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Ecotoxicological risk of polycyclic aromatic hydrocarbons (PAHs) in urban soil of Isfahan metropolis, Iran

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Abstract Concentration, distribution, probable sources, and health risks of 16 polycyclic aromatic hydrocarbons (PAHs) were investigated in 52 soil samples collected within a radius 50 km from Isfahan metropolis center. Total concentration of PAHs ranged from 57.70 to 11,730.08 μg/kg averaging 2,000.56 μg/kg. Spatial PAH profiles were site-specific and higher concentration of PAHs was observed in the vicinity of industrial zones within Isfahan metropolis. The molecular indices, ring classes, and principal component analysis indicated that the sources of PAHs were both geogenic and pyrogenic. The incremental lifetime cancer risks of exposure to soil PAHs for adults and children living in the study area were 2.3×10^{-2} and 2.2×10^{-3}, respectively. The results suggest that current PAHs levels in Isfahan metropolis soil are highly carcinogenic and may hold a serious health risk for local resident.

Keywords Polycyclic aromatic hydrocarbons (PAHs) · Ecotoxicological risk · Soil contamination · Source apportionment · Isomer ration · Incremental lifetime cancer risks (ILCRs)

Introduction

Toxic organic compounds in the environment originate from different geogenic, biogenic, and anthropogenic sources (Lewis and Pryor 2013). Growing population, industrialization, and global urbanization considerably increase anthropogenic environmental pollution (Qasim and Mane 2013). Surface and ground water, sediments, and topsoil pollution by effluents containing burned and unburned petroleum products (mainly from automobile exhausts) pose a serious threat to human and aquatic/terrestrial organisms. Exposure to some of these compounds such as polycyclic aromatic hydrocarbons (PAHs) can potentially lead to several health-related problems including irritation of the eyes, mucous membranes, and skin, to weakened nervous system, reduced bone marrow function, and different types of cancers (Costa et al. 2012; Yu et al. 2014; Jiao et al. 2013).

Based on the chemical structure and physiochemical properties, total petroleum hydrocarbons (TPHs) are divided into two main classes, i. e., aliphatic and

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aromatic. These organic compounds contain both ring (including PAHs) and non-ring hydrocarbons, heavy metals, sulfur, and nitrogen compounds (Abdollahi et al. 2013; Zhang et al. 2012).

PAHs have two to six benzene rings in linear, cluster, and angular arrangement. These compounds are divided into high molecular weight (HMW) compounds containing four to six combined rings, like dibenz[a,h]anthracene, and low molecular weight (LMW) compounds with two or three benzene rings, like naphthalene (Abdollahi et al. 2013; Tolosa et al. 2005). The carcinogenicity of several high molecular weight PAHs to human and animals implies that chronic exposure creates significant harm to ecosystem inhabitants (Saito et al. 2010).

PAHs sources include incomplete organic matter combustion (pyrolytic origin), spills of petroleum products from petrochemical plants or natural oil leakage (petrogenic origin), and finally via natural precursor transformations during early diagenesis processes (diagenetic origin) (Abdollahi et al. 2013; Cardellicchio et al. 2006; Grova et al. 2002; Tam et al. 2001; Cheney et al. 2009; Valavanidis et al. 2008).

Isfahan metropolis is an urbanized and industrialized city in Iran. During the last few decades, rapid urbanization, economic development, and population growth are leading to environmental contaminations. Industrial plants emissions, foundries, gas stations, terminals, and emissions from vehicles are the main sources of PAHs in Isfahan metropolis.

The present study aims to determine the concentration, distribution, potential toxicity, and probable sources of PAHs in soil within 50 km of Isfahan metropolis center, considering its recent industrialization and urbanization.

Materials and methods

Geological setting and sampling

The study area (50 km from the center of Isfahan metropolis), with a total surface area of 7,850 km^2, is located between 51°8′ to 52°12′E and 32°11′ to 33°6′ N (Fig. 1). The northern, eastern, and central parts generally experience a hot and dry climate, while the western part practices a semi-humid climate and the climate of southern part is semi-arid.

Based on a tectono-sedimentary classification, Isfahan Province comprises parts of central Iran, Orumiye-Bazman magmatic arc, Sanandaj-Sirjan, and Zagros thrust belt (Ghorbani 2013). As shown in Fig. 1c, the study area is characterized by complex geology with widely distributed Quaternary unconsolidated alluvial sediments, Cretaceous conglomerate, sandstone, orbitolina-bearing limestone and shale deposition in south and center, Cretaceous gray limestone and Tertiary gray shale in northwest, and Miocene gypsum marl to the east.

In this study, the soil was divided into three categories, i.e., agricultural, industrial, and urban. In March 2012, 52 topsoil (1–5 cm deep) samples were collected from different areas of the study area and immediately placed in a glass container previously washed with soapy water, rinsed with distilled water, and then left to dry. The dried containers were then washed with *n*-hexane and dried in an oven at 180 C for 3 h, and finally screw aluminum foil caps were used to provide a gas-tight seal. Samples were stored at 4 °C in a cool box in order to minimize microbial degradation during transport to laboratory.

Sample extraction

All samples were freeze-dried before analysis. An ultrasonic bath (KUDOS, SK3210LHC model) was used during the extraction. Approximately 5 g of each freeze-dried samples was spiked with surrogate standards (Pyrene-D10, lot: 10510 semivolatile internal standard). The samples were then extracted using a 30-mL mixture of organic solvents (*n*-hexane and dichloromethane [DCM] in a 1:1 *v/v*) for 30 min at room temperature. The filtered extracts were concentrated to 2 mL by using amorphous sodium sulfate. The last fraction was then analyzed for 16 PAHs (naphthalene (Nap), acenaphthylene (Acy), acenaphthene (Ace), fluorene (Flu), phenanthrene (Phe), anthracene (Ant), fluoranthene (Fla), pyrene (Pyr), benzo[a]anthracene (BaA), chrysene (Chr), benzo[b]fluoranthene (BbF), benzo[k]fluoranthene (BkF), benzo[a]pyrene (BaP), benzo[ghi]perylene (BghiP), indeno(1,2,3cd) pyrene (IP), and dibenz[a,h]anthracene (DahA)) commonly determined in environmental investigations using gas chromatography/mass spectrometry (Agilent 6890N GC, 5975C mass selective detector (MSD), USA) equipped with an HP-5MS Capillary column (30 m× 0.32 mm×0.25 μm, Agilent, USA) in selected-ion monitoring (SIM) mode. The carrier gas was helium at a flow rate of 1.5 mL/min. Oven temperature was initially set at 60 C (1-min hold) and increased to 295 C at a rate of 11 C/min (5-min hold). Mass spectral data, retention

