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Distribution, composition, levels, source, and risk assessment of PAHs in surface water and sediment from the mainstream Three Gorges Reservoir

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ABSTRACT

Polycyclic aromatic hydrocarbons (PAHs) pose risks to the environment and human beings. Distribution, composition, levels, source, and risk assessment of PAHs in water and sediment samples collected from 19 sites in the Three Gorges Reservoir (TGR) were analyzed systematically during the wet season and the dry season from 2015 to 2016. The results indicated that ΣPAHs in surface water were 3.9–139.3 ng/L (mean 42.4 ng/L), whereas ΣPAHs in sediment were 185.5–2055.6 ng/g (mean 726.1 ng/g); PAH monomers with 2–3 rings were dominant in water, whereas PAH monomers with 3–5 rings were dominant in sediment. Distribution of ΣPAHs had no significant regularity in water and sediment. Compared with rivers at home and abroad, Surface water levels of ΣPAHs were low, whereas the sediment levels of ΣPAHs were moderate, but surface water PAH monomers including anthracene, benzo[a]pyrene, indeno[1,2,3-c,d]pyrene, and dibenzo[a,h]anthracene at some sampling points exceeded the USEPA water quality standard or the Canadian environmental quality guidelines. These indicated potentially detrimental effects on human health and ecological integrity due to PAHs bioaccumulation. Diagnostic ratios showed that the main sources of PAHs in water and sediment were pyrogenic sources, such as biomass, coal, and petroleum combustion. The research result could provide valuable data and technical support for the protection of the TGR.

Keywords: TGR; PAHs; Distribution; Composition; Levels; Source and risk assessment

1. Introduction

Persistent organic pollutants (POPs) persevere in various environmental media such as water and sediment for a long time; POPs are difficult to degrade and cause serious harm to human health; moreover, they are highly toxic and migrate over long distances. Polycyclic aromatic hydrocarbons (PAHs) are a typical class of POPs; PAHs exhibit carcinogenic, mutagenic, and teratogenic properties [1]. PAHs sources have mainly been reported to be pyrogenic (petroleum combustion, coal combustion, biomass combustion, etc.) [2]. Sixteen PAH monomers have been listed as priority pollutants by the United Sates Environmental Protection Agency (USEPA) and the European Union [3].

With a length of 665 kilometers, the Three Gorges Reservoir (TGR) is currently the largest water conservation project in the world, with a total water area of 1,084 km^2 [4]. The reservoir starts in Chongqing City and ends in Hubei Province. The TGR is paramount for flood control, electric power generation, navigation, and water supply, with the total surface area of 1.08 × 10^3 km^2 and the total water storage of 39.3 billion cubic meters [5], whereas the water

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quality of the TGR is crucial for human health and ecological integrity in China. The slow water flow in the TGR promotes the adsorption of dissolved pollutants on suspended sediments and sediments [6], which may change the concentration of pollutants in different environmental media and the transport and discharge of pollutants to downstream of the TGR.

In order to alleviate the potential negative impact of the operation of the super-large reservoirs on the ecological environment, TGR had adopted the staged water storage plan. Three main phases of the water storage plan were completed in 2003, 2006 and 2010, with the aim of increasing the water level in the TGR to 135, 156, and 175 m, respectively. Therefore, since 2010, the TGR had been fully operational, with water levels fluctuating between 145 m in the wet season (from April to September) and 175 m in the dry season (from October to mid-April) [7].

Therefore, relevant reports about PAH pollution in the TGR have been studied since the 2010s. A 2012 survey showed that the ΣPAHs of the water phase in the TGR ranged from 130.8 to 227.5 ng/L, whereas the PAHs were mainly emitted by the combustion of petroleum, coal, and biomass [8]. In 2013, Wang et al. [9] reported that the ΣPAH concentrations of TGR water were 15–381 ng/L in the period of impounding water, and observed that the PAH concentration decreased after 175 m water impounding. Floehr et al. [10] found that the ΣPAH concentrations of sediments were 165–1,653 ng/L, which were high enough to cause an ecotoxicological risk. On the whole, the current data are not sufficient to comprehensively evaluate the overall status of PAHs in water and sediments after comprehensive operation in the TGR, and then systematically evaluate the potential risk levels for humans and aquatic ecosystems.

The present study systematically analyzed the distributions of PAHs and the proportions of PAH monomers in the water and sediment during the wet season and the dry season by continuous multi-year field investigation (2015–2016). Meanwhile, pollution levels, source apportionment, and ecological risks of PAHs in surface water and sediment of the mainstream TGR are discussed, which can provide scientific information and decision support for the effective control of PAHs in the TGR.

2. Materials and methods

2.1. Chemicals and reagents

A standard mixture solution for PAHs that contained 16 components, namely naphthalene (Nap), acenaphthene (Ace), acenaphthylene (Acy), 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-c,d]pyrene (InP), dibenzo[a,h]anthracene (DahA), and benzo[g,h,i] perylene (BghiP), was obtained from AccuStandard, Inc, New Haven, CT, USA. Chromatographically pure ethyl acetate, acetone, and dichloromethane were obtained from Fisher Chemical Co. (USA). Solid-phase extraction membranes (ENVI-18 DSK) were obtained from Sigma-Aldrich Chemistry Co. (USA).

