



Characterization of Polycyclic Aromatic Hydrocarbons (PAHs), Iron and Black Carbon within Street Dust from a Steel Industrial City, Central China

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ABSTRACT

Twenty-two street dust samples collected from a small steel city, central China, were analyzed for 16 USEPA priority PAHs to investigate the concentration, spatial distribution relationship with black carbon (BC) and Iron (Fe), and the source apportionment and to assess the health risk of these compounds. The mean contents of PAHs, BC and Fe were 4.43 $\mu\text{g g}^{-1}$, 12837.97 mg kg^{-1} , 70205.70 mg kg^{-1} , respectively. The highest spot was in the surrounding of the E'zhou Steel Plant and the Steel Rolling Mill of E'zhou. The correlation analysis indicated that there was no obvious relationship between Fe with each other, the PAHs significantly correlated to black carbon (BC), which might be caused by the continuous emission sources of iron and steel production. The results of sources identification suggested that PAHs contaminations in street dust were a mixed source of industrial production and traffic emission combustion. The incremental lifetime and cancer risks (ILCRs) of exposing to PAHs in the street dust of the E'zhou city for the three age groups (namely childhood, adolescence, adulthood) fluctuated with in the range of 10^{-6} to 10^{-4} , indicating a potential of carcinogenic risk for exposed populations.

Keywords: Polycyclic aromatic hydrocarbons (PAHs); Street dust; Industrial city; Source apportionment; Health risk assessment.

INTRODUCTION

With the rapid development of industrialization and urbanization in China, the problem of environmental pollution caused by Polycyclic Aromatic Hydrocarbons (PAHs), black carbon (BC) and heavy metals becomes more and more serious to human health and ecological environment (Han *et al.*, 2006; Wei *et al.*, 2015; Zhang *et al.*, 2015). Street dust being a useful indicator of environmental quality in urban area was used to assess the PAHs, carbon components and heavy metals in street dust of industrial city (Amato *et al.*, 2009; Lu *et al.*, 2010; Lee and Dong, 2011). Further, street

dust is also a major component of fugitive dust rendering it chemically close to the principal fraction of atmospheric aerosol which exhibits vital relationship during continuous process of re-suspension and re-deposition (Kong *et al.*, 2012). So, commuters and people near the road side are particularly vulnerable to exposure to street dust combined with pollutants like the PAHs, BC and heavy metals.

BC and PAHs are produced by the incomplete combustion of fossil fuels and biomass (Han *et al.*, 2015), and the burning conditions significantly influenced the formations of BC and PAHs. PAHs are composed of two or more fused aromatic rings, and 16 PAHs were specified as a priority control list by the US environmental protection agency (US-EPA) due to their carcinogenic and mutagenic properties related to health problems (Xu *et al.*, 2006; Hussain *et al.*, 2016). PAHs are ubiquitous pollutants in different environment mediums, such as atmosphere, soil, sediment and surface dust (Xing *et al.*, 2011; Jiang *et al.*, 2014; Pozo *et al.*, 2015). Atmosphere is a major approach for the transport and deposition of PAHs (Lee *et al.*, 2011; Keyte *et al.*, 2013), and the aromatic hydrocarbon in atmospheric adhere

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mainly on the atmospheric particulate matter.

PAHs in environment mainly originated from anthropogenic activities such as the release of incomplete combustion of organic materials (e.g., fossil fuels, wood and straw), vehicle emissions and many industrial processes (Lee *et al.*, 1995; Cheruyiot *et al.*, 2015). The street dust can be considered as one of key links of exchange of PAHs from air to surface. Thus, the street dust has been considered as an important carrier of PAHs (Lian *et al.*, 2008; Wu *et al.*, 2005). Intake PAHs, especially particle-bound PAHs, can cause various cancer risks to humans, such as lung and skin cancer (Kim *et al.*, 2013; Yue *et al.*, 2015). Therefore, estimating the carcinogenic risks of PAHs in particulate matter is necessary for human health research.

The southeast of Hubei Province is an important iron and steel industry base in central China. It assembles many associated industrial facilities, for instance, coke production, sintering, iron production, iron preparation, steel production, semi-finished product preparation, finished product preparation, heat and electrical supply, and the handling and transport of raw, intermediate, and waste materials (Tsai *et al.*, 2007). The iron and steel industry produces important materials for automotive, construction and consumer product applications. But it is also one of the most energy-intensive industries and produces significant pollutions, and the contaminant levels depend on the fuel used and the performance of the combustion control system. The study area is a typical iron and steel industrial city (E'zhou City) which has already formed an important metal smelting and metal processing industrial base in the west of the city. Therefore, the long-time extensive development of steel industry has made the situation of environmental pollution more serious over the small city. So, to investigate the contamination status of PAHs in the city is beneficial to understanding of the contribution of the heavy industry to the

anthropogenic release of contamination from the productive process of steel and fossil combustion. Furthermore, it is especially significant to evaluate the human health risk due to exposure to PAHs in the industrial city. The objectives of the present study were: (a) to investigate the level and distribution of PAHs with carbon components and Fe; (b) to determine the potential sources in street dust of the steel city; and (c) to evaluate the potential cancer risk of PAHs using incremental lifetime cancer risk.