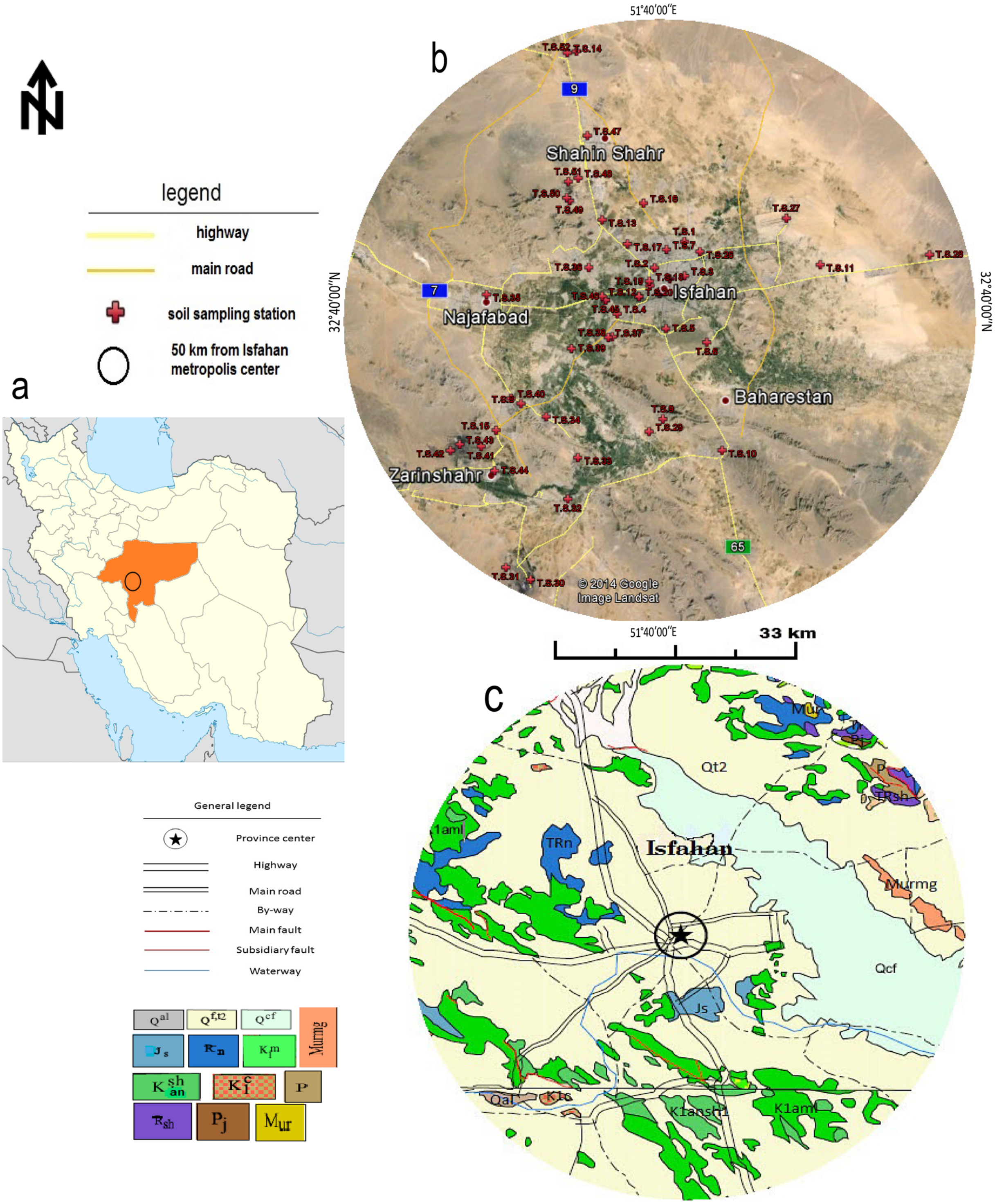

Fig. 1 **a** Study area; **b** sampling stations within 50 km from Isfahan metropolis center; and **c** geological map of the study area. Q^{t2} recent terraces; Q^{cf} argillaceous flats; Q^{al} flood plains; *Murmg* gypsiferous marls; *Js* shale containing conglomerate, sandstone, radiolarite and limestone; *TRn* quartzarenite, shale, and limestone; K_l^m gray limestone containing orbitolina and ammonites; K_{an}^{sh} gray limestone containing orbitolinas and ammonites; K_l^c red conglomerate and sandstone; *TRsh* dolomite; P_j limestone and dolomite; M_{ur} sandstone, gypsic marl, siltstone, and shale; *P* undifferentiated Permian rocks

Table 1 Parameters used in the incremental lifetime cancer risk assessment

Exposure variables	Unit	Child		Adult		References
		Male	Female	Male	Female	
Body weight (BW)	kg	18.6	16.5	71.6	53.1	Jiao et al. (2013); USEPA (2011)
Exposure frequency (EF)	day/year	350	350	350	350	Yu et al. (2014); Jiao et al. (2013)
Exposure duration (ED)	year	6	6	30	30	Jiao et al. (2013)
Inhalation rate (IR_{air})	m^3/day	10.9	10.9	17.5	17.5	Jiao et al. (2013)
Soil intake rate (IR_{soil})	mg/day	200	200	100	100	USEPA (2011); Yu et al. (2014); Jiao et al. (2013); Chen et al. (2013)
Dermal surface exposure (SA)	cm^2/day	2,000	2,000	5,800	5,800	USEPA (2011)
Dermal adherence factor (AF)	mg/cm^2	0.25	0.25	1	1	USEPA (2011); Chen et al. (2013)
Dermal adsorption fraction (ABS)	Dimensionless	0.13	0.13	0.13	0.13	USEPA (2011); Yu et al. (2014); Chen et al. (2013)
Dermal exposure ration to soil (FE)	Dimensionless	0.61	0.61	0.61	0.61	Jiao et al. (2013)
Average life span (AT)	Day	25,550	25,550	25,550	25,550	USEPA (2011); Yu et al. (2014); Jiao et al. (2013); Chen et al. (2013)
Soil dust produce factor (PEF)	m^3/kg	1.36×10^9	1.36×10^9	1.36×10^9	1.36×10^9	USEPA (2011); Yu et al. (2014); Chen et al. (2013)

times, and peak areas of the calibration standards according to USEPA Methods 8270D and 3550C, 2007, were used for quantification of PAHs.

