn	0.756	0.569	0.142								
	Sr	0.791	0.670	−0.398	0.265							
	Cr	0.885*	0.676	−0.199	0.927**	0.473						
	Cu	0.207	0.151	0.144	0.392	0.067	0.462					
	V	0.420	0.138	0.265	0.869*	−0.201	0.710	0.326				
	Pb	0.938**	0.698	−0.059	0.922**	0.596	0.930**	0.236	0.653			
	Ni	0.829*	0.886*	−0.044	0.853*	0.553	0.851*	0.125	0.531	0.919**		
	Co	0.708	0.483	0.073	0.983**	0.152	0.910*	0.331	0.923**	0.877*	0.799	
QG	Hg	0.619	0.589	−0.379	0.245	0.658	0.313	−0.603	−0.054	0.535	0.612	0.225
	Al	0.382										
	Si	−0.736	−0.385									
	Mn	0.954**	0.311	−0.831*								
	Sr	0.801	0.818*	−0.637	0.686							
	Cr	−0.020	0.393	0.554	−0.247	0.249						
	Cu	−0.669	−0.459	0.779	−0.818*	−0.517	0.280					
	V	0.957**	0.280	−0.848*	0.997**	0.679	−0.276	−0.795				
	Pb	0.905*	−0.011	−0.663	0.899*	0.526	−0.266	−0.504	0.913*			
	Ni	0.301	0.606	0.217	0.128	0.505	0.907*	−0.147	0.087	−0.018		
AD	Co	0.939**	0.062	−0.707	0.909*	0.591	−0.214	−0.540	0.932**	0.975**	0.047	
	Hg	0.482	0.434	0.028	0.202	0.670	0.693	0.182	0.210	0.310	0.662	0.369
	Al	0.899*										
	Si	−0.139	−0.158									
	Mn	0.761	0.867*	−0.435								
	Sr	0.993**	0.922**	−0.137	0.803							
	Cr	0.522	0.817*	−0.097	0.762	0.554						
	Cu	−0.312	0.048	−0.308	0.013	−0.253	0.286					
	V	0.952**	0.742	−0.220	0.668	0.920**	0.325	−0.514				
	Pb	0.905*	0.746	0.110	0.429	0.876*	0.310	−0.328	0.856*			
TAB	Ni	0.866*	0.899*	0.028	0.572	0.864*	0.619	0.047	0.710	0.904*		
	Co	0.435	0.683	−0.551	0.904*	0.497	0.781	0.350	0.306	0.059	0.331	
	Hg	0.577	0.473	0.466	−0.001	0.530	0.204	−0.235	0.503	0.848*	0.780	−0.304
	Al	0.099										
	Si	−0.257	0.761									
	Mn	0.119	−0.823*	−0.953**								
	Sr	0.645	−0.056	−0.332	0.376							
	Cr	0.196	−0.265	0.063	−0.044	0.394						
	Cu	0.459	−0.488	−0.375	0.323	−0.079	0.001					
	V	0.132	−0.936**	−0.915*	0.924**	0.307	0.261	0.412				
	Pb	0.098	−0.578	−0.395	0.432	0.522	0.845*	−0.075	0.650			
	Ni	0.971**	0.364	−0.507	0.063	0.702	0.384	0.343	0.357	0.282		
	Co	0.774	0.512	−0.856	0.172	0.506	0.187	0.026	0.377	0.225	0.839	
	Hg	0.242	−0.313	0.249	−0.089	0.649	0.941*	−0.218	0.758	0.949*	0.426	0.216

** Correlation is significant at the 0.01 level (1-tailed)

* Correlation is significant at the 0.05 level (1-tailed)

the possibility of common sources of elements (Table 6). As it is clear, the high R^2 values showed significant correlation

between the elements. In this study, for example, the correlations coefficient between Co and Mn at the AG, V and Mn at

Fig. 6 The correlation between some metals (Co–Mn at the AG, V–Mn at the QG, Sr–Fe at the AD and Ni–Fe at the TAB)

the QG, Sr and Fe at the AD and Ni and Fe at the TAB were higher than 0.971 (p value < 0.01), showing the possibility of a

same source for these metals. In addition, Fig. 6 shows the correlation between Co–Mn at the AG, V–Mn at the QG, Sr–

Table 7 Varimax rotated PCA loadings for the metals of the DF at the studied sites

