Source Identification of Urban dust Heavy Metals Using in Situ and Satellite Data in Three Mega Cities of Iran

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Abstract

The aim of this study was an integrative assessment of heavy metals associated with urban dust data in Iran (Ahvaz, Isfahan, and Shiraz). Samples of urban dust from four sites (traffic, industrial, residential, and Greenland) were collected, and ten heavy metal concentrations were determined using ICP_MS in each sample. The highest average concentrations of metals were at the traffic site for the Mn, Zn, and Cr metals. The PMF model indicates a higher percentage of Pb participation, which shows the importance of traffic resources. The highest non-carcinogenic risk (HI) was for the Cr and the carcinogenic risk was tolerable. To evaluate aerosol and its effects on urban dust, Aerosol Optical Depth (AOD) data were used during 2003–2023. According to the Mankendall test, the trend of AOD has been increasing in Esfahan (p_value < 0.05) and Shiraz. Although Ahvaz's AOD is about two times greater than other cities, the aerosol trend in Ahvaz is decreasing.

Keywords Dust · Heavy metals · Health risk assessment · Sources apportionment · Aerosol optical depth

Introduction

Today, the assessment and identification of environmental pollutants are important because of their dangerous effects on human health and the quality of the urban environment (Alvan et al. 2023; Chang and Li 2020; Mohammad Asgari et al. 2023; Sadouni et al. 2023). Pollutants such as heavy metals can enter the ecosystem through atmospheric dust, especially in urban areas, and accumulation in the dust of road (Hovmand et al. 2008; Tang and Han 2017; Zheng et al. 2010). The high concentration of heavy metals in airborne dust has been reported in previous studies (Behrooz et al. 2021; MalAmiri et al. 2022). Since urban dust acts as a temporary sink of pollution through various sources, and in the case of the re-suspension of materials, it also plays an effective role as a source of pollution. Global coverage and short revisit times of MODIS Terra and Aqua with high spatial, temporal, spectral, and radiometric resolutions provide a very good opportunity to assess aerosols. (Behera et al. 2021; Safarianzengir et al. 2020). The innovation of this research is the simultaneous use of in situ heavy metal measurement and satellite data. AOD as the most important source of urban dust, encompasses various aerosols, especially dust particles, in the studied cities. The other air pollutants like O3, SO2, NO2, CO, and CO2 are negligible, according to the Air Quality Index (AQI) reported by environmental organizations (https://aqms.doe.ir/).This integration helps to use the advantage of near-real-time satellite data with global coverage to solve the limitation of ground-based observation for accurate heavy metal pollution monitoring. The main objectives of this study are: 1-Investigating the difference in the average concentration of metals in urban dust between Ahvaz, Esfahan, and Shiraz; 2- Investigate the level of pollution and identify sources of pollution for each metal (natural or human) using the PMF model; 3-Assessing carcinogenic and non-carcinogenic health risks through three pathways: ingestion, inhalation, and dermal; 4- Investigating the relationship between aerosols and urban dust using satellite data.

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Materials and Methods

The concentration of heavy metals in urban dust in Ahvaz, Esfahan, and Shiraz was compared in this study, and the variables influencing their variations, such as industry, traffic, population density, and natural dust, were examined. Table 1 lists each of their attributes.

Sampling

36 samples of urban dust with an amount of about 200 gr (for each sample) were collected from each city of Ahvaz, Esfahan, and Shiraz. Samples were collected from four industrial, high-traffic, residential-recreational, and Green-land sites in August-September 2020. we use plastic broom and dustpan to collect the road dust without using any metal devices. plastic hand broom was frequently used in previous studies to collect road dust (Mihankhah et al. 2020; Nazar-pour et al. 2019) because plastic brooms do not affect heavy metals. We collect samples from a section with a 2 m*m area using a random systematic method to determine the location of each sample. The first location was randomly selected, and the other sample was collected at equal intervals. Sampling was carried out in the summer without rain (to prevent of washing) in cities with the highest dust levels. In order to match the size of the particles with the size of the dust particles, the finest particles with the highest level of heavy metals must be considered. So, we passed the samples through a 325-mesh sieve (45 micrometers) in the lab. Heavy metal concentrations were determined using inductively coupled plasma mass spectrometry (ICP_MS) in the Zar Azma laboratory in Tehran, Iran.

