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Characteristics and sources of polycyclic aromatic hydrocarbons in impervious surface run-off in an urban area in Shanghai, China*

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Abstract: Rainwater and run-off from three kinds of impervious surface in the Shanghai urban area, China were sampled. Polycyclic aromatic hydrocarbons (PAHs) were measured in the samples, and their sources were assessed. The mean sum of the 16 PAH concentrations measured in rainwater and run-offs from ceramic tiles, asphalt roofs, and asphalt roads were 873, 1404, 1743, and 4023 ng/L, respectively. The PAH concentrations found in this study were moderate compared to PAH concentrations found in run-offs in other studies. The main PAH components in the rainwater, roof run-off, and asphalt road run-off samples were 3-ring PAHs, 3–4-ring PAHs, and 4–6-ring PAHs, respectively. Source apportionment results indicated that combustion (47.4%–55.5%) and vehicular emissions (30.5%–33.0%) were the major contributors to PAHs in roof run-off. Vehicular emissions were the most significant contributors to asphalt road run-off (47.2%), followed by combustion (23.5%), and petroleum (16.3%). Vehicular emissions and coal and natural gas combustion are therefore the most significant sources of PAHs in run-off from impervious surfaces in the Shanghai urban area.

Key words: Polycyclic aromatic hydrocarbons (PAHs), Impervious surface, Run-off pollution, Source apportionment
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1 Introduction

Many surfaces in urban areas are impervious, including roads (Krein and Schorer, 2000) and the roofs of buildings (Chang *et al.*, 2004). Stormwater run-off from urban impervious surfaces can contain significant quantities of pollutants, including nutrients, heavy metals, and polycyclic aromatic hydrocarbons (PAHs) (Ngabe *et al.*, 2000; Chang *et al.*, 2004; Lau *et al.*, 2009). PAHs are of great concern because of their potential toxicities, carcinogenicities, and teratogenicities. PAHs are organic compounds that contain two or more fused benzene rings and have mainly anthropogenic sources, including the incomplete combustion of organic matter (such as coal, wood, oil, and petroleum), vehicle exhausts, road aging, and oil spills (Valle *et al.*, 2007). PAHs are ubiquitous in urban stormwater run-off, so monitoring the PAH contamination in the run-off and apportioning the PAH sources are critical for assessing and protecting aquatic ecosystems.

PAH pollution in stormwater run-off has been studied in a number of places and relatively high PAH concentrations have been found (Ngabe *et al.*, 2000; Grynkiewicz *et al.*, 2002; Lau *et al.*, 2009; Mitsova *et al.*, 2011; Bartlett *et al.*, 2012). However, PAH characteristics and sources vary between different urban areas, making it necessary to study PAH pollution specifically in stormwater run-off in Shanghai.

Shanghai is located in the Yangtze River Delta in eastern China, and is one of the largest cities in China, with a total population of over 23 million and an area of 6340 km^2. Shanghai has been troubled by serious environmental problems because of its rapid

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urbanization. Several recent studies have shown that various environmental media, such as soils, sediments, and wet deposition, in the Shanghai region are severely contaminated with PAHs (Liu *et al.*, 2008; Liang *et al.*, 2011; Yan *et al.*, 2012). However, little research has been conducted on PAHs in impervious surface run-off. The objectives of this work were (1) to measure PAH concentrations in impervious surface run-off in the Shanghai urban area, (2) to compare the PAH compositions of different surface run-offs, and (3) to determine the primary PAH sources and their relative contributions in the study area. In this work, for the first time PAHs in rainwater, roof run-off and road run-off samples were measured simultaneously in Shanghai. The results of this study provide information on the characteristics and sources of PAHs in impervious surface run-off in the Shanghai urban area, which is important for protecting water resources and human health in that region.

2 Materials and methods

2.1 Sampling site

A mixed residential and commercial area around Tongji University was selected as the study area. Samples were collected from three impervious surfaces, and rainwater samples were collected on the rooftop of the Shengtai building at Tongji University. The sites, which are described in Table 1 and shown in Fig. 1, were less than 450 m from each other, and their environmental situations were considered to be comparable.