MATERIALS AND METHODS

Sampling

Sampling station locations are shown in Fig. 1. Twenty-two street dust samples were collected from E'zhou City of Hubei Province during October 2013. Approximately 100 g of the dust particles accumulated on impervious surfaces of the pavement and street within a 5-m radius circle were collected using plastic brushes and dustpans by gentle sweeping motion to collect fine particulates. After each sampling, brushes and dustpans were cleaned with paper towels. All samples were stored in paper bags wrapped with solvent-rinsed aluminum foil and then sealed in polyethylene bags for transport to the laboratory. The samples were then placed in a desiccator to get rid of moisture, and then a 100 μm sieve was used to remove coarse debris and small stones.

PAHs Analysis

Compounds measured were 16 USEPA priority 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), Indeno[1,2,3-cd]pyrene (IcdP), Dibenzo[a,h]anthracene

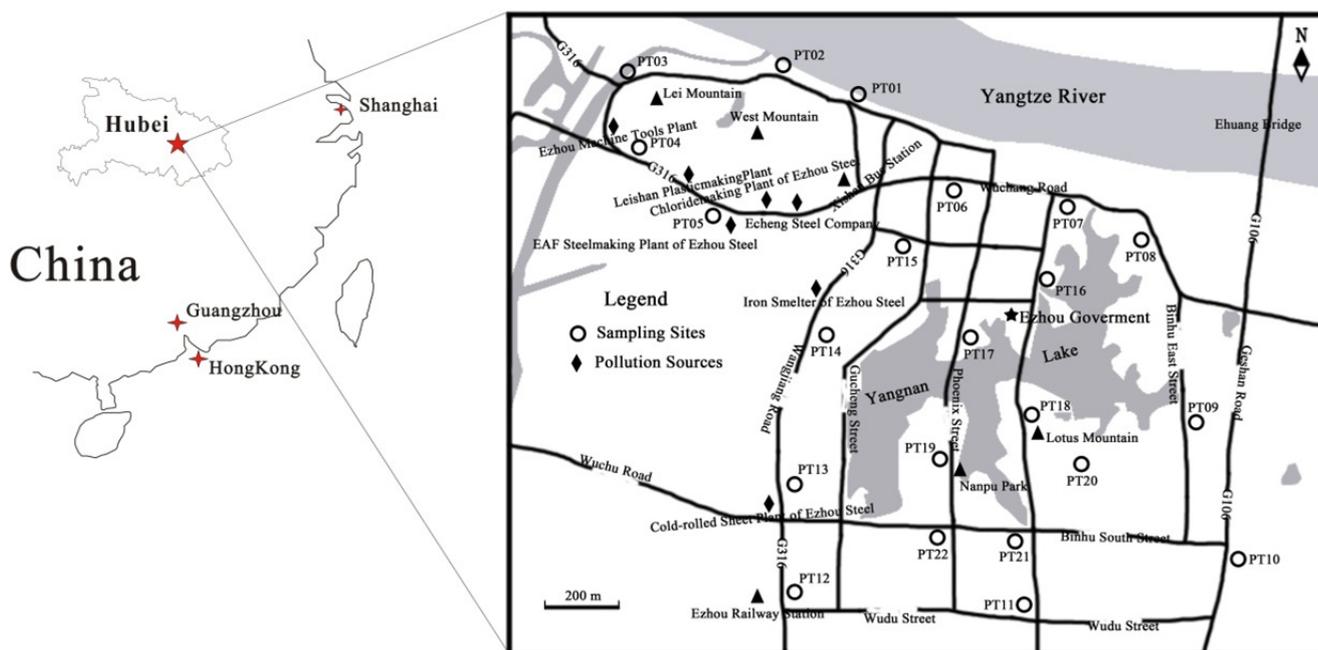


Fig. 1. Sampling sites of street dust in the E'zhou City.

(DBA), and Benzo[g,h,i]perylene (BghiP).

The procedures for the preparation of the sample were similar to that described previously (Zhang *et al.*, 2015). After preparation 10 g of each dust samples were spiked with 5 μL ($200 \mu\text{g mL}^{-1}$) mixed recovery surrogates (naphthalence-d8, acenaphthene-d10, phenanthrene-d10, chrysene-d12 and perylene-d12, bought from Supelco, USA) and Soxhlet-extracted with dichloromethane (DCM, GC, bought from J.T Baker, USA) for 24 h. Elemental sulphur was removed by adding activated copper granules to the collection flasks. The sample extract was concentrated and solvent - exchanged to hexane (GC, bought from Tedia, USA) and further reduced to 2–3 mL by a rotary evaporator (Heidolph 4000, Germany). A 1:2 (v/v) alumina/silica gel column (48 h extraction with DCM, then 180°C and 240°C muffle drying for 12 h, both 3% deactivated with H₂O before use) was used to clean up the extract and PAHs were eluted with 30 mL of DCM/hexane (2:3). The eluate was concentrated to 0.2 mL under a gentle nitrogen stream. Prior to analysis, a known quantity (1000 ng) of hexamethylbenzene was added as an internal standard.

PAHs were analyzed using GC-MS (Agilent 7890A/5975MSD) equipped with a DB-5 capillary column (30 m \times 0.25 mm i.d \times 0.25 μm film thickness). The MS was operated using electron impact (EI) ionization mode at 70 eV. The chromatographic conditions were as follows: injector temperature 270°C; detector temperature 280°C; oven temperature program was kept at 60°C for 5 min and increased to 290°C at a rate of 5 °C min⁻¹ and kept at 290°C for 20 min. The highly pure carrier gas was helium at a constant flow rate of 1.0 mL min⁻¹. The mass spectrometer was operated in the selected ion monitoring (SIM) mode.