In order to evaluate quality control reagent blanks, analytical duplicates, and examination of the standard reference material (SRM-Montana I SRM-2710) (multi-element soil standard OREAS45EA and OREAS24P) were carried out. There is good agreement between the measured and certified values, as seen by the mean recovery rate of almost 92–108%. To determine precision, Relative standard deviation (RSD < 5%) was calculated.

Statistical Analysis

On the metal concentration, descriptive statistics (mean, minimum, maximum, skewness, standard deviation, and median) were run. Using Pearson correlation, the link between the heavy metal concentrations in each city was discovered in order to pinpoint any potential heavy metal sources. Using the ANOVA test, significant differences in the mean heavy metal concentrations in the several study regions (sites) were identified at a 95% level of significance.

Source Apportionment by PMF Model

One of the ways to reduce and control heavy metal pollution in dust is to identify quantitatively and accurately potential sources of metals (Fei et al. 2020; Huang et al. 2018). The PMF model is an ideal method recommended by the EPA. This model decomposes the sample data matrix into two participation matrices and the factor profile matrix according to the observations at the sampling site (Liu et al. 2017; Paatero 2000).

Human Health risk Assessment

Human health risk assessment model for exposure to heavy metals in road dust (As, Cr, Cd, Cu, V, Zn, and Pb) by the US Environmental Protection Agency (EPA) (US EPA, 1996) and the National Health Organization General and Environmental Protection of the Netherlands (Van den Berg 1994) as well as technical guidelines for risk assessment of polluted areas (PRC 2014) are provided. Carcinogenic and non-carcinogenic risk assessments are performed by calculating the exposure dose for the three possible routes mentioned.

The CR index is used to assess the risk of carcinogenicity in the lifetime of individuals due to exposure to heavy metals with carcinogenicity, which calculates the risk of exposure. Considering that the metals As, Ni, Cd, and Cr and their compounds are carcinogenic according to IARC guidelines (IARC 2012) and EPA standards.

Table 1 Meteorological characteristics of the studied areas (Ahvaz, Esfahan and Shiraz)

City	Climate	Height of see level (m)	Temperature (°C)	Population	Rainfall (mm)	Number of dusty days	Industry	Dominant Wind Direction
Ahvaz	Hot and dry	12	26.3	1,184,788	202.5	98	medium	NorthEast
Esfahan	Desert, cold and dry	1571	16.4	2,961,211	127	62	heavy	NorthEast
Shiraz	Temperate	1480~1670	18	1,565,572	297.22	56	light	NorthWest

Google Earth Engine and AOD Data

The MCD19A2 V6 data product is a MODIS Terra and Aqua Combined Multi-Angle Implementation of Atmospheric Correction (MAIAC) Land Aerosol Optical Depth (AOD) gridded Level 2 product produced daily at 1 km resolution. The daily AOD data was extracted from Google Earth Engine during 2003–2023 for the three studied cities. For time series trend analysis, mean monthly and mean yearly were calculated, and to compare means for cities, ANOVA and post-hoc tests were used.

Result and Discussion

Statistical Analysis Results

Using the Kolmogorov-Smirnov test, the normal distribution of the data was investigated. The average concentrations of heavy metals in 4 different sites in urban dust in the three megacities of Ahvaz, Esfahan, and Shiraz are given in Fig. 1.

According to the findings, when compared to other heavy metals, Mn, Zn, and Cr had the greatest quantities, while Cd and Co had the lowest concentrations. At the traffic site, the average concentrations of all metals were higher in all three cities. With the exception of Ni and Cr metals, the cities of Ahvaz and Esfahan exhibited greater heavy metal average concentrations than Shiraz in most sites. There was a substantial variation in the concentrations of most metals in the three cities, according to a comparison of the differences between the concentrations of heavy metals in the cities and at each site.

Compared to the rest of the Middle East, Ahvaz City's average Cr content is greater. Compared to previous research conducted in Esfahan, this study's average Cr content in Esfahan was greater (Soltani et al. 2015). Shiraz has a greater content of Cr than was found in the 2015 research by (Keshavarzi et al. 2015).