Quality control and quality assurance

All analytical data were subjected to strict quality control procedures to ensure the accuracy and precision of the analyses. The spiked blanks (standards spiked into solvent), matrix spikes, matrix blank, procedural blanks (solvent), and sample duplicates were routinely analyzed with field samples and the PAHs concentrations in the soils were corrected accordingly. The average recoveries based on surrogate deuterated PAHs were approximately 78–105 % for the 16 measured PAHs.

Table 2 Descriptive statistics of PAHs in Isfahan metropolis soil (μg/kg)

Descriptive statistics *N*=52 PAH types	Range	Minimum	Maximum	Mean	STD. deviation	Variance	Skewness
Naphthalen	1,015.97	0.17	1,016.14	48.11	148.02	21,918.2	5.838
Acenaphthylene	509.02	0.04	509.06	36.15	91.01	8,297.2	3.705
Acenaphthene	187.97	0.02	187.99	23.88	46.01	2,116.57	2.588
Fluorene	608.26	0.07	608.33	70.54	139.76	19,532.96	2.686
Phenanthrene	3,461.24	3.02	3,464.26	343.75	616.54	380,122.06	3.456
Anthracene	5,024.09	0.02	5,024.11	155.10	710.32	504,551.01	6.614
Fluoranthene	2,438.16	1.15	2,439.31	404.55	556.63	309,836.82	2.305
Pyrene	2,788.85	0.36	2,789.21	503.48	653.78	427,435.90	2.067
Benzo[a]anthracene	2,088.03	0.02	2,088.05	86.95	307.28	94,419.77	5.94
Chrysene	3,345.72	0.02	3,345.74	216.97	565.32	319,591.61	4.544
Benzo[b+K]fluoranthene	1,415.09	0.02	1,415.11	63.94	220.18	48,480.60	5.362
Benzo[a]pyrene	552.86	0.13	552.99	47.15	102.79	10,565.51	4.389
ΣPAHs	11,672.38	57.70	11,730.08	2,000.56	2,787.49	7,770,124.8	2.154

Table 3 Characteristic PAH molecular diagnostic ratios (Kanzari et al. 2014; Wang et al. 2010; Zhang et al. 2013)

	Petrogenic	Pyrogenic
Ant/(Ant+Phe)	Petroleum (<0.1)	Petroleum, biomass, and coal combustion (>0.1)
Fla/(Fla+Pyr)	Petroleum (<0.4)	Petroleum combustion (0.4–0.5)
		Biomass and coal combustion (>0.5)
BaA/(BaA+Chr)	Petroleum (<0.2)	Petroleum combustion (0.2–035)
		Biomass and coal combustion (>0.35)
BaA/Chr	<0.4	>0.4
LMW/HMW	>1	<1
	Fuel combustion	Grass/coal/wood combustion
Fla/(Fla+Pyr)	0.4–0.5	>0.5

Data analysis

Statistical analysis was carried out using SPSS 21.0 software. Minimum, maximum, mean, standard deviation, variance, and skewness of PAHs were calculated using descriptive statistics. Principal component analysis was used to reduce dimension of multivariate problems and also diagnostic ratios, e.g., LMW/HMW, Ant/(Ant+Phe), Fla/(Fla+Pyr), and BaA/(BaA+Chr) were measured to diagnose PAHs sources.

Ecotoxicological risk assessment

Toxic equivalency factor (TEF) is defined as the carcinogenic potency of the individual PAHs relative to BaP. Toxicity equivalence (TEQ) was calculated using the following equation:

$$TEQ = \sum C_n \times \mathrm{TEF}_n$$

Where C_n is the concentration of each PAH in sample and TEF_n is toxic equivalency factor for that PAH (Yu et al. 2014). Kriging interpolation method was used to analyze the spatial distributions of TEQ values using Golden Surfer 10 software package.

Incremental lifetime cancer risks (ILCRs) associated with exposure to PAHs in soils were evaluated following USEPA standard model (USEPA 1991; Yu et al. 2014; Jiao et al. 2013; Chen et al. 2013). The cancer risk was assessed based on exposure routes, i.e., direct ingestion, dermal contact, and inhalation exposure considering land use pattern over the entire lifetime using the following equations: (Yu et al. 2014; Jiao et al. 2013; Chen et al. 2013).

$$ILCR_{Singestion} = \frac{\mathrm{CS} \times \left(\mathrm{CSF}_{ingenstion} \times \sqrt[3]{\left(\frac{\mathrm{BW}}{70}\right)}\right) \times \mathrm{IR_{soil}} \times \mathrm{EF} \times \mathrm{ED}}{\mathrm{BW} \times \mathrm{AT} \times 10^6}$$

$$ILCR_{Sdermal} = \frac{\mathrm{CS} \times \left(\mathrm{CSF_{dermal}} \times \sqrt[3]{\left(\frac{\mathrm{BW}}{70}\right)}\right) \times \mathrm{SA} \times \mathrm{EF} \times \mathrm{AF} \times \mathrm{ABS} \times \mathrm{FE} \times \mathrm{ED}}{\mathrm{BW} \times \mathrm{AT} \times 10^6}$$

$$ILCR_{Sinhalation} = \frac{\mathrm{CS} \times \left(\mathrm{CSF_{inhalation}} \times \sqrt[3]{\left(\frac{\mathrm{BW}}{70}\right)}\right) \times \mathrm{IR_{air}} \times \mathrm{EF} \times \mathrm{ED}}{\mathrm{BW} \times \mathrm{AT} \times \mathrm{PEF}}$$