The procedural blanks, spiked blanks, sample duplicates (the ratio was twenty percent of the total samples) were analyzed to evaluate the precision. The PAHs found in the procedural blanks were generally below the Limit of detection (LOD) (the amount of analysis that would generate a signal-to-noise ratio of 3:1). No target compounds of PAHs were detected in blanks. The variation of PAHs contents in duplicates was less than 15%. MDLs for 16 PAHs were in the range of 0.27–0.78 ng g⁻¹ dry weight. The average percentage recoveries (mean \pm SD) were 58 \pm 6%, 82 \pm 9%, 108 \pm 10%, 112 \pm 13% and 118 \pm 11% for naphthalence-d8, acenaphthene-d10, phenanthrene-d10, chrysene-d12 and perylene-d12, respectively.

Carbon and Iron Analysis

Acid pretreatment with HCl (10%) acids was used to remove the carbonate. After each acids-treatment step, the residue was centrifuged and rinsed with deionized (DI) water, and the retentate dried in an oven at 35°C for 6 h for carbon analysis. Black carbon (BC) and organic carbon (OC) contents in all dust samples were determined by method CTO-375 as earlier adopted by Gustafsson *et al.* (1996). BC: A 5.00 g fresh soils was fumigated with ethanol-free chloroform and another 5.0 g was non-fumigated as blank then dark treatment for 24 hours at 25°C in an evacuated extractor. Sample blanks and duplicates were treated as quality control. Fumigated and non-fumigated soils were extracted with 20 mL 0.5 mol L⁻¹ K₂SO₄ by horizontal

shaking for 1 hour. The extracts were filtered using a glass fiber microporous membrane filter with diameter of 0.45 μm , then frozen stored at -15°C prior to analysis. The analytical equipment used in the method was total organic carbon (TOC) analyser (Analytik Jena, Germany, multi N/C 2100-HT1100). Total Fe concentration was determined by dissolving 0.20 g dust sample with HNO₃-HCl-HF-HClO₄ mixture followed by elemental analysis using the flame atomic absorption spectrometry method (240FS AA, Varian, USA). Quality assurance and quality control were determined by method blanks, duplicates, and China Soil Standard Reference Material (GSS-3, GSS-5). The blank levels were determined to be less than 0.50% of proceeding samples. The relative percentage difference of Fe concentration in sample duplicates was < 10%.

Risk Assessment

The incremental lifetime cancer risk (ILCR) was calculated to conduct quantitative evaluation on the integrated lifetime risks of exposure to street dust by PAHs in the industrial corridor. The ILCR in terms of ingestion, dermal contact and inhalation were estimated on the following equation, which were adapted from the USEPA standard models (Peng *et al.*, 2011; Jamhari *et al.*, 2014; Zhang *et al.*, 2015):

$$\text{ILCRs}_{\text{Ingestion}} = \frac{CS \times (CSF_{\text{Ingestion}} \times \sqrt[3]{(BW/70)}) \times IR_{\text{Ingestion}} \times EF \times ED}{BW \times AT \times 10^6} \quad (1)$$

$$\text{ILCRs}_{\text{Dermal}} = \frac{CS \times (CSF_{\text{Dermal}} \times \sqrt[3]{(BW/70)}) \times SA \times AF \times ABS \times EF \times ED}{BW \times AT \times 10^6} \quad (2)$$

$$\text{ILCRs}_{\text{Inhalation}} = \frac{CS \times (CSF_{\text{Inhalation}} \times \sqrt[3]{(BW/70)}) \times IR_{\text{Inhalation}} \times EF \times ED}{BW \times AT \times PEF} \quad (3)$$

where CS is the sum of BaP equivalent concentration (BaP_{eq}) ($\mu\text{g kg}^{-1}$), BaP_{eq} is the product of the concentration of individual PAH compound and its corresponding toxic equivalence factor (TEFs) (Table 2) (Tsai *et al.*, 2004; Chen *et al.*, 2014; Tiwari *et al.*, 2015); CSF is the carcinogenic slope factor ($\text{mg}^{-1} \text{kg}^{-1} \text{d}^{-1}$); BW is the average body weight (kg); AT is the average life span (d); LT is the Lifetime (yr); EF is the exposure frequency ($\text{d} \cdot \text{yr}^{-1}$); ED is the exposure duration (yr); IR_{ingestion} is the ingestion rate of soil (mg d^{-1}); IR_{inhalation} is the inhalation rate ($\text{m}^3 \text{d}^{-1}$); SA is the surface area of the skin that contacts the soil ($\text{cm}^2 \text{d}^{-1}$); AF is the skin adherence factor for soil ($\text{mg} (\text{cm}^2)^{-1}$); ABS is the dermal absorption factor (chemical specific); PEF is the particle emission factor ($\text{m}^3 \text{kg}^{-1}$) (Peng *et al.*, 2011; Qin *et al.*, 2015).