A Pearson correlation coefficient for metals was performed to determine possible common sources. In **Ahvaz**, there was a significant positive correlation between Ni-Co (0.954), Zn-Co (0.624), Pb-Cr (0.691), Zn-Cr (0.529), V-Pb (0.858), Zn-Pb (0.780), and Zn- V (0.590). This relationship indicates the existence of possible common human resources between Zn, Ni, Co, Pb, Cr, and V metals. The significant mean correlation between Mn-Cd (0.560) indicates a similar and common human source of cadmium and manganese. On the other hand, there is a significant negative relationship between Ni-Mn (-0.667). In **Esfahan**, a significant positive correlation was observed between Pb-Cr (0.852), Mn-Cr (0.540), Zn-Cr (0.569), Pb-Cu (0.575), Zn-Cu (0.760), and Zn-Pb (0.707). This relationship indicates a possible common human source of Pb, Cr, Mn, Zn, and Cu metals. A strong, significant positive correlation between Ni-Co (0.973) indicates the possibility of similarity between the human sources of nickel and cobalt. In **Shiraz**, there was a significant positive correlation between Co-As (0.752), Ni-As (0.558), Ni-Co (0.852), Zn-Co (0.864), Cu-Cr (0.661), Pb-Cr (0.787), Ni-Cu (0.549), Zn-Ni (0.694), and Zn-Pb (0.554) were observed. Therefore, the As, Co, Ni, Zn, Cu, Cr, and Pb metals may have similar human resources (due to industrial activities and road traffic). Manganese had a strong positive relationship only with vanadium (0.917).

PMF Model Results

Another way of dividing and determining sources of heavy metals is the PMF model. In this study, for all three cities, the number of runs was 20 and the number of factors was 3. The results of the model showed that in Ahvaz City, factor 1 with 50.63% is the most effective factor. This factor included a heavy load of Pb (100%) and a medium load of Zn (84.72%) and Cu (75.69%). Due to the fact that Pb is from traffic and its concentration was higher than the background value, the main source of lead pollution, and therefore factor 1, is probably humans and traffic. Factor 2, with 32.16% of the total participation, primarily included a high load of Cr (71.6%), Ni (62.37%), and Co (48.22%). On the other hand, the concentration of Cr and Ni was higher than the background value. Chromium is also the result of oil exploration and is present in drilling mud. Therefore,
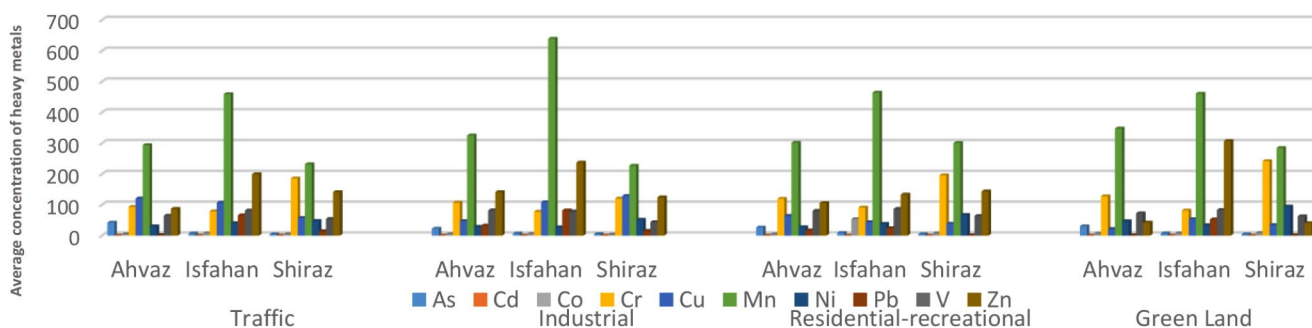

Fig. 1 Average concentration of heavy metals in different land uses in each city

factor 2 can be considered to be derived from industrial sources such as oil exploration and drilling mud. On the other hand, factor 3, with 20.44% participation, included a heavy load of As (75.36%). Since, As is often from a terrestrial source, factor 3 is probably of natural origin, such as dust or soil. In Isfahan, the highest metal load in factor 1, which includes 31.02% of the total participation, was related to Cr (73.82%) and Ni (72.36%). The concentration of Ni and Cr metals was higher than the amount of crust. So this factor is probably of human origin, such as industry. Factor 2, with 25.67% of the total participation, had a heavy load of As (90.97%) and a medium load of Cd (39.01%) and V (29.12%). Because these metals were less concentrated than the Earth's crust, factor 2 is probably of natural origin, such as soil raw materials. Factor 3 had the highest participation rate at 43.30%. This factor included a heavy load of Pb (100%) and a medium load of Zn (83.97%) and Cu (73.17%). Given that lead plays a major role in traffic pollution, the source of factor 3 may be traffic. In Shiraz, factor 1, with 29.41% of the total participation, had primarily a heavy load of Cr (73.55%) and Ni (65.06%). These metals are often emitted from industries such as metal plating, so factor 1 is likely to be of human and industrial origin. Factor 2, with 19.23%, had the highest load related to As (87.86%). Arsenic is often of natural origin and is found in the earth's crust. So, factor 2 is probably of natural origin. The highest percentage of participation in Shiraz was related to factor 3, with 51.34%. The highest loads were observed in Pb (100%), Zn (83.87%), and Cu (76.45%). Lead, copper, and