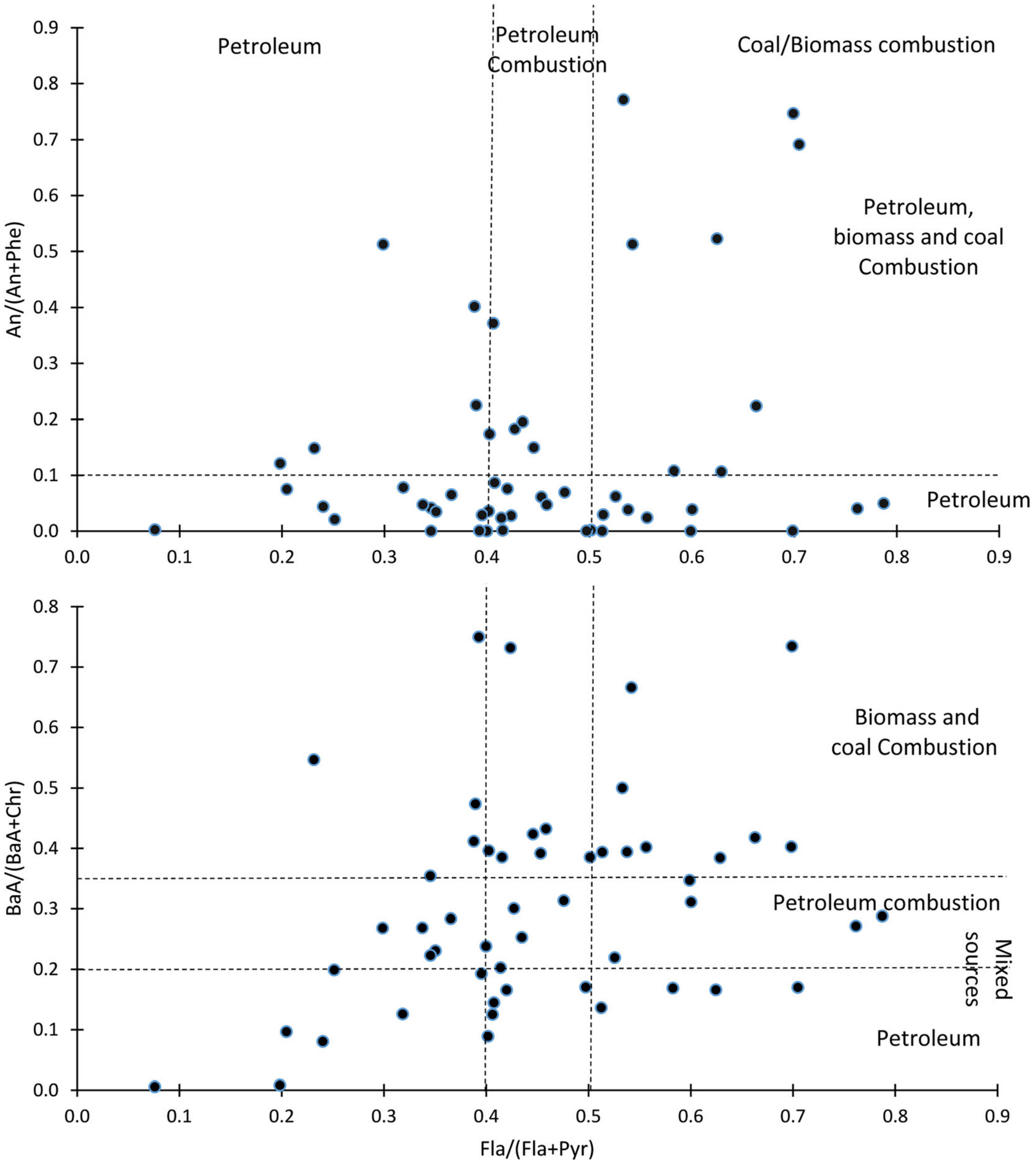

Fig. 2 Cross plots. **a** Fla/(Fla+Pyr) vs. Ant/(Ant+Phe); **b** Fla/(Fla+Pyr) vs. BaA/(BaA+Chr)

Where CS is the PAHs concentration of soils (μg/kg), CSF is the carcinogenic slope factor (mg/kg day)$^{-1}$, BW is the body weight (kg), AT is the average life span (day), EF is exposure duration (year), IR_{air} is the inhalation rate (m^3/day), IR_{soil} is the rate of intake of soil (mg/day), SA is the dermal surface exposure (cm^2/day), FE is the dermal exposure ratio to soil, AF is the dermal adherence factor (mg/cm^2), ABS is the dermal adsorption fraction, and PEF is the soil dust producing factor (m^3/kg). The determination of carcinogenic slope factor is based on the carcinogenecity of BaP. $CSF_{ingestion}$, CSF_{dermal}, and $CSF_{inhalation}$ of BaP is suggested to be below 7.3, 25, and 3.85(mg/kg day)$^{-1}$, respectively (Yu et al. 2014; Jiao et al. 2013; Chen et al. 2013). The CS was obtained by converting PAHs concentrations to toxic equivalents of BaP using the TEF discussed above. Other parameters are presented in Table 1. The risk of cancer for children and adults of different gender was calculated separately. The total risks were calculated as the sum of risks associated with each exposure.