2.2 Sample collection and preparation

Run-off samples were collected manually at each site during each storm event. The samples were taken from a road gully and roof downspouts. When run-offs were generated, samples were collected every 5 min during the first 0.5 h of the storm event, and then every 10 min until the run-off ended. Rainwater samples were collected in sampling basins and a rain gauge was used to measure the amount of rain at the sampling site. Seven rainfall events, between July and September, 2012, were monitored; the rainfall at the events ranged from 1.6 to 81.3 mm.

The samples were transported to the laboratory immediately after collection. A flow-weighted composite sample for each sample site was prepared, so that the mean concentration for each pollution event could be obtained (Kafi *et al.*, 2008; Diblasi *et al.*, 2009). It was not possible to measure the run-off flow at every sample site because of experimental restrictions, so the cumulative rainfall weight was used instead of the run-off flow weight; we consider that is appropriate because of the small catchment areas and the short measurement times. The samples were stored below 4 °C and analyzed for PAHs within 48 h of collection.

2.3 PAH extraction and analysis

The procedure for the extraction and analysis of PAHs in rainwater and run-off samples is briefly described in Fig. 2. The samples were liquid-liquid

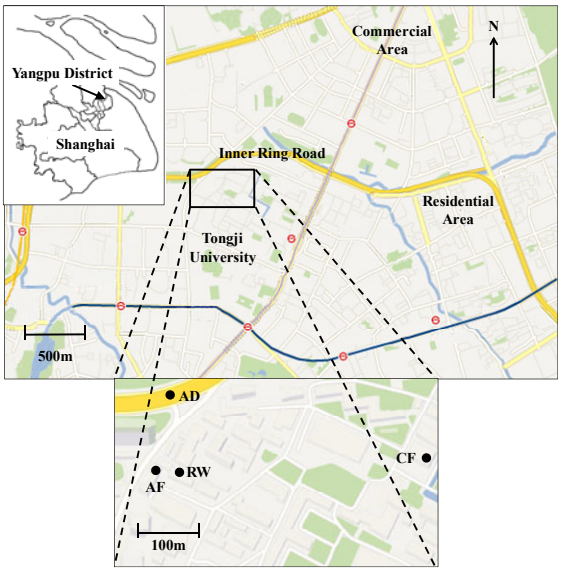

Fig. 1 Sample location map

Table 1 Characteristics of the sampling sites

Description	Sampling site	Location	Catchment area (m^2)
Ceramic tile roof (CF)	Haiyang building	Tongji University	120
Asphalt roof (AF)	Engineering center	Tongji University	85
Asphalt road (AD)	Inner ring road	North Zhongshan 2nd road	300
Rainwater (RW)	Shengtai building	Tongji University	–

extracted then analyzed by high performance liquid chromatography (HPLC), based on the method HJ478-2009. 500 ml of samples were transferred to a 500 ml separatory funnel for liquid-liquid extraction. Each sample was extracted three times and the organic phases were combined in a 250 ml round-bottomed flask, dried with anhydrous sodium sulfate, and concentrated to 1 ml using a rotary evaporator. The concentrated extract was cleaned up on a 1 g silica gel column, which had been washed with 4 ml of a mixture of hexane and dichloromethane (1:1, in volume) then 10 ml hexane, and eluted with 10 ml of a mixture of hexane and dichloromethane (1:1, in volume). The cleaned extract was concentrated to 1 ml, added to 3 ml acetonitrile, and finally concentrated to 0.5 ml.