zinc metals are often emitted from traffic sources, thus being a possible source of human factor 3 and originating from road traffic (Fig. 2).

Human Health Risk Assessment Results

All metals in the three regions showed high levels of Hazard Quotient (HQ) from the dermal and ingestion pathways, except Co, which had the highest levels of HQ_{ing} and HQ_{inh}. In this study, the highest amount of hazard index (HI) was observed in Cr > As > Cd > Ni and the lowest amount of HI was observed in Co, Cu, Zn, and Pb metals. The highest non-cancer risk was observed in Shiraz, Ahvaz, and Esfahan, respectively, and for Cr metal in children (HI_{Shiraz} > HI_{Ahvaz} > $HI_{Esfahan}$). The HI value for all metals was below the threshold of 1, except for arsenic in Ahvaz and in the Esfahan for children and Cr metal in all 3 cities. The highest amount of HI_{As} was in the traffic site of Ahvaz (6.80) and HI_{Cr} in the greenland of Shiraz (84.95). Other metals Cd, Co, (Cu, Mn, Ni, Pb, V, and Zn) did not pose a non-carcinogenic health risk. The non-cancer risk of HI was higher in children than in adults due to its susceptibility to infection.

The results of carcinogenic hazards due to exposure to As, Cd, Cr, and Ni metals is shown in Table 2. The level of carcinogenic risk is obtained by calculating the LADD lifetime of the average daily dose received in the slope factor (SF) of cancer risk. The highest risk of cancer was in Shiraz and for Cr (5.1E-06). Cr metal was in the tolerable/
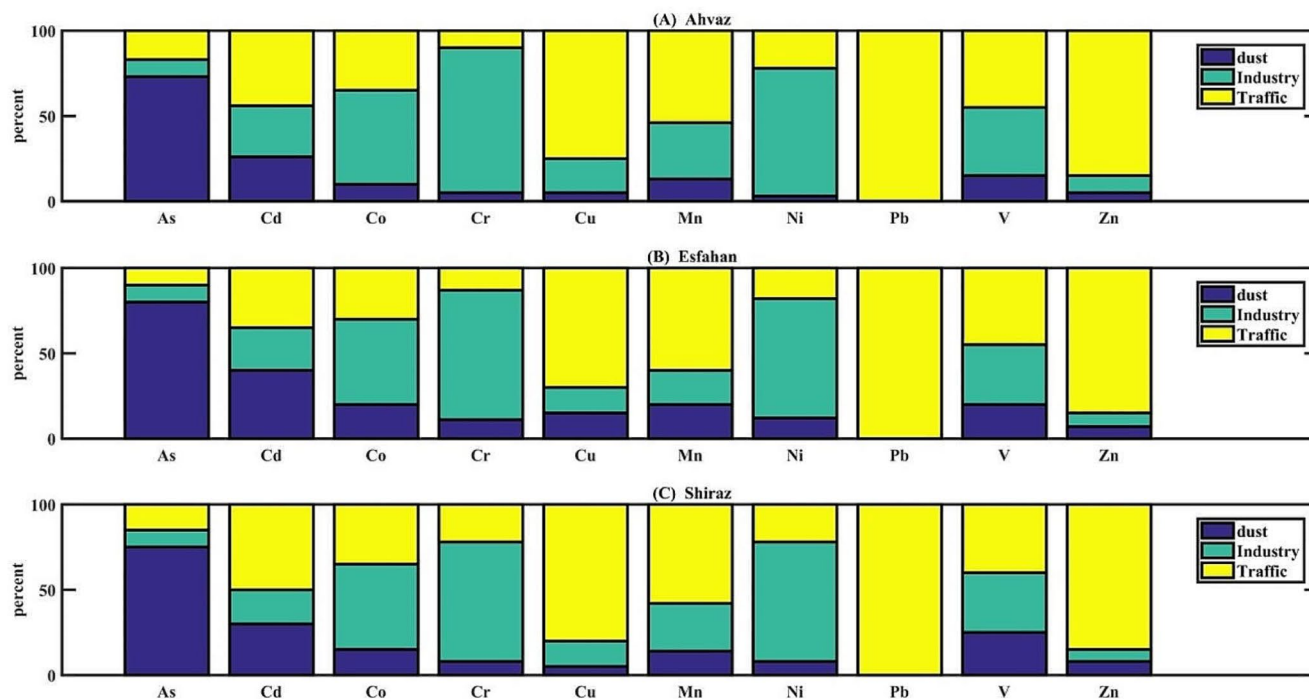