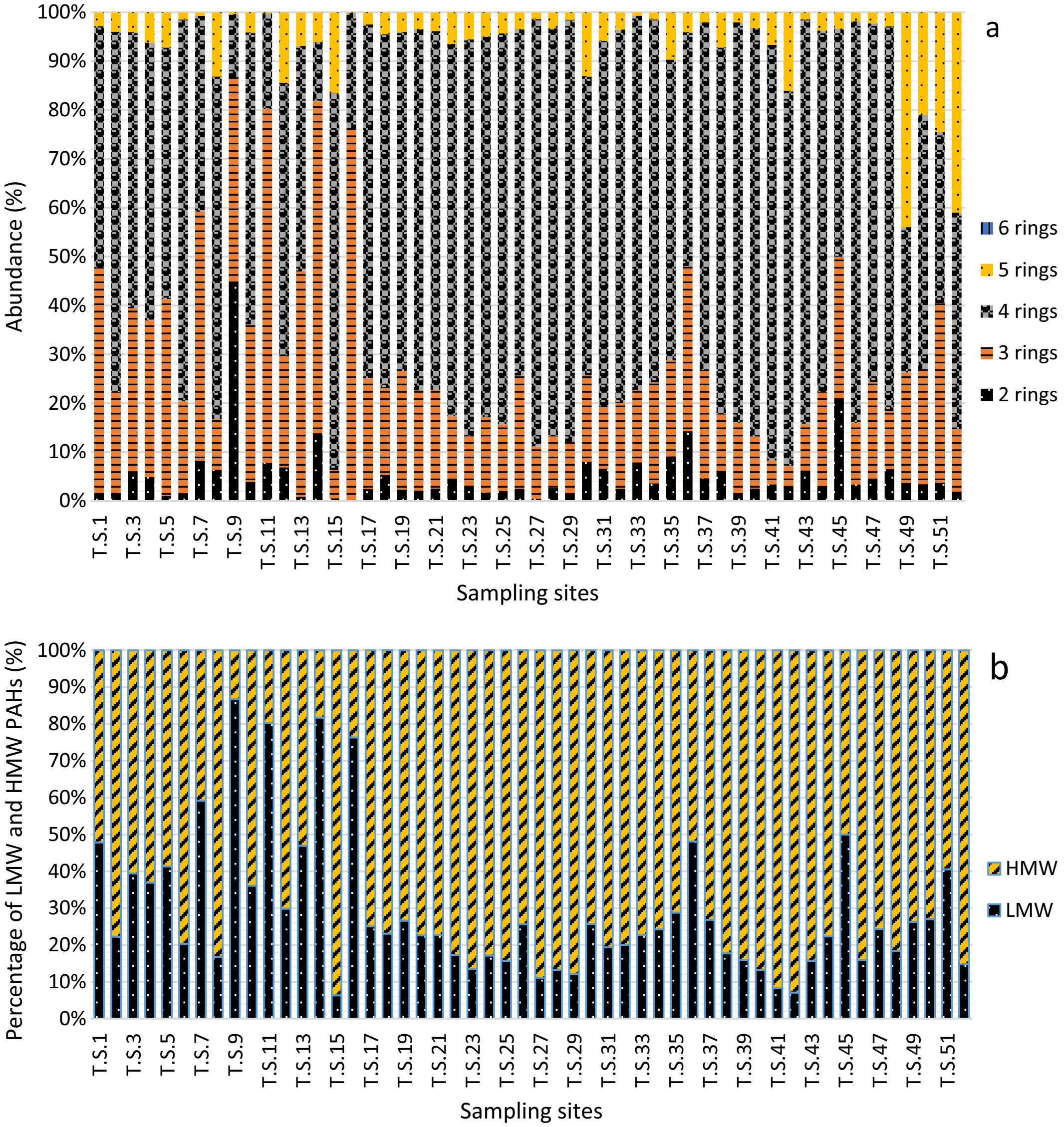

Fig. 3 **a** Ring classes and **b** percentage of PAHs (low and high molecular weight) of 52 sampling site located 50 km from Isfahan City center

Results and discussion

PAHs concentration and distribution in soils

In this study, 16 USEPA priority PAHs were detected in all soil samples. Benzo[ghi] perylene, indeno(1,2,3cd) pyrene, and dibenz(ah) anthracene were not detected, and the sum of benzo[b]fluoranthene and benzo[k]fluoranthene is given. The measured data is statistically analyzed and presented in Table 2. Total concentrations of ΣPAHs, Σ non-carcinogenic PAHs (Nap, Acy, Ace, Flu, Phe, Ant, Fla, Pyr, and BghiP), weakly carcinogenic PAH (Chr), Σ carcinogenic PAHs (BaA, BbF, BkF, IP, DahA), and strongly carcinogenic PAH (BaP) in soil samples range from 57.70 to 11,730.08, 32.7 to 9,940.36, 0.02 to 3,345.74, 0.72 to 3,503.16, and 0.13 to 552.99 μg/kg, respectively. High ΣPAHs concentration were detected in sites 15 (11,730.1 μg/kg), 11 (10,117.2 μg/kg), 8 (10,012.2 μg/kg), 7 (8,382.2 μg/kg), 33 (6,422.5 μg/kg), and 27 (5,430 μg/kg) in mid-southern, mid-western, and central part of the study area, where different industrial plants, transport terminals, and the airport are located. By contrast, the lowest concentration of ΣPAHs were found to occur in samples collected from small cities and suburban area (sites 47, 10, 39, 32, 44, and 35) close to Isfahan metropolis, and are not directly affected by industrial activities and

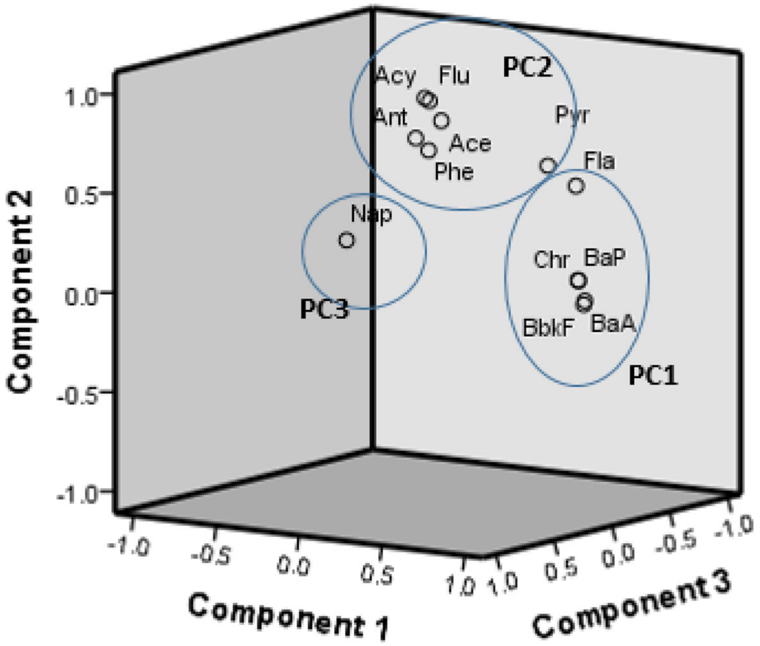

Fig. 4 Principal component analysis loading plot for three rotated components (PC1, PC2, and PC3)

heavy traffic. The highest reported concentration of PAHs in soil profiles from different parts of the world are 37,000, 22,200, 8,357.2, and 14,100 μg/kg from South Carolina marsh (USA), Elizabeth River Wetland (USA), Mediterranean Coast (Egypt), and Bejing and Tianjin (China), respectively (Kimbrough and Dickhut 2006; Barakat et al. 2011; Bu et al. 2009; He et al. 2009). Compared with these areas, the PAHs contamination in Isfahan Metropolis is moderate.

The soil PAHs profiles are highly affected by human activity. Furthermore, different transport potential of each PAHs is also important. LMW PAHs are generally transported to remote areas and considered as "multi-hop" chemicals, while HMW PAHs are subjected to rapid deposition close to the source region and undergo "single-hop" transport behavior (Wang et al. 2007). Moreover, plant leaves are well known for their ability to capture air particulates (Wei et al. 2014). Manzetti 2013 indicated that PAHs tend to deposit first on vegetation and then into soil. Thus, higher vegetation cover in suburban and rural parts of the study area would lower the deposition rate of particulate-bound PAHs from atmosphere to soil.