The carcinogenic slope factor (SCF) based on the cancer-causing ability of BaP were addressed as 7.30, 25 and 3.85 ($\text{mg}^{-1} \text{kg}^{-1} \text{d}^{-1}$)⁻¹ for ingestion, dermal contact and inhalation, respectively (Peng *et al.*, 2011). The cancer risk was estimated

for three age groups: childhood (0–10 yr), adolescence (11–18 yr), and adulthood (19–70 yr). Moreover, the cancer risk for males and females were calculated separately. Details of the values of exposure parameters used to derive the ILCR were shown in Table 1 (Zhang *et al.*, 2015). The total risks were estimated as the sum of individual risk of above each exposure route.

Statistical Analysis

The spatial distribution, correlation coefficients, principal component analysis (PCA) and other statistical analyses of the geochemical data were carried out using Surfer 9.0, SPSS 18.0 and Origin 8.5.

RESULTS AND DISCUSSION

Contents

The statistical data for individual PAH, total PAHs, Fe and carbon fractions in the street dust of the city were shown in Table 2. The mean contents of Σ PAHs, Fe and BC were $4.43 \mu\text{g g}^{-1}$, $70205.70 \text{ mg kg}^{-1}$ and $12837.93 \text{ mg kg}^{-1}$, respectively. Compared with other studies, the contents of Fe was less than those in dust from E'zhou city ($35\text{--}214 \text{ g kg}^{-1}$, mean 142 g kg^{-1}) (Zhu *et al.*, 2013), and also less than those in the street dust from the Loudi city ($39.9\text{--}579.4 \text{ g kg}^{-1}$) (Zhang *et al.*, 2012), the contents of BC was less than those in the street dust from Guwahati city ($17.99\text{--}20.11 \text{ mg g}^{-1}$,

Table 1. Values of the parameters for the estimation of the incremental lifetime cancer risk.

Exposure parameters	Unit	Childhood		Adolescence		Adulthood	
		Male	Female	Male	Female	Male	Female
Body weight (BW)	kg	14.3	13.6	48.1	45.4	62.8	54.7
Ingestion rate ($\text{IR}_{\text{ingestion}}$)	mg d^{-1}	200	200	100	100	100	100
Exposure frequency (EF)	d yr^{-1}	350	350	350	350	350	350
Exposure duration (ED)	yr	6	6	14	14	30	30
Average life span (AT)	d	$\text{LT} \times 365$					
Lifetime (LT)	yr	72	72	72	72	72	72
Surface area (SA)	$\text{cm}^2 \text{d}^{-1}$	2800	2800	2800	2800	5700	5700
Dermal surface factor (AF)	mg cm^{-2}	0.2	0.2	0.2	0.2	0.07	0.07
Dermal absorption factor (ABS)	unitless	0.13	0.13	0.13	0.13	0.13	0.13
Inhalation rate ($\text{IR}_{\text{Inhalation}}$)	$\text{m}^3 \text{d}^{-1}$	10.9	10.9	17.7	17.7	17.5	17.5
Particle emission factor (PEF)	$\text{m}^3 \text{kg}^{-1}$	1.36×10^9					

Table 2. Summary of PAHs contents ($\mu\text{g g}^{-1}$), Fe and carbon fractions in street dust.

Compounds	Abbreviation	Rings	TEF	Minimum	Maximum	Mean	$\pm \text{SD}^{\text{a}}$	Median
Naphthalene	Nap	2	0.001	0.09	1.73	0.33	0.34	0.25
Acenaphthylene	Acy	3	0.001	0.05	0.70	0.18	0.14	0.12
Acenaphthene	Ace	3	0.001	0.01	0.12	0.05	0.03	0.04
Fluorene	Fl	3	0.001	0.03	0.31	0.11	0.06	0.09
Phenanthrene	Phe	3	0.001	0.25	1.43	0.73	0.33	0.66
Anthracene	Ant	3	0.01	0.03	0.29	0.10	0.06	0.08
Fluoranthene	Flu	4	0.001	0.29	2.12	0.84	0.43	0.72
Pyrene	Pyr	4	0.001	0.16	1.54	0.58	0.32	0.50
Benzo[a]anthracene	BaA	4	0.1	0.04	0.52	0.23	0.13	0.20
Chrysene	Chr	4	0.01	0.06	0.70	0.35	0.17	0.33
Benzo[b]fluoranthene	BbF	5	0.1	0.09	0.69	0.31	0.16	0.26
Benzo[k]fluoranthene	BkF	5	0.1	0.05	0.37	0.16	0.08	0.13
Benzo[a]pyrene	BaP	5	1	0.06	0.44	0.20	0.11	0.17
Dibenzo[a,h]anthracene	DBA	5	1	0.01	0.13	0.05	0.03	0.04
Indeno[1,2,3-cd]pyrene	IcdP	6	0.1	0.02	0.25	0.09	0.06	0.08
Benzo[g,h,i]perylene	BghiP	6	0.01	0.04	0.30	0.12	0.07	0.10
LMW-PAHs ^b				0.51	4.50	1.50	0.89	1.24
HMW-PAHs ^c				0.84	6.41	2.93	1.44	2.56
LMW-PAHs/HMW-PAHs				0.32	0.88	0.51	0.12	0.48
Σ PAHs ^d				1.35	9.60	4.43	2.23	3.91
Fe mg kg^{-1}				26894.03	154040.46	70205.70	35425.58	64339.04
BC mg kg^{-1}				3228.50	33634.09	12837.93	8069.38	11760.88
OC mg kg^{-1}				242.31	14217.22	5350.41	3923.75	5953.21
TOC mg kg^{-1}				6023.56	40220.51	18188.34	9592.27	16344.87