Fig. 2 Percentage of species for each factor of different source in Ahvaz, Esfahan and Shiraz

Table 2 Carcinogen elemental cancer risk of different sites in Ahvaz, Esfahan and Shiraz

| Site	Heavy metals	Industrial		Traffic		Residential-recreational		Greenland	
		$LADD_{inh}$	CR	$LADD_{inh}$	CR	$LADD_{inh}$	CR	$LADD_{inh}$	CR
Ahvaz									
	As	1.1E-08	1.7E-07	2.15E-08	3.24E-07	1.3E-08	2E-07	1.6E-08	2.3E-07
	Cd	5.3E-011	3.2E-10	8.56E-11	5.4E-10	5.13E-11	3.2E-10	5.12E-11	3.2E-10
	Cr	4.14E-08	**2.3E-06**	4.71E-08	**2E-06**	6.03E-08	**2.5E-06**	6.43E-08	**2.7E-06**
	Ni	1.41E-08	1.2E-08	1.49E-08	1.3E-08	1.34E-08	1.1E-08	2.32E-08	2E-08
Esfahan									
	As	3.28E-09	5E-08	3.28E-09	5E-08	4.46E-09	6.7E-08	3.52E-09	.3E-08
	Cd	4.91E-11	3.1E-10	4.58E-11	2.9E-10	4.59E-11	2.9E-10	8.46E-11	5.3E-10
	Cr	4.56E-11	**1.9E-06**	3.95E-08	**1.7E-06**	3.88E-08	**1.6E-06**	4.07E-08	**1.7E-06**
	Ni	1.31E-08	1.1E-08	1.98E-08	1.7E-08	1.89E-08	1.6E-08	1.66E-08	1.4E-08
Shiraz									
	As	2.49E-09	3.08E-08	1.98E-09	3E-08	2.33E-09	3.5E-08	1.99E-09	3.01E-08
	Cd	6.30E-11	4E-10	3.74E-11	2.4E-10	2.81E-11	1.8E-10	4.6E-11	2.9E-10
	Cr	6.4E-08	**2.5E-06**	9.33E-08	**3.9E-06**	9.85E-08	**4.1E-06**	1.22E-07	**5.1E-06**
	Ni	2.54E-08	2.1E-08	2.36E-08	2E-08	3.32E-08	2.8E08	4.66E-08	3.9E-08
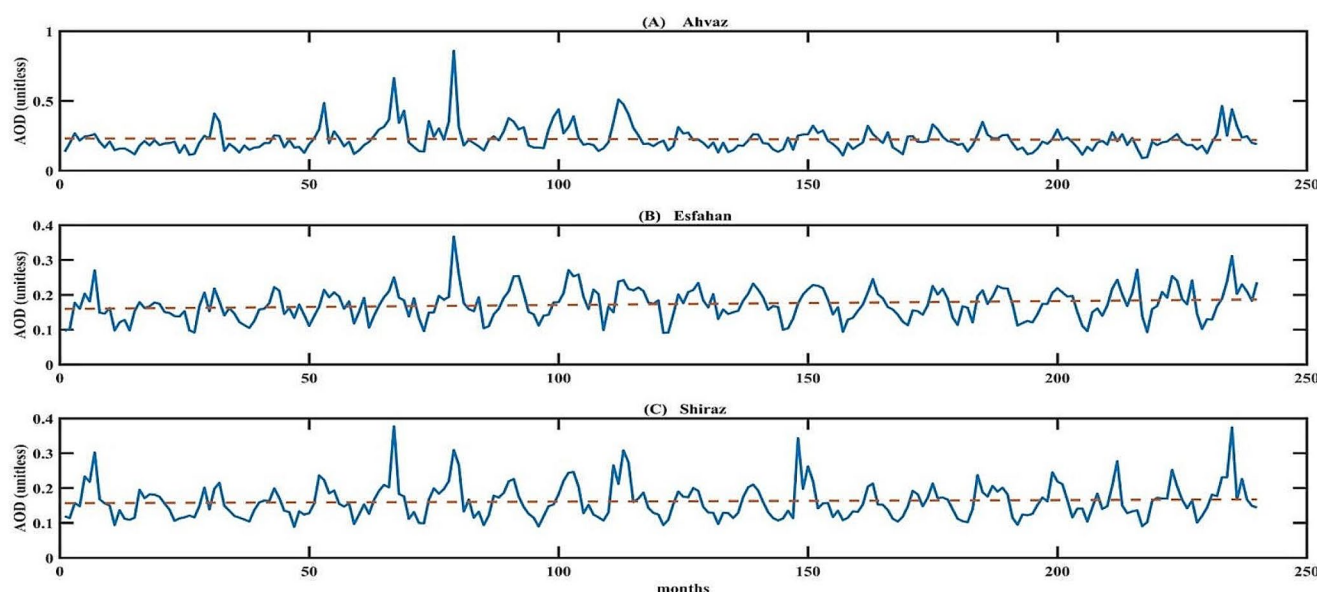
Fig. 3 Mean monthly AOD time series in each city during 2003–2023