PAHs sources

Aromatic diagnostic criteria commonly used in the interpretation of PAH sources are as follows: abundance ratio of two- to three-ring hydrocarbons to four- to six-ring hydrocarbons (LMW/HMW), Ant/(Ant+Phe), Fla/(Fla+Pyr), BaA/(Ba+Chr), and BaA/Chr (Table 3) (Kanzari et al. 2014; Wang et al. 2010; Zhang et al. 2013).

The ratios of Fla/(Fla+Pyr), Ant/(Ant+Phe), and BaA/(BaA+Chr) ranged from 0.08 to 0.79, 2×10^{-5} to 0.77, and 0.006 to 0.75, respectively (Fig. 2). The results indicate that social and economic factors control the regional distribution of PAHs up to 50 km from Isfahan metropolis center. PAHs in the soil samples are mainly derived from petroleum and petroleum combustion products (mixed sources). High traffic load and energy consumption due to urbanization and industrial activity in the study area are the most probable pyrogenic sources of the PAHs.

For the 52 different sampling stations in the study area, the ring classes of PAHs and percentage of low and high molecular weight PAHs are shown in Fig. 3. The ratio of LMW PAHs (two and three rings)/HMW PAHs (four to six rings) ranged from 0.07 to 6.55 in soil samples, with HMW PAHs making 71 % of the total PAHs. Overall, the petrogenic sources are rich in (LMW) PAHs and the pyrogenic sources contain a greater percentage of (HMW) (four to six rings) (Yu et al. 2014). Furthermore, the high HMW content is probably the result of LMW PAHs tendency to evaporate from soil. Wei et al. (2014) already demonstrated

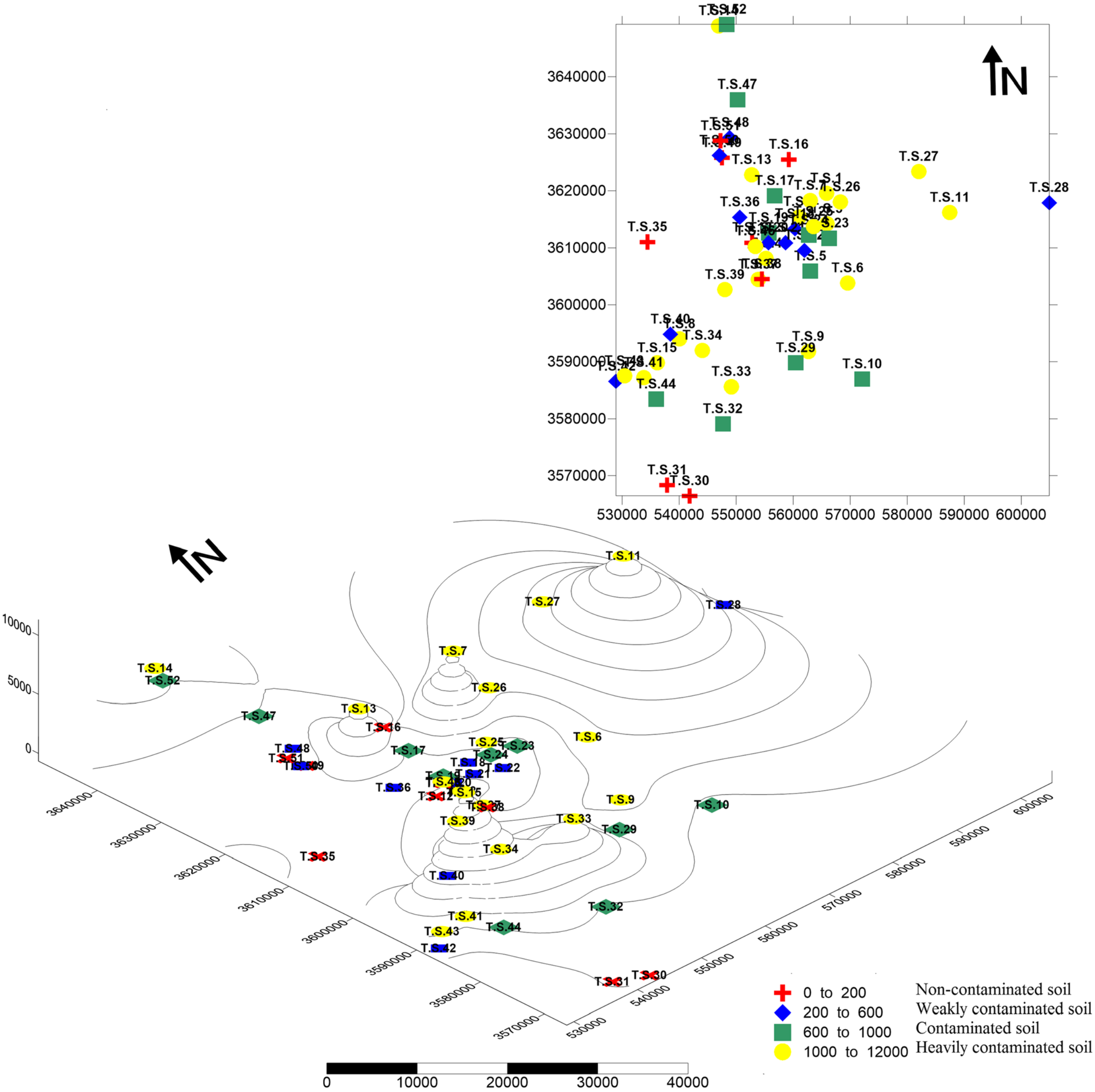

Fig. 5 Topsoils classes based on Maliszewska-Kordybach classification

that two- and three-ring PAHS (Acy, Ace, Flu, Phe, and Ant) tend to evaporate from soil to air, whereas five- and six-ring PAHs (BaP, DahA, IP, and BghiP) are likely to deposit from air to soil. Considering the fact that more than 90 % of the PAH burden in surface soil come from dry and wet deposition of atmospheric particulate matter, the high percentage of heavy molecular weight PAHs is anticipated in soil (Wang et al. 2010). In the current study, four-ring PAHs are dominant and the LMW/HMW ratio in most stations is less than 1, indicating the similarity of pyrogenic sources. Wilcke and Amelung (2000) suggested that four-ring PAHs mostly come from industrial and traffic pollutions. As LMWs are more hydrophilic and biodegradable than HMW (Wang et al. 2010), the presence of LMWs in some stations such as 11 (brickyard), 7 (bus terminal), 9 (waste disposal site), 14 (traffic police check point), and 16 (highway side) probably indicated recent pollution

Principal component analysis (PCA) was also used to conduct quantitative assessments (Yu et al. 2014).