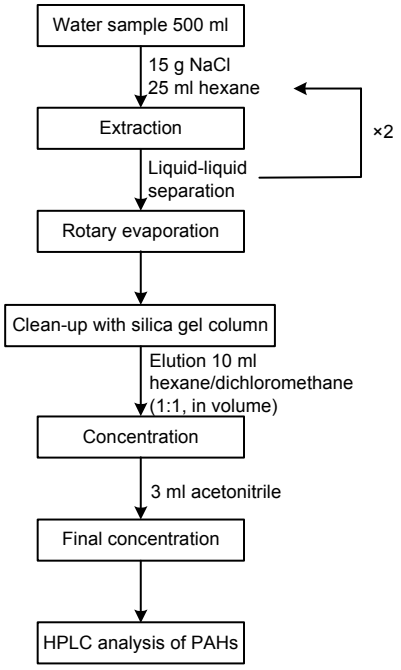

Fig. 2 Scheme of analytical procedure

The samples were analyzed by HPLC (LC-20A, Shimadzu, Kyoto, Japan) with a photodiode array detector (SPD-M20A) and an Inertsil ODS-P C_{18} column (4.6 mm×250 mm, 5 μm particles; GL Sciences, Torrance, CA, USA). A gradient elution program was used, with acetonitrile and deionized water mobile phases. A flow rate of 1.2 ml/min was maintained at a temperature of 35 °C, and the equilibration time was 30 min. The elution profile had three steps: 0–15 min with 55% acetonitrile in deionized water, 55%–100% acetonitrile linear gradient over 30 min, then a constant 100% acetonitrile for 15 min.

A series of calibration standard solutions, between 0.1 and 10 μg/ml, were used. Sixteen PAHs that have been classified as priority control pollutants by the US Environmental Protection Agency were analyzed. These were naphthalene (NaP), acenapthylene (AcNy), fluorene (FL), acenaphthene (AcNe), phenanthrene (PhA), anthracene (An), fluoranthene (FlA), pyrene (Py), benzo [*a*] anthracene (BaA), chrysene (Chy), benzo [*b*] fluoranthene (BaF), benzo [*k*] fluoranthene (BkF), benzo [*a*] pyrene (BaP), dibenzo [*a*,*h*] anthracene (DBahA), indeno [1,2,3-cd] pyrene (IP), and benzo [*g*,*h*,*i*] perylene (BghiP).

2.4 PAH quality control

All analytical procedures were monitored using strict quality control measures. Decafluorobiphenyl (99.99%) was spiked into each water sample before extraction, to monitor the efficiency of the extraction and cleanup procedures; its recoveries were 61% –110%. In addition, a method blank (solvent), a spiked blank (standards spiked into solvent), and duplicate samples were analyzed. The average spiked PAH recovery was 62%–107%. The differences between individual PAH congener concentrations in the duplicate samples were all <16%.

2.5 PAH source identification

Identifying the possible PAH sources and their relative contributions in run-off is critical for understanding and controlling PAH pollution in aquatic environments. Several useful methods have been developed to identify PAH sources and estimate their relative contributions, such as positive matrix factorization (PMF), principal component analysis-multiple linear regression (PCA-MLR) and unmix (Larsen and Baker, 2003; Junninen *et al.*, 2009; Yang *et al.*, 2013). Compared with other models, PMF imposes non-negativity constraints on both the source profiles and the resulting contributions, and allows for proper variable scaling (Sofowote *et al.*, 2008; Ma *et al.*, 2010). Due to the relatively small number of samples and large variation of PAHs in samples, we used PMF to identify the PAH sources and their relative contributions to impervious surface run-off in the Shanghai urban area.

Detailed descriptions of PMF can be found in

previous studies (Norris *et al.*, 2008; Sofowote *et al.*, 2008). In this study, the EPA PMF 3.0 (Norris *et al.*, 2008) was used.

3 Results and discussion

3.1 PAH concentrations

Fig. 3 shows the mean concentrations of the ∑16 PAHs (the sum of the sixteen PAHs analyzed) and the ∑7 PAHs (the sum of seven carcinogenic PAHs, BaA, BaP, BbF, BkF, Chy, DBahA, and IP) in the three impervious surface run-off samples and the rainwater. The mean ∑16 PAH concentrations in the rainwater, ceramic tile roof run-off, asphalt roof run-off, and asphalt road run-off samples were 873, 1404, 1743, and 4023 ng/L, respectively. The mean ∑16 PAH concentration ratios between rainwater and ceramic tile roof run-off and between rainwater and asphalt roof run-off were 62.2% and 50.1%, respectively,