2.2. Sample collection

Fig. 1 illustrates the locations of 19 sampling points in the TGR (S1 to S19). Surface water samples and sediment were collected in June (wet season) and December (dry season) from 2015 to 2016.

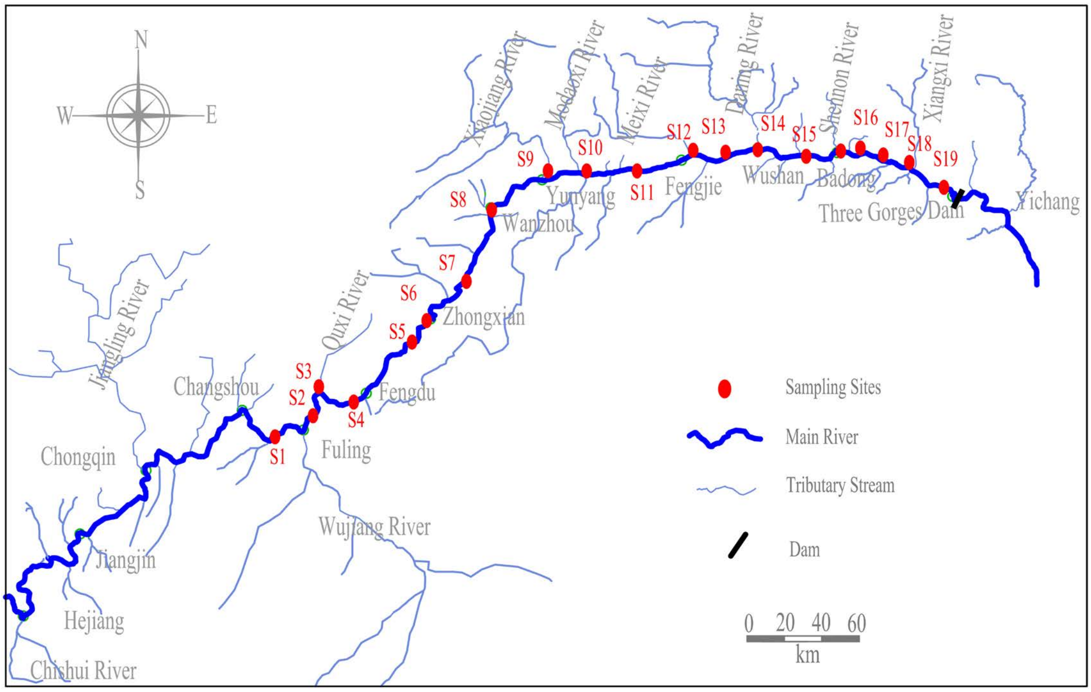

Fig. 1. Study area and the sampling points of the TGR.

In accordance with the relevant literature [11–13], in brief, a 4-L surface water (about 20 cm below water surface) was passed through 0.45 μm glass fiber membrane on the spot, and then the water sample was passed through a methanol-activated solid-phase extraction membrane to produce the PAHs. Finally, the solid-phase extraction membrane that contained the PAHs was wrapped in foil and then refrigerated. Sediments were collected using precleaned stainless steel bucket, and then stored in glass petri dish.

2.3. Sample analysis

2.3.1. Extraction process of water and sediment

By using the extraction methods of previous published papers [13], SPE extraction disks were eluted twice with ethyl acetate and dichloromethane-ethyl acetate (1:1, v:v). Then, the extracts were combined and dried over anhydrous sodium sulfate. The extracts were concentrated to 0.1 mL in a rotary evaporator (R-210, Buchi, Switzerland) and a termovap sample concentrator (N-EVAP, Organomation, USA). Finally, the samples were redissolved in 1 mL of *n*-hexane for analysis.

A certain amount of sediment was evenly spread in a glass dish. Sediment was lyophilized by freeze drier (FD5-series, SIM, USA) with 48 h, then crushed and passed through a 100-mesh sieve. Approximately 2 g of the dry sample was accurately weighed, then transferred to a 50-mL extract tube containing 25 mL of acetone-hexane (1:1, v:v) organic extraction solvent. Each mixture was extracted with a microwave digestion system (Mars6, CEM, USA), wherein the temperature changed at 10°C/min from room temperature to 120°C; this temperature was maintained for 30 min. After the microwave extraction was completed, the supernatant was passed through anhydrous sodium sulfate. Then, each sample was extracted and purified in a glass chromatography column. Finally, the eluate from the glass chromatography column was evaporated to 0.1 mL by using a rotary evaporator (R-210, Buchi, Switzerland) and a termovap sample concentrator (N-EVAP, Organomation, USA). Finally, each sample was redissolved in 1 mL of *n*-hexane for analysis.

2.3.2. GC/MS analysis

Analytical detection of PAHs was performed using a gas chromatography mass spectrometer (GC-MS) (7890B/5977A, Agilent, USA) equipped with a DB-5ms fused silica capillary column (30 m × 0.25 mm × 0.25 μm, Agilent, USA). High-purity helium (99.999%) served as the carrier gas at a flow rate of 1.