^a Standard Deviations; ^b Low molecular weight 2–3 rings PAHs; ^c High molecular weight 4–6 rings PAHs; ^d Total contents of 16 individual PAHs.

mean 19.30 mg g^{-1}) (Hussain *et al.*, 2015). The average proportions of Flu, Phe, and Pyr in PAHs were 18.90%, 16.52% and 13.09% of the Σ PAHs, respectively. They were considered to be the predominant compounds among the PAHs. In respect to the number of aromatic rings, 2-, 3-, 4-, 5- and 6-rings PAHs contributed 7.52%, 26.29%, 45.25%, 16.06% and 4.87% on average to Σ PAHs, respectively. The contents of low molecular weight PAHs (LMW-PAHs) varied from 0.51 to $4.50 \text{ }\mu\text{g g}^{-1}$ with a mean of $1.50 \text{ }\mu\text{g g}^{-1}$, and the contents of high molecular weight PAHs (HMW-PAHs) varied from 0.84 to $6.41 \text{ }\mu\text{g g}^{-1}$ with a mean of $2.93 \text{ }\mu\text{g g}^{-1}$. The LMW-PAHs/HMW-PAHs ratio from 0.32 to 0.88 , with a mean of 0.51 , so the composition pattern of PAHs in street dust had a common characteristic with high molecular weight PAHs (HMW-PAHs) contribution. Obviously, the HMW-PAHs were considered as the major fraction of the total PAHs quantified. Due to the volatility,

the LMW-PAHs have a greater tendency to evaporate into the air-phase than those of the HMW-PAHs (Agarwal *et al.*, 2009). In addition, compared with the LMW-PAHs, the HMW-PAHs have more emission sources in this city, such as the iron and steel industries related activities. Therefore, this observation may be illustrated as a result of the differences of properties and emission sources among the two groups of PAHs.

Spatial Distribution

The spatial distribution of Σ PAHs, ratio of LMW-PAHs/HMW-PAHs, Fe and BC are shown using the kriging map (Fig. 2). The site of PT05 was near the steel plant, the highest Σ PAHs concentration ($9.60 \text{ }\mu\text{g g}^{-1}$) and the ratio of LMW-PAHs/HMW-PAHs (0.88) were the highest spot in the Σ PAHs map, this result was consistent with previous research (Yang *et al.*, 2002). The BC and PAHs are supposed