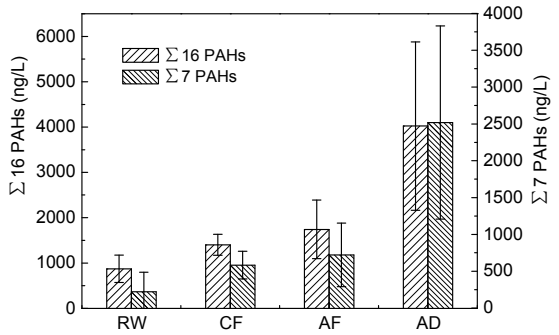

Fig. 3 Mean PAH concentrations in the samples analyzed
RW: rainwater, CF: ceramic tile roof run-off, AF: asphalt roof run-off, AD: asphalt road run-off

implying that wet deposition was a primary source of PAHs in roof run-off. The mean ∑16 PAH concentration was higher in AF than in CF, possibly because PAHs were leached from the asphalt roofing materials at the AF site because of high temperatures caused by exposure to the sun. The PAH sources in road run-off are complicated, and include vehicle exhausts, emissions caused by tire friction, and road aging. The PAH concentrations were much higher in the road run-off than in the roof run-off. The mean ∑7 PAH concentration at AD was 2517 ng/L, which could constitute a great threat to the environment and humans. The mean ∑7 PAH concentrations in the run-off from the two types of roof were not considered to be a significant threat to the environment and humans.

The PAH concentrations in the surface run-off found in this study and in other studies around the world are shown in Table 2. The PAH concentrations found in the run-off from the asphalt road surface in Shanghai were similar to that found in other areas. The PAH concentrations in this study in the run-off from a ceramic tile roof in Shanghai were lower than that found in Beijing, and the PAH concentrations in asphalt roof run-off were lower in Shanghai than in Nanjing. The PAH concentrations were higher in asphalt roof run-off than in run-off from roofs made of other materials. In summary, the PAH concentrations in impervious surface run-off in the Shanghai urban area were moderate compared to concentrations found elsewhere.

3.2 PAH composition characteristics

Concentrations of the individual PAHs in the RW and run-off samples were calculated (Table 3).

Table 2 PAH concentrations in surface run-offs in different regions

Location	PAHs	Concentration (ng/L)	Reference
Asphalt road, Shanghai, China	∑16	4023	This study
Urban road, Beijing, China	∑16	500–38900	Zhang *et al.*, 2008
Highway, Netherlands	∑16	5200–5800	Berbee *et al.*, 1999
Highway, USA	∑14	400–16300	Ngabe *et al.*, 2000
Ceramic tile roof, Shanghai, China	∑16	1404	This study
Asphalt roof, Shanghai, China	∑16	1743	This study
Asphalt roof, Nanjing, China	∑15	4261.7	Zhang *et al.*, 2012
Tile roof, Nanjing, China	∑15	351.2	Zhang *et al.*, 2012
Ceramic tile roof, Beijing, China	∑16	2320	Hu *et al.*, 2010
Zinc roof, Poland	∑6	232.6	Tsakovski *et al.*, 2010
Ceramic tile roof, Poland	∑6	197	Tsakovski *et al.*, 2010

The PAHs found at the highest concentrations in the RW were An, Fl, NaP, and PhA, and the low molecular weight PAHs were, generally, the dominant components. This suggested that the low molecular weight PAHs were mostly present in the gaseous phase because of their high vapor pressures. The dominant PAHs in the CF samples were An, BaA, FlA, and Py, and the dominant PAHs in the AF samples were An, BaA, Chy, FlA, PhA, and Py (i.e., similar to the dominant PAHs in the CF samples but at higher concentrations). The high molecular weight PAHs dominated the AD samples, with IP, FlA, and BaA being found at the highest concentrations (in descending order). In some studies, FlA, PhA, and Py have been found to be the main PAHs that threaten aquatic ecological systems (Boxall and Maltby, 1997). These three PAHs were found at relatively high concentrations in our study, suggesting that impervious surface run-off is a potential threat to local ecological systems, and should be discharged only after being treated properly.