	AG			QG		AD			TAB			
	PC1	PC2	PC3	PC1	PC2	PC1	PC2	PC3	PC1	PC2	PC3	PC4
Fe	.731	.639	-.022	.921	.241	.979	.182	-.074	.082	.921	.096	.368
Al	.552	.654	-.079	.838	.500	.901	.239	.356	-.442	.273	.714	.470
Si	.166	-.687	.051	-.701	.319	.017	-.823	-.028	.202	-.171	-.223	-.938
Mn	.993	.049	.109	.905	-.021	.675	.669	.243	-.231	-.017	.963	.139
Sr	.225	.906	-.064	.558	.509	.967	.215	-.012	.447	.559	.695	.074
Cr	.893	.361	.218	-.266	.941	.556	.269	.676	.959	.187	-.181	-.109
Cu	.287	.045	.950	-.517	.204	-.290	.099	.855	-.292	.668	-.663	-.170
V	.882	-.389	.123	.925	-.040	.902	.240	-.347	.892	.014	-.372	.255
Pb	.914	.372	-.049	.993	-.009	.948	-.222	-.129	.998	-.038	.052	.017
Ni	.859	.400	-.171	-.015	.893	.927	-.140	.299	.302	.846	.091	.430
Co	.984	-.027	.071	.994	.048	.342	.775	.505	.223	.470	.118	.846
Hg	.301	.583	-.754	.333	.890	.716	-.670	-.002	.953	.216	.161	-.138
Eigenvalue	6.194	3.053	1.594	5.748	3.190	6.754	2.520	1.861	4.344	2.730	2.639	2.288
% of Variance	51.618	25.442	13.287	68.024	26.583	56.287	21.000	15.509	36.198	22.747	21.990	19.065
% of Cumulative	51.618	77.061	90.348	47.901	94.607	56.287	77.287	92.796	36.198	58.945	80.935	100

Bold numbers represent the significant correlation.

Fe at the AD and Ni–Fe at the TAB as an example for presentation of the correlation among the elements.

At all the sampling sites, the significant correlations between Fe and Al with Cr, Pb, and Ni cleared that the major part of the elements in this area originated predominantly from the polluted soil with anthropogenic activities such as automobile exhausts and metal melting plants. Moreover, the significant correlation between Mn with Cr, Pb, V, Ni, and Co indicated that these heavy metals came from automobile exhausts and oil combustion. Each of the above mentioned elements can turn into the DF from emissions of particulate matters and exhaust gases to urban or suburban environments.

In contrast, at the TAB sampling site, Al and Si showed negative correlation and Al represented zero or weak correlation with the anthropogenic parameters such as Mn, V, and Pb, revealing that these metals are to be emitted from soil by wind-blown.

Principal component analysis of the metals in dust fall (DF)

The principal component analysis (PCA) with Varimax rotation was conducted for the metal content of the DF at the AG, GQ, AD, and TAB sites with eigenvalues exceeding 1.0 to obtain groups containing species with a similar behavior and identify their possible sources. As shown in Table 6, three, two, three, and four principal factors were obtained for the AG, QG, AD, and TAB sites, respectively, which accounted for 90.35, 94.61, 92.79, and 100.0% of the total variance for each studied site, respectively.

Based on Table 7, the PCA cleared that at all the sites, the first PC showed high correlation between Al and Fe with the other elements such as Mn, Cr, V, Pb, Ni, and Co. With respect to the existing elements in this group, it was concluded that about 52%, 68%, 56%, and 36% of the heavy metals content of the DF at the AG, GC, AD, and TAB sites, respectively, originated predominantly from soil and resuspension of the polluted soil with anthropogenic activities such as automobile exhausts and oil combustion [34, 39].

At the AG sampling site, the second PC showed the high loading of Fe, Al, and Sr with a variance of 25.4%. As mentioned previously, these elements originated from the crustal and natural soil of the region [34]. Moreover, the third important source of the elements associated to the DF of the AG was combusted with the variance of 13.3% due to the high loading of Cu.

The second PC for the QG showed the high correlation among Cr, Ni, and Hg, indicating that about 27% of the heavy metals of the DF in this area originated from the combustion sources [9, 11].

For the TAB, the PC2 showed the high loading of Fe, Cu, and Ni, which originated from the oil combustion (the portion of 23%). In addition, the PC3 showed the high loading of Mn

and Sr, which were the crustal components. The PC4 consisted of Co, which was related to transportation, road traffic and soil [40].

Conclusions

In this study, the DF and their content of heavy metals were measured. The DF amounts in compared with the standard 1929:2011 SANS D < 18 was shown to be less than 18 g/m².month at all the sites during the study period (except the AG in May with the DF of 27.63 g/m².month). Moreover, the average elemental concentrations followed the order of Fe > Al > Si > Mn > Sr > Cu > Cr > Co > V > Pb > Ni > Hg > Se > Cd > Ti in the studied areas.