permissible range (1E-06~1E-04) for cancer risk in all cities. But the carcinogenic health risks for nickel, cadmium, and arsenic in all three cities and different sites were negligible (< 1E-06). In general, in the three cities, the risk of cancer in metals had a decreasing trend of Cr > As > Ni > Cd.

Satellite Aerosol Monitoring Results

Over the examined cities between 2003 and 2023, the MCD19A2 V6 data product was used to assess aerosol concentration. The MCD19A2 V6 data product is a daily, 1 km-resolution, combined MODIS Terra and Aqua Multi-angle Implementation of Atmospheric Correction (MAIAC) Land Aerosol Optical Depth (AOD) gridded Level 2 product. Figure 3 depicts the mean monthly AOD time series for

the cities of Ahvaz, Isfahan, and Shiraz from 2003 to 2023, while Fig. 4 depicts the mean annual AOD data for the cities under study from 2003. The results of the ANOVA test for the mean comparison of pollution in cities showed that there is a notable difference between the AOD in cities. In contrast to the other two cities, Ahvaz has different levels of AOD, according to the post-hoc test. The trend of time series data was examined using the Mankendall and Sen Slope tests. Figure 4; Table 3 show that the AOD trend has been rising in Esfahan (significant, p_value 0.05) and Shiraz but declining in Ahvaz. The recent increase in precipitation and flooding in the province of Khuzestan, as well as the decline in the activity of dust sources in this area, may be the cause of the declining trend in AOD in Ahvaz. It follows from this section that there has been an increase in both natural and
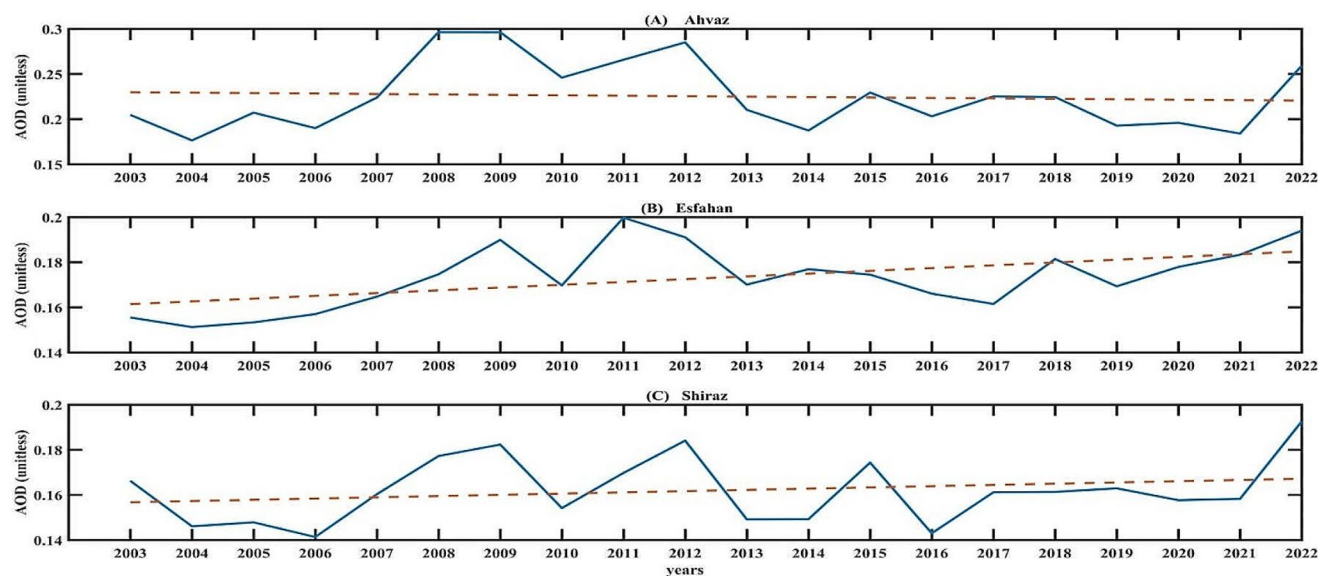
Fig. 4 Mean yearly AOD time series in each city during 2003–2023