As shown in Table 4, the 16 PAHs can be divided into five groups, containing 2-, 3-, 4-, 5-, and 6-ring PAHs, according to the number of benzene rings in the molecule. RW was dominated by 3-ring PAHs and the roof run-off samples (CF and AF) were dominated by 3–4-ring PAHs, accounting for more than 50% of the total PAHs. The major components of the AD samples were 4–6-ring PAHs. The PAH compositions of the roof run-off samples were similar to the RW sample compositions, further proving that wet deposition was an important source of PAHs in roof run-off. PAHs in the road run-off were less affected by wet deposition.

3.3 PAH source identification using positive matrix factorization

Three 16×7 (16 PAHs and 7 samples) datasets were used in the EPA PMF 3.0 model, to estimate the source contributions to the ∑PAH concentrations in the impervious surface run-off. For each dataset, the number of factors and Q values were tested to obtain

Table 4 Distributions (%) of PAHs (grouped by the number of rings) in the samples

Sample	Distribution of PAHs (%)				
	2-ring	3-ring	4-ring	5-ring	6-ring
RW	12.0	50.9	23.3	11.2	2.5
CF	6.7	29.3	28.2	22.7	13.1
AF	3.6	30.2	32.3	21.6	12.3
AD	3.0	14.7	34.4	23.4	24.5

RW: rainwater, CF: ceramic tile roof run-off, AF: asphalt roof run-off, AD: asphalt road run-off)

Table 3 Concentrations of the individual PAHs in the samples (ng/L) (n=7)

PAH*	Concentration (ng/L)			
	RW	CF	AF	AD
NaP	97±27 (66–128)	95±23 (63–129)	65±42 (5–112)	92±26 (67–137)
AcNy	n.d.	77±38 (n.d.–108)	51±48 (n.d.–112)	24±45 (n.d.–115)
Fl	85±39 (n.d.–116)	68±42 (n.d.–114)	87±71 (23–232)	91±34 (32–137)
AcNe	81±56 (n.d.–130)	74±56 (n.d.–136)	101±45 (8–155)	114±27 (86–157)
PhA	103±30 (51–141)	47±37 (14–125)	143±93 (11–241)	154±128 (22–369)
An	134±27 (102–178)	135±27 (100–175)	129±80 (5–273)	108±41 (45–168)
FlA	71±39 (30–138)	108±63 (8–202)	193±131 (19–352)	567±395 (155–1150)
Py	65±31 (32–119)	128±28 (86–169)	136±68 (63–260)	98±42 (45–175)
BaA	34±39 (n.d.–109)	113±37 (54–161)	119±78 (19–259)	524±416 (10–1324)
Chy	39±28 (6–90)	49±31 (12–98)	116±142 (4–402)	336±361 (34–890)
BbF	41±61 (n.d.–158)	88±31 (49–149)	82±82 (n.d.–243)	364±305 (108–951)
BkF	42±59 (n.d.–140)	110±33 (69–166)	107±72 (37–260)	264±247 (6–545)
BaP	12±26 (n.d.–69)	32±32 (3–83)	64±63 (9–159)	182±251 (19–718)
DBahA	42±73 (n.d.–168)	93±27 (54–130)	133±75 (11–258)	121±79 (30–264)
BghiP	16±43 (n.d.–113)	89±35 (53–149)	116±66 (64–258)	259±253 (66–749)
IP	9±3 (7–16)	97±71 (16–228)	101±68 (43–250)	727±393 (141–1351)

* PAH abbreviations were given in Section 1.3. Data were expressed as mean±SD (range); n.d.: not detected; RW: rainwater, CF: ceramic tile roof run-off, AF: asphalt roof run-off, AD: asphalt road run-off

well-fitting results that could fully explain the raw data. Factor numbers ranging from 3 to 6 were tried in order to choose the "optimal solution". Fifty runs were made for each factor, and the convergent run with the minimum Q_{robust} was used for the optimal solutions (Ma *et al.*, 2010). The PMF model identified four factors for roof run-off and five factors for road run-off, as shown in Tables 5, 6, and 7.