Based on the measured concentration of the elements and their calculated EF and also by using the factor analysis, natural sources such as crustal and soil and also resuspension of particulate from the polluted soil, and anthropogenic sources such as industrial activities, fossil fuel combustion, and road traffic contributed a substantial amount of heavy metals to the DF.

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Compliance with ethical standards

Competing interests The authors declare no competing interest with respect to the publication and authorship of this paper.

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References

1. Rai PK. Chapter one - particulate matter and its size fractionation. Biomagnetic monitoring of particulate matter: Elsevier; 2016. p. 1–13.
2. Alahmr FOM, Othman M, Wahid NBA, Halim AA, Latif MT. Compositions of dust fall around semi-urban areas in Malaysia. *Aerosol Air Qual Res.* 2012;12:629–42.
3. Norouzi S, Khademi H, Ayoubi S, Cano AF, Acosta JA. Seasonal and spatial variations in dust deposition rate and concentrations of dust-borne heavy metals, a case study from Isfahan, central. *Iran Atmospheric Pollution Research.* 2017;8(4):686–99.
4. Gholampour A, Nabizadeh R, Naseri S, Yunesian M, Taghipour H, Rastkari N, et al. Exposure and health impacts of outdoor particulate matter in two urban and industrialized area of Tabriz, Iran. *J Environ Health Sci Eng.* 2014;12(1):27.