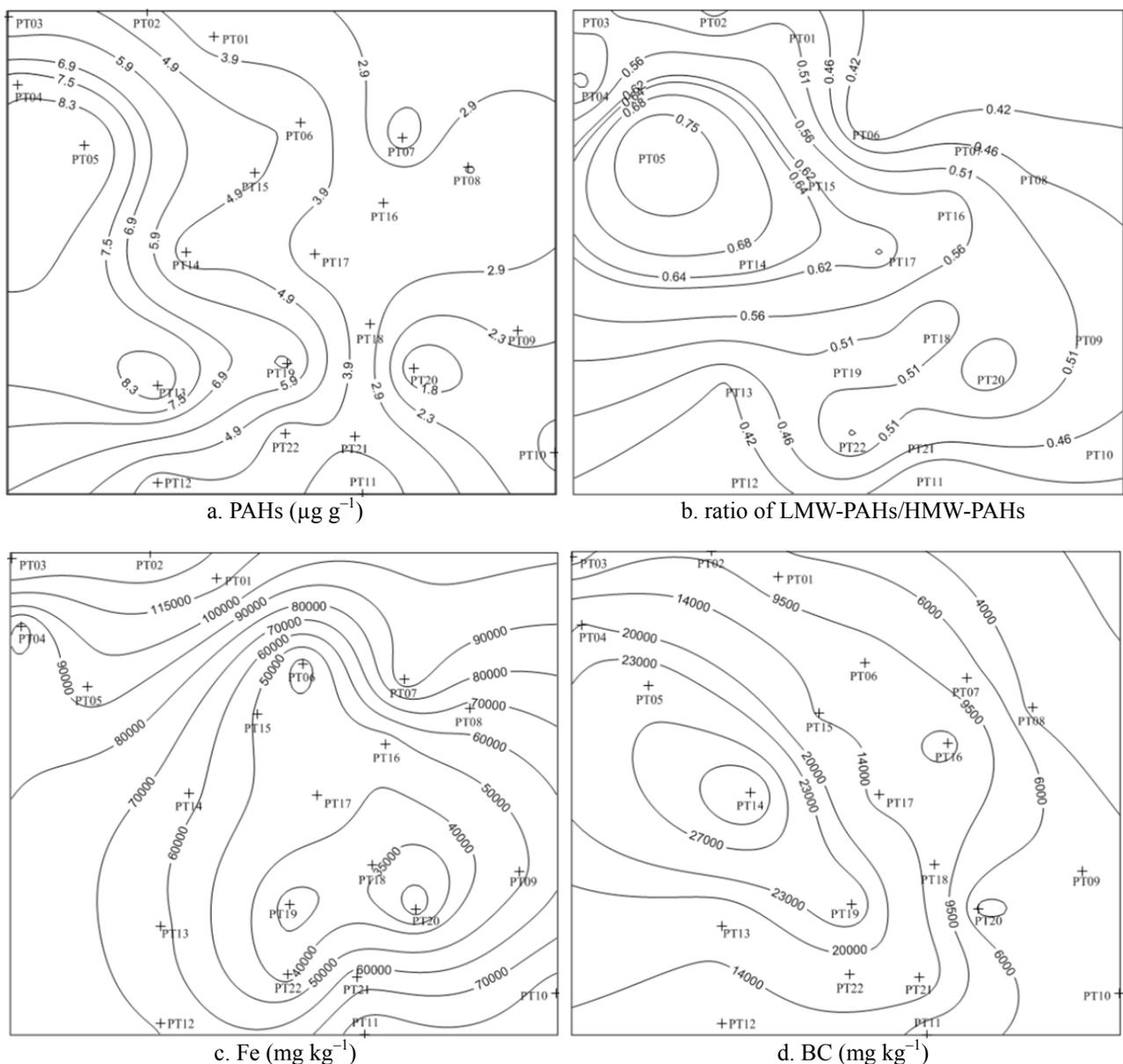


Fig. 2. Spatial distribution of PAHs, ratio of LMW-PAHs/HMW-PAHs, Fe and BC in street dust.

to be transported together, resulting in co-deposition of them to dust, the BC and PAHs contents were gradually becoming higher from west to east, so the BC in this city have a similar distribution characteristics of Σ PAHs. The spatial of Fe was concentric mode distribution in this area, and the lowest spot was near the largest lake in the central city, but the west was significantly higher than the east.

The Correlations among PAHs, Fe and Carbons

Pearson's correlation coefficients are presented in Table 3 for Σ PAHs, LMW-PAHs, HMW-PAHs, Fe, BC, OC and TOC in 22 street dust samples of the steel city. The correlations among the individual PAHs can be performed to determine whether or not originating from the same source of these compounds (Yang et al., 2013). Correlation efficient matrix among the Σ PAHs, LMW-PAHs and HMW-PAHs reflected that most of the compounds were significantly positively correlated with each another. The Fe presented a poor correlation with other compounds. The results indicated that except for the steel source, the environmental background value was another source of Fe, such as the environmental background, the mining activities and the metal processing. TOC and BC were significantly correlated with those of Σ PAHs, LMW-PAHs and HMW-PAHs. The possible reason was that PAHs and BC were emitted together from iron and steel production. But, OC was not significantly correlated with BC, suggesting fossil fuel combustion to be the dominant sources of TOC (Liu et al., 2011). And OC was not significantly correlated with Σ PAHs, LMW-PAHs and HMW-PAHs. These results showed that the BC and PAHs have the similar source, such as the iron and steel industry.

Molecular Composition Analysis

Molecular indices based on isomeric ratios of selected individual PAH have been established to discriminate between petrogenic and pyrolytic sources. The isomer ratios of Flu/(Flu + Pyr), Ant/(Ant + Phe) and BaA/(BaA + Chr) were popular to be applied to identification of the possible source categories of PAHs (Wu et al., 2014; Kamal et al., 2016). Paired isomer ratios are usually used as markers for the source diagnostics of PAHs, assuming that the isomers are diluted to a similar extent during atmospheric transport, although there are many criticisms of this method. An Ant/(Ant + Phe) ratio of 0.10 is used to distinguish petrogenic (< 0.10) and pyrogenic (> 0.1) sources. A Flu/(Flu + Pyr) ratios used to distinguish petroleum (< 0.40) and (> 0.50) combustionsources, while a Flu/(Flu + Pyr) ratio

0.40–0.50 is more characteristic of petroleum combustion (traffic emission) (Menezes and Cardeal, 2012). A BaA/(BaA + Chr) ratio < 0.20 is indicative of petrogenic origins, > 0.35 is indicative of combustion origins, while 0.20–0.35 suggests mixed origins(Yunker et al., 2002; Wu et al., 2014; Kamal et al., 2016).

According to the triangular diagram of PAH isomer ratios in street dust from the steel city are shown in Fig. 3. The ratios of BaA/(BaA + Chr), Flu/(Flu + Pyr) and Ant/(Ant + Phe) were in the range of 0.21–0.57, 0.39–0.66, 0.09–0.18, respectively. Therefore, the twenty two sampling sites were demonstrated to be influenced by petroleum combustion and coal/biomass combustion, indicating that PAHs in street dust were mainly originated from the source of combustion, what's more, fuel oil is used mainly for processing of cast iron and motor traffic (Han et al., 2011; Menezes and Cardeal, 2012). Moreover, as a street dust, it also presented a mixed source of vehicular traffic emission. The result was in agreement with the conclusion that the vehicular traffic and coal combustion are the dominating contributors to PAHs in street dust of the heavy industry area, such as Chang-Zhu-Tan Region, and Lanzhou (Long et al., 2013; Jiang et al., 2014).