1. Ceramic tile roof run-off

The first factor had high concentrations of the PAHs AcNy, An, Fl, and FlA, which are associated with coal combustion (Larsen and Baker, 2003; Bzdusek *et al.*, 2004), so this factor represented coal combustion sources. The second factor was dominated by BbF, BghiP, BkF, DBahA, and IP. Of these, BbF, BghiP, and BkF are markers of gasoline sources (Larsen and Baker, 2003) and IP is a marker for diesel sources (Harrison *et al.*, 1996; Li *et al.*, 2006), so the second factor represented vehicular emission sources. The third factor was highly related to BaA, which is an indicator of natural gas combustion (Simcik *et al.*, 1999). The fourth factor had no significant markers, and was possibly associated with mixed sources, so it is referred to as 'others'.

2. Asphalt roof run-off

The first factor was dominated by BbF, BghiP, BkF, DBahA, and IP, which are associated with vehicular emissions (Harrison *et al.*, 1996; Larsen and Baker, 2003; Li *et al.*, 2006). The second factor had high weightings for An, FlA, PhA, and Py, which are associated with coal combustion (Larsen and Baker, 2003; Bzdusek *et al.*, 2004). The third factor was highly related to Chy, FlA, and Py. Chy is a marker of petroleum sources (Li *et al.*, 2006), indicating that this factor represented petroleum sources. The fourth factor was dominated by BaA, which is a marker for natural gas combustion sources (Simcik *et al.*, 1999).

3. Asphalt road run-off

The first factor represented gasoline emissions, based on its weightings for BaP, BghiP, and IP (Larsen and Baker, 2003). The second factor was highly weighted toward BaA, Chy, FlA, and IP. BaA is a marker for natural gas combustion and FlA is a marker for coal combustion (Larsen and Baker, 2003; Bzdusek *et al.*, 2004), so the second factor was identified as representing combustion sources (Simcik *et al.*, 1999). The third factor was identified as representing diesel emissions because it was strongly

Table 5 Source profiles for ceramic tile roof run-off obtained using positive matrix factorization

PAH*	Factor 1	Factor 2	Factor 3	Factor 4
NaP	0.062	0.072	0.065	0.098
AcNy	0.104	0.000	0.074	0.033
Fl	0.109	0.006	0.028	0.000
AcNe	0.000	0.000	0.093	0.182
PhA	0.001	0.049	0.031	0.058
An	0.117	0.110	0.004	0.038
FlA	0.136	0.034	0.000	0.160
Py	0.062	0.086	0.076	0.033
BaA	0.047	0.089	0.204	0.037
Chy	0.001	0.060	0.027	0.051
BbF	0.039	0.093	0.064	0.070
BkF	0.104	0.098	0.082	0.010
BaP	0.000	0.025	0.001	0.102
DBahA	0.096	0.086	0.098	0.118
BghiP	0.085	0.109	0.074	0.009
IP	0.037	0.082	0.079	0.000
Contribu-tion (%)	33.8	30.5	21.7	14.1
Source	Coal combustion	Vehicular emission	Natural gas combustion	Others

* PAH abbreviations were given in Section 1.3

Table 6 Source profiles for asphalt roof run-off obtained using positive matrix factorization

PAH*	Factor 1	Factor 2	Factor 3	Factor 4
NaP	0.008	0.036	0.000	0.116
AcNy	0.001	0.076	0.011	0.000
Fl	0.095	0.043	0.011	0.013
AcNe	0.079	0.071	0.002	0.070
PhA	0.000	0.111	0.131	0.137
An	0.123	0.091	0.000	0.038
FlA	0.000	0.161	0.152	0.179
Py	0.059	0.098	0.115	0.027
BaA	0.069	0.014	0.044	0.232
Chy	0.042	0.012	0.238	0.028
BbF	0.088	0.000	0.059	0.055
BkF	0.102	0.054	0.040	0.010
BaP	0.020	0.020	0.108	0.000
DBahA	0.118	0.103	0.005	0.033
BghiP	0.105	0.061	0.039	0.040
IP	0.091	0.049	0.044	0.022
Contribu-tion (%)	33.0	32.7	19.6	14.7
Source	Vehicular emission	Coal combustion	Petroleum	Natural gas combustion

* PAH abbreviations were given in Section 1.3

Table 7 Source profiles for asphalt road run-off obtained using positive matrix factorization