Table 4 Description of 16 PAHs USEPA priority

Compound	Aromatic ring	Potential carcinogenic	Toxic equivalency factor (TEF)
Naphthalene	2	NC	0.001
Acenaphthylene	2	NC	0.001
Acenaphthene	2	NC	0.001
Fluorene	3	NC	0.001
Phenanthrene	3	NC	0.001
Anthracene	3	NC	0.01
Fluoranthene	4	NC	0.001
Pyrene	4	NC	0.001
Benzo[a]anthracene	4	C	0.1
Chrysene	4	WC	0.01
Benzo[b]fluoranthene	5	C	0.1
Benzo[k]fluoranthene	5	C	0.1
Benzo[a]pyrene	5	SC	1
Benzo[ghi] perylene	6	NC	0.01
Indeno(1,2,3cd) pyrene	6	C	0.1
Dibenz(ah)anthracene	6	SC	1

According to the initial component matrix, most of PAHs displayed large values on factor 1, suggesting their high rate association. Hence, the component matrix was rotated. After the rotation, first factor (PC1), accounting for 36.95 % of the total variance, predominantly indicate four- and five-ring PAHs (Fla, BaA, Chr, Bb+kF, and BaP) related to PAHs from mixed pyrogenic sources, such as combustion of coal/biomass and refined petroleum products (Fig. 4). The second factor (PC2) displays 36.00 % of the total variance. This component represents two- and three-ring PAHs (Acy, Ace, Flu, Phe, and Ant) related to petrogenic sources, such as crude and fuel oil. Finally, the third factor (PC3) indicated that naphthalene makes 9.06 % of the total variance. Naphthalene generally accounts for most of the mass in highway tunnels and gasoline engine samples. Thus, PC3 is related to petroleum spill (Wei et al. 2014; Zhang et al. 2013; Yuan et al. 2014). Based on earlier discussions, PCA results indicated that PAHs in the soil samples are mostly derived from petroleum and petroleum combustion (mixed sources).

Ecotoxicological risk

Human may be exposed to soil PAHs through skin, ingestion, and inhalation. Potential environmental impacts of PAHs on the soil organisms could be assessed by comparing PAHs levels with soil quality guidelines (SQGs) (Yuan et al. 2014). However, there are only a few soil quality guidelines such as Canadian Soil Quality Guidelines (CCME), Netherland maximum permissible concentrations (NMPC), New Zealand Human Health Based PAHs guidelines, New Jersey Human Health based soil cleanup criteria, USEPA human health, and Danish soil quality criteria (CCME 2008; Wei et al. 2014).

Compared with CCME, USEPA human health, and New Zealand and New Jersey soil quality guidelines, the results showed that the concentrations of 16 PAHs in Isfahan metropolis soil are below the recommended values; however, when compared with NMPC, the maximum concentration of Nap, Phe, Ant, BaA, and BaP exceed the recommended values. Finally compared with Danish soil quality criteria, results indicated BaP, DahA, and ΣPAHs exceed the threshold level in some stations close to the industrial area.

Maliszewska-Kordybach (1996) suggested a soil contamination classification system based on ΣPAH_{16}. According to this classification, 42.3 % (22 samples) of the samples in the study are heavily contaminated, 21.2 % (11 samples) are contaminated, 19.2 % (10 samples) are weakly contaminated, and 17.3 % (9 samples) are uncontaminated (Fig. 5).