Principal Component Analysis

For further analysis the possible sources of PAHs in street dust of E'zhou City, the first two principal components (PC1 and PC2) were extracted with the eigenvalues > 1, and collectively represented the majority (87.58%) of the total variance of Σ PAHs (Fig. 4). PC1 explained 77.50% of the total variance and had a high load with BbF, DBA, BaP, Ant, BkF, BaA, Phe, Pyr and Flu, which are typical markers for steel industry pyrolysis or incomplete combustion emissions (Han et al., 2011; Kong et al., 2011; Li et al., 2013). Flu, Pyr, BaA, BaP and Chr are the typical markers for coal combustion (Wu et al., 2014), while BkF and BbF are components of fossil fuels associated with their combustion (Kavouras et al., 2001). Phe, Ant, Flu and Pyr are often the results from the low-temperature pyrogenic processes (Jenkins et al., 1996). Therefore, PC1 seems to represent mixed sources of coal combustion and steel industry emissions. PC2 accounted for 10.09% of the total variance and was mainly loaded with IcdP, Chr and BghiP, this results represents traffic emission (Sadiktsis et al., 2012; Jiang et al., 2014).

Health Risk Assessment

The result of the ILCRs of three exposure routes and the

Table 3. Pearson's correlation coefficient for metals and PAHs contents of street dust.

	Σ PAHs	LMW-PAHs	HMW-PAHs	Fe	TOC	BC	OC
Σ PAHs	1	0.929**	0.973**	0.102	0.598**	0.569**	0.292
LMW-PAHs		1	0.819**	0.116	0.672**	0.636**	0.335
HMW-PAHs			1	0.086	0.511*	0.489*	0.243
Fe				1	-0.214	-0.256	0.005
TOC					1	0.916**	0.562**
BC						1	0.182
OC							1

* Correlation is significant at the 0.05 level (2-tailed); ** Correlation is significant at the 0.01 level (2-tailed).

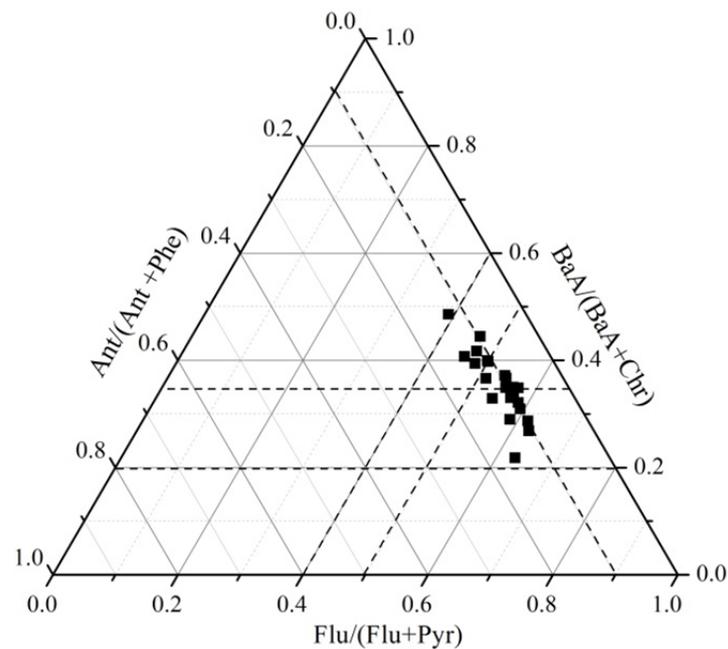


Fig. 3. Triangular diagram of the molecular indices to identify PAHs contamination sources.

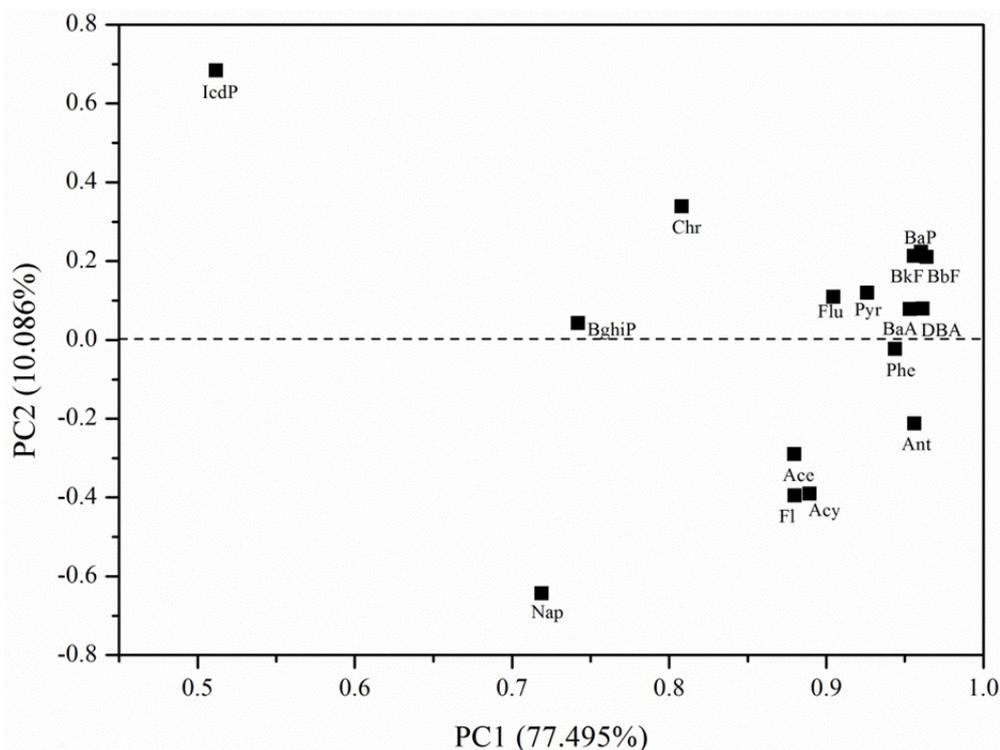


Fig. 4. Plot with PC1 and PC2 from principal component analysis of 16 PAHs.

total ILCRs of different sampling site are presented in Table 4. As shown in Table 4, the cancer risks for PAHs decreased in the following order of different exposure routes: dermal contact > ingestion > inhalation. The levels of cancer risks through inhalation of PAHs resuspended particles ranged from 10^{-9} to 10^{-11} , approximately 10^{-3} to 10^{-6} times less than that through ingestion and dermal contact.