PAH*	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
NaP	0.008	0.008	0.036	0.016	0.072
AcNy	0.000	0.000	0.000	0.003	0.001
Fl	0.013	0.004	0.042	0.000	0.081
AcNe	0.006	0.009	0.043	0.033	0.086
PhA	0.028	0.064	0.005	0.108	0.005
An	0.010	0.001	0.055	0.002	0.099
FlA	0.130	0.194	0.062	0.291	0.079
Py	0.004	0.003	0.062	0.018	0.049
BaA	0.088	0.237	0.112	0.129	0.023
Chy	0.136	0.059	0.000	0.257	0.000
BbF	0.040	0.096	0.051	0.023	0.077
BkF	0.004	0.242	0.001	0.000	0.093
BaP	0.161	0.004	0.022	0.007	0.033
DBahA	0.027	0.000	0.001	0.049	0.109
BghiP	0.181	0.028	0.034	0.000	0.077
IP	0.163	0.053	0.473	0.062	0.115
Contribu-tion (%)	24.2	23.5	23.0	16.3	13.1
Source	Gasoline emission	Combus-tion	Diesel emission	Petroleum	Others

* PAH abbreviations were given in Section 1.3

weighted toward IP (Harrison *et al.*, 1996; Li *et al.*, 2006). The fourth factor was strongly related to Chy and FlA, which are indicators of petroleum sources. The fifth factor was dominated by An, BkF, DBahA, Fl, and IP, and was possibly associated with mixed sources, referred to as 'others'.

4. Comparison of source contributions in different surface run-off samples

The estimated source contributions to the samples from each site were calculated in Table 8. To facilitate comparisons, coal and natural gas combustion were combined as 'combustion', and gasoline and diesel emissions were combined as 'vehicular emission'. As shown in Table 8, PAHs in the roof run-off samples mainly came from combustion (47.4%–55.5%) and vehicular emissions (30.5%–33.0%). Petroleum was also a source (19.6%) for asphalt roof run-off, possibly because of PAHs being leached from the asphalt roof material. Vehicular emissions were the most significant sources (47.2%) for asphalt road run-off, followed by combustion (23.5%), and petroleum (16.3%). In summary, vehicular emissions and coal/natural gas combustion were the main PAH sources for impervious surface run-offs in urban Shanghai.

Table 8 Source contribution of PAHs in different impervious surface run-offs (%)

Source	CF	AF	AD
Combustion	55.5	47.4	23.5
Vehicular emission	30.5	33.0	47.2
Petroleum		19.6	16.3
Others	14.1		13.1

CF: ceramic tile roof run-off, AF: asphalt roof run-off, AD: asphalt road run-off

Coal is the main energy source in Shanghai and accounts for almost 32% of Shanghai's total energy consumption in 2011 (Shanghai Municipal Statistics Bureau, 2012) and explains the high contribution of coal combustion to the PAHs found in the run-off samples. The number of private cars in Shanghai has risen sharply in the last few years, causing heavy traffic and significant traffic pollution, especially in urban areas. Vehicular emissions have, therefore, become an important source of pollution in the urban environment in Shanghai. Natural gas is the primary residential energy source in Shanghai. The study area is a combined residential area, so natural gas combustion is a primary source of PAHs in run-off in the area. In summary, energy consumption is the dominant factor affecting the PAHs in the run-off from impervious surfaces in the Shanghai urban area.

4 Conclusions

The characteristics and sources of 16 priority PAHs were studied in run-off from three types of impervious surfaces and in rainwater in an urban area of Shanghai, China. The mean ∑16 PAH concentrations in the rainwater, ceramic tile roof run-off, asphalt roof run-off, and asphalt road run-off were 873, 1404, 1743, and 4023 ng/L, respectively. The PAH concentrations found in the run-off in this study were moderate compared with concentrations found in other studies. The rainwater samples were dominated by 3-ring PAHs, whereas 3–4-ring PAHs dominated the roof run-off samples, and 4–6-ring PAHs were dominant in the road run-off samples. Positive matrix factorization suggested that vehicular emissions and coal and gas combustion were the main sources of

PAHs in the run-off samples. These results will be of use in identifying appropriate measures for controlling PAH pollution in stormwater run-off and improving environmental quality in the Shanghai urban area.

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