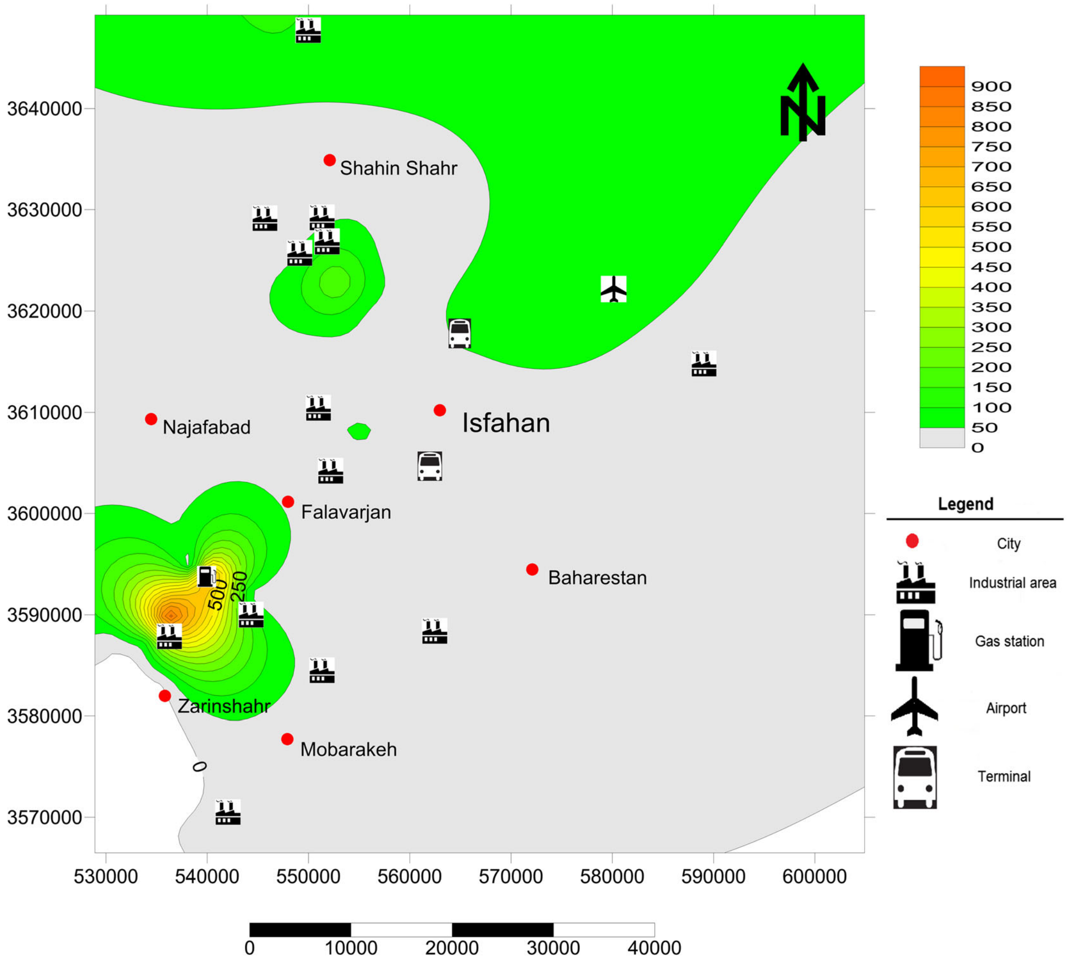

Fig. 6 Distribution of TEQ in the study area

Moreover, BaP is the most potential toxic PAHs and has been used as carcinogenic PAHs marker in food and environmental samples (Zhang et al. 2013). Table 4 shows the description and TEF of 16 PAHs USEPA priority. TQE also ranged from 1.00 to 900.53 μg/kg with a mean of 67.39 μg/kg in the study area (Fig. 6). The TQE in the vicinity of Isfahan metropolis center is moderate compared with different world soils (Jiang et al. 2009; Nadal et al. 2004; Masih and Taneja 2006; Liu et al. 2010; Zhang et al. 2013). The sample with maximum TEQ in the study area is “T.S. 15” (900.53 μg/kg).

Incremental life cancer risks were employed to investigate the potential cancer risks due to human exposure to environmental PAH contamination sources (Jiao et al. 2013; Chen et al. 2013). Depending on the TEQ, CSF the cancer risk levels for children (boys and girls) and adults (male and female) via ingestion, dermal contact, and inhalation was calculated (Table 5). The 95 % cumulative probability ILCRs for adult (male and female) and child (boy and girl) are 2.3×10^{-2}, 2.8×10^{-2}, 2.2×10^{-3}, and 2.5×10^{-3}, respectively. Cancer risks for women/girls exposed to PAHs are slightly greater than for men/boys due to the differences of body weight between men and women (boys and girls). In general, the 95 % of cumulative probability cancer risk distribution is often considered to starting point for risk management; ILCRs of 10^{-6} or less denote virtual safety, and ILCRs of greater than 10^{-4} indicate potentially high risk (Jiao et al. 2013; Yu et al. 2014; Chen et al. 2013).

Cancer risks through inhalation is lower than through dermal contact and ingestion in both adults and children, and does not exceed 10^{-6} reflecting the fact that cancer risk through inhalation of soil particles is negligible.

Ninety-five percent of ILCR through soil ingestion by children (1.3×10^{-3}) and adults (1.4×10^{-3}) are similar, while through dermal contact for adults (2.2×10^{-2})

Table 5 Cancer risk due to exposure to PAHs in Isfahan metropolis

Age	Gender	Exposure pathways	Mean	Max	Min	95 percentile
Child	Boy	Ingestion	2.7×10^{-4}	3.7×10^{-3}	4.1×10^{-6}	1.3×10^{-3}
		Dermal contact	1.8×10^{-4}	2.5×10^{-3}	2.8×10^{-6}	9.0×10^{-4}
		Inhalation	5.6×10^{-9}	7.9×10^{-8}	8.7×10^{-11}	2.8×10^{-8}
		Cancer risk	4.4×10^{-4}	6.2×10^{-3}	6.9×10^{-6}	2.2×10^{-3}
	Girl	Ingestion	2.8×10^{-4}	4.0×10^{-3}	4.5×10^{-6}	1.5×10^{-3}
		Dermal contact	2.0×10^{-4}	2.7×10^{-3}	3.1×10^{-6}	9.8×10^{-4}
		Inhalation	6.0×10^{-9}	8.5×10^{-8}	9.5×10^{-11}	3.1×10^{-8}
		Cancer risk	4.8×10^{-4}	6.7×10^{-3}	7.6×10^{-6}	2.5×10^{-3}
Adult	Male	Ingestion	2.7×10^{-4}	3.8×10^{-3}	4.2×10^{-6}	1.4×10^{-3}
		Dermal contact	4.2×10^{-3}	6.0×10^{-2}	6.7×10^{-5}	2.2×10^{-2}
		Inhalation	1.8×10^{-8}	2.6×10^{-7}	2.8×10^{-10}	9.2×10^{-8}
		Cancer risk	4.5×10^{-3}	6.4×10^{-2}	7.1×10^{-5}	2.3×10^{-2}
	Female	Ingestion	3.3×10^{-4}	4.6×10^{-3}	5.2×10^{-6}	1.6×10^{-3}
		Dermal contact	5.2×10^{-3}	7.3×10^{-2}	8.1×10^{-5}	2.6×10^{-2}
		Inhalation	2.2×10^{-8}	3.2×10^{-7}	3.5×10^{-10}	1.1×10^{-7}
		Cancer risk	5.5×10^{-3}	7.7×10^{-2}	8.6×10^{-5}	2.8×10^{-2}

is higher than children (9×10^{-4}). Children usually play outdoors and, hence, their soil ingestion can be greater. However, greater body weight, longer exposure time for ingestion, and greater skin surface area cause higher potential cancer risks in adults (Jiao et al. 2013).

Conclusion

In this study, distribution, probable sources, and possible adverse ecological effects of 16 PAHs were identified in soils within 50 km of Isfahan metropolis center. Analyses of 52 surface soil samples indicated that the PAHs soil contamination in the study area is moderate compared with soil profiles from different parts of the world. High levels of PAHs were detected in industrial zones such as iron foundry, gas stations, terminals, and roadsides. Pyrene was the dominant compound and HMW PAHs were more abundant in most stations. The results indicated that PAH concentrations are related to land use, population density, emission sources, atmospheric transport, and physiochemical properties of PAH compounds. Source identification based on distribution ratios, ring classes, and PCA analysis indicated that there are a variety of PAHs sources in the study area. Anthropogenic impacts such as industrial activity and high traffic load play an important role in the spatial pattern of PAHs. Ecological risk assessments indicated that PAHs level are well below soil quality guidelines in some stations. However, occurrence of PAHs-contaminated soil and ILCRs greater than 10^{-4} near commercial/industrial centers potentially bears serious health risk for local resident. Based on the results of this study, industrial and traffic emissions should be controlled in highly polluted areas. Moreover, long-term monitoring seems necessary in order to identify the fate of PAHs and their effects on local residents.

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