Table 3 Represent Mankendall Z and Sen slope value

	Ahvaz_monthly	Ahvaz _yearly	Esfahan_monthly	Esfahan _yearly	Shiraz_monthly	Shiraz _yearly
Mankendall _Z	0.00	-0.42	3.21	1.82	1.30	0.49
Sen_Slope	0E+00	-5E-04	1E-04	1E-03	6E-05	4E-04

artificial sources of urban dust in Esfahan and Shiraz. This finding supports rising levels of heavy metals in urban dust and their detrimental consequences for human health.

Conclusion

This study focuses on a comparative assessment of urban dust heavy metals among three megacities in Iran. Four different sites were considered for urban dust sampling in each city. Our findings demonstrate that there are significant differences between heavy metal concentrations among sites and cities. These differences may originate from different conditions of climate, population, industry, and traffic in cities. The non-cancer (HI) risk of metals for Cr was higher for children (HI_{Shiraz}> HI_{Ahvaz}> $HI_{Esfahan}$). The risk of cancer was also generally tolerable or insignificant in the study areas. Pearson correlation and the PMF model were used to identify potential sources of metals. The PMF model for all three cities showed that the factor with a 100% load was more effective for lead. That is, the main source of metal pollution in all three cities originates from road traffic and car friction. To evaluate aerosols and their effects on urban dust, MODIS AOD data were used in the studied cities during 2003–2023. Results show that Ahvaz has higher levels of aerosol than other cities. Based on the Mankendall and Sen Slope tests, the trend of aerosol (AOD) has been

increasing in Esfahan and Shiraz, except in Ahvaz. The decreasing trend of AOD in Ahvaz may be due to high precipitation, flooding, and reducing dust sources activities in this area. The comparison of heavy metals in the current study with other studies in Isfahan and Shiraz confirms that the trend of heavy metals is increasing. Therefore, it is concluded that the natural and anthropogenic sources of urban dust in these cities have been increasing. This result confirms that the levels of heavy metals in urban dust and their harmful effects on human health have been increasing in Esfahan and Shiraz. This result helps district managers identify infected areas and make correct and serious decisions to confront them.

Author Contributions Zahra Mansouri and Ali Azhdari conducted the experiments and data curation, Zahra Mansouri analyzed the results. Zahra Mansouri, Hossein mohammad Asgari, Majid Heidari and Sedigheh Battaleb-Looie reviewed and edited the manuscript, Hossein mohammad Asgari and Zahra Mansouri designed the study. All authors read and approved the final manuscript.

Data Availability The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

"All authors have read, understood, and have complied as applicable with the statement on "Ethical responsibilities of Authors" as found in the Instructions for Authors and are aware that with minor exceptions, no changes can be made to authorship once the paper is submitted."

Ethical Approval Not applicable.

Consent to Participate Not applicable.

Consent to Publish Not applicable.

Competing Interests The authors declare that they have no competing interests.

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