5. Chew MJ. Assessment of heavy metals in dust fall in Kampar: UTAR; 2015.
6. Sami M, Waseem A, Akbar S. Quantitative estimation of dust fall and smoke particles in Quetta Valley. *J Zhejiang Univ Sci B*. 2006;7(7):542–7.
7. Lawrence CR, Neff JC. The contemporary physical and chemical flux of aeolian dust: a synthesis of direct measurements of dust deposition. *Chem Geol*. 2009;267(1–2):46–63.
8. Malakootian M, Ghiasseddin M, Akbari H, NAJ-H F. Urban dust fall concentration and its properties in Kerman City, Iran. *Health Scope*. 2013;1(4):192–8.
9. Gao Y, Nelson E, Field M, Ding Q, Li H, Sherrell R, et al. Characterization of atmospheric trace elements on PM_{2.5} particulate matter over the New York–New Jersey harbor estuary. *Atmos Environ*. 2002;36(6):1077–86.
10. Wang X, Sato T, Xing B. Size distribution and anthropogenic sources apportionment of airborne trace metals in Kanazawa. *Japan Chemosphere*. 2006;65(11):2440–8.
11. Zoller WH, Gladney E, Duce RA. Atmospheric concentrations and sources of trace metals at the south pole. *Science*. 1974;183(4121):198–200.
12. Escudero M, Querol X, Pey J, Alastuey A, Pérez N, Ferreira F, et al. A methodology for the quantification of the net African dust load in air quality monitoring networks. *Atmos Environ*. 2007;41(26):5516–24.
13. Khan MS, Zaidi A, Goel R, Musarrat J. Biomangement of metal-contaminated soils. Springer Science & Business Media; 2011.
14. Tchounwou PB, Yedjou CG, Patlolla AK, Sutton DJ. Heavy metal toxicity and the environment. *Molecular, clinical and environmental toxicology*: Springer; 2012. p. 133–64.
15. Chang J, Zhou G, Christensen ER, Heideman R, Chen J. Graphene-based sensors for detection of heavy metals in water: a review. *Anal Bioanal Chem*. 2014;406(16):3957–75.
16. La Colla NS, Domini CE, Marcovecchio JE, Botté SE. Latest approaches on green chemistry preconcentration methods for trace metal determination in seawater—a review. *J Environ Manag*. 2015;151:44–55.
17. Ho KF, Lee SC, Cao JJ, Chow JC, Watson JG, Chan CK. Seasonal variations and mass closure analysis of particulate matter in Hong Kong. *Sci Total Environ*. 2006;355(1–3):276–87. <https://doi.org/10.1016/j.scitotenv.2005.03.013>.
18. Goudie AS, Middleton NJ. Desert dust in the global system. Springer; 2006.
19. Szczepaniak K, Biziuk M. Aspects of the biomonitoring studies using mosses and lichens as indicators of metal pollution. *Environ Res*. 2003;93(3):221–30. [https://doi.org/10.1016/S0013-9351\(03\)00141-5](https://doi.org/10.1016/S0013-9351(03)00141-5).
20. Yin L, Niu Z, Chen X, Chen J, Xu L, Zhang F. Chemical compositions of PM_{2.5} aerosol during haze periods in the mountainous city of Yong'an, China. *J Environ Sci*. 2012;24(7):1225–33.
21. Han G, Gable K, Yan L, Allen MJ, Wilson WH, Moitra P, et al. Expression of a novel marine viral single-chain serine palmitoyltransferase and construction of yeast and mammalian single-chain chimera. *J Biol Chem*. 2006;281(52):39935–42.
22. Kozak Z, Niećko J, Kozak D. Precipitation of heavy metals in the L zna-Włodawa lake region. *Sci Total Environ*. 1993;133(1–2):183–92.
23. Norela S, Nurfatihah M, Maimon A, Ismail B. Wet deposition in the residential area of the Nilai Industrial Park in Negeri Sembilan. *Malaysia World Appl Sci J*. 2009;7:170–9.
24. Momani KA, JIRIES AG, Jaradat QM. Atmospheric deposition of Pb, Zn, Cu, and Cd in Amman, Jordan. *Turk J Chem*. 2000;24(3):231–8.
25. Biglari H, Geravandi S, Mohammadi MJ, Porazmey EJ, Chuturkova RZ, Khaniabadi YO, et al. Relationship between air particulate matter and meteorological parameters. *Fresenius Environ Bull*. 2017;26(6):4047–56.
26. Naddafi K, Nabizadeh R, Soltanianzadeh Z, Ehrampoosh M. Evaluation of Dustfall in the air of Yazd. 2007.
27. Cipurković A, Selimbašić V, Tanjić I, Mičević S, Pelemiš D, Čeliković R. Heavy metals in sedimentary dust in the industrial city of Lukavac. *Eur J Sci Res*. 2011;54(3):347–62.
28. Jaradat QM, Momani KA, Jbarah A-AQ, Massadeh A. Inorganic analysis of dust fall and office dust in an industrial area of Jordan. *Environ Res*. 2004;96(2):139–44.
29. Rout TK, Masto RE, Padhy PK, George J, Ram LC, Maity S. Dust fall and elemental flux in a coal mining area. *J Geochem Explor*. 2014;144:443–55.
30. Yongming H, Peixuan D, Junji C, Posmentier ES. Multivariate analysis of heavy metal contamination in urban dusts of Xi'an, Central China. *Sci Total Environ*. 2006;355(1–3):176–86.
31. Qiao Q, Huang B, Zhang C, Piper JD, Pan Y, Sun Y. Assessment of heavy metal contamination of dustfall in northern China from integrated chemical and magnetic investigation. *Atmos Environ*. 2013;74:182–93.
32. Rasmussen P, Subramanian K, Jessiman B. A multi-element profile of house dust in relation to exterior dust and soils in the city of Ottawa, Canada. *Sci Total Environ*. 2001;267(1–3):125–40.
33. Joshi UM, Vijayaraghavan K, Balasubramanian R. Elemental composition of urban street dusts and their dissolution characteristics in various aqueous media. *Chemosphere*. 2009;77(4):526–33.
34. Gholampour A, Nabizadeh R, Hassanvand MS, Nazmara S, Mahvi AH. Elemental composition of particulate matters around Urmia Lake, Iran. *Toxicol Environ Chem*. 2017;99(1):17–31.
35. Celo V, Dabek-Zlotorzynska E. Concentration and source origin of trace metals in PM_{2.5} collected at selected Canadian sites within the Canadian National air Pollution Surveillance Program. *Urban airborne particulate matter*. Springer; 2011. p. 19–38.
36. Hasheminassab S, Daher N, Saffari A, Wang D, Ostro B, Sioutas C. Spatial and temporal variability of sources of ambient fine particulate matter (PM_{2.5}) in California. *Atmospheric Chemistry and Physics Discussions*. 2014;14(14):20045–81.
37. CHEN B, Kitagawa H, HU K, JIE D, YANG J, Li J. Element and Mineral characterization of dust emission from the saline land at Songnen plain, Northeastern China. *J Environ Sci*. 2009;21(10):1363–70.
38. Lin C-W, Yeh J-F, Kao T-C. Source characterization of total suspended particulate matter near a riverbed in Central Taiwan. *J Hazard Mater*. 2008;157(2):418–22.
39. Han Y, Cao J, Jin Z, An Z. Elemental composition of aerosols in Daihai, a rural area in the front boundary of the summer Asian monsoon. *Atmos Res*. 2009;92(2):229–35.
40. Gao J, Tian H, Cheng K, Lu L, Wang Y, Wu Y, et al. Seasonal and spatial variation of trace elements in multi-size airborne particulate matters of Beijing, China: mass concentration, enrichment characteristics, source apportionment, chemical speciation and bioavailability. *Atmos Environ*. 2014;99:257–65.