Therefore, the cancer risks caused by the inhalation of PAHs resuspended particles can be neglected since it has little contribution to the total ILCRs in comparison with those in other routes. The difference of the ILCRs of three exposure routes is not significant among different genders from the same age group. The ILCRs for childhood or adulthood were higher than for adolescence, suggesting that adolescence

Table 4. Risk of cancer due to human exposure to PAHs via street dust in E'zhou City.

	Male				Female			
	Ingestion	Dermal contact	Inhalation	The total ILCRs	Ingestion	Dermal contact	Inhalation	The total ILCRs
Childhood	Mean	6.66E-06	8.30E-06	1.41E-10	1.50E-05	6.89E-06	1.46E-10	1.55E-05
	± SD	3.62E-06	4.52E-06	7.66E-11	8.14E-06	3.75E-06	7.92E-11	8.42E-06
	Median	5.57E-06	6.94E-06	1.18E-10	1.25E-05	5.75E-06	1.22E-10	1.29E-05
	Minimum	1.83E-06	2.28E-06	3.87E-11	4.11E-06	1.89E-06	4.00E-11	4.25E-06
	Maximum	1.45E-05	1.81E-05	3.07E-10	3.27E-05	1.50E-05	3.18E-10	3.38E-05
	Mean	3.46E-06	8.63E-06	2.38E-10	1.21E-05	3.60E-06	2.47E-10	1.26E-05
Adolescence	± SD	1.88E-06	4.70E-06	1.29E-10	6.58E-06	1.96E-06	1.34E-10	6.84E-06
	Median	2.89E-06	7.21E-06	1.99E-10	1.01E-05	7.49E-06	2.06E-10	1.05E-05
	Minimum	9.51E-07	2.37E-06	6.53E-11	3.32E-06	9.88E-07	6.78E-11	3.45E-06
	Maximum	7.55E-06	1.88E-05	5.19E-10	2.64E-05	7.85E-06	5.39E-10	2.74E-05
	Mean	6.21E-06	1.10E-05	4.21E-10	1.72E-05	6.81E-06	4.62E-10	1.89E-05
	± SD	3.38E-06	6.00E-06	2.29E-10	9.38E-06	3.70E-06	2.51E-10	1.03E-05
Adulthood	Median	5.19E-06	9.22E-06	3.52E-10	1.44E-05	5.69E-06	3.86E-10	1.58E-05
	Minimum	1.71E-06	3.03E-06	1.16E-10	4.74E-06	1.87E-06	1.27E-10	5.19E-06
	Maximum	1.36E-05	2.41E-05	9.20E-10	3.76E-05	1.49E-05	1.01E-09	4.13E-05

have relatively lower potential health risks among three age groups. The result was consistent with our previous studies in atmospheric dustfall from the southeast of Hubei (Zhang *et al.*, 2015).

In terms of regulatory, an ILCR between 10^{-6} and 10^{-4} means the potential risks of human health, and an ILCR less than or equal to 10^{-6} means the risks can be negligible, whereas a potentially high health risk was estimated by ILCR larger than 10^{-4} (Chen and Liao, 2006). In this study, the total ILCRs for the three age groups fluctuated within the range of 10^{-6} to 10^{-4} , indicating a potential carcinogenic risk. The results showed that the residents of the industrial corridor are confronted with the potential cancer risk due to exposures to PAH in the street dust. As shown in Table 4, the total ILCRs of different sampling sites demonstrated the trend that the regions of the high PAHs concentration are faced with more cancer risk.

CONCLUSIONS

PAHs, BC and Fe in street dust of the steel industrial city were analyzed to investigate the spatial distribution, possible source and health risk. The contents of PAHs, BC and Fe were $4.43 \mu\text{g g}^{-1}$, $12837.97 \text{ mg kg}^{-1}$ and $70205.70 \text{ mg kg}^{-1}$, respectively. The highest concentration of PAHs was found in an industrial area surrounded by the E'zhou Steel Plant. PAHs and BC were gradually becoming higher from west to east, but the Fe was concentric mode distribution, the lowest spot was near the central lake in the city. The composition pattern of PAHs in street dust had a common characteristic with HMW-PAHs contribution. Based on the results of source identification, combustion and traffic emission were suggested as major sources of PAHs in street dust of the industrial city. The correlation analysis indicated that PAHs contents were not significant correlated to Fe, but highly correlated of TOC, especially with BC. This result suggested that BC had the same source with PAHs in the steel city. The total cancer risk of PAHs in street dust fluctuated within the range of 10^{-6} to 10^{-4} , suggesting that there is a potential of carcinogenic risk for exposed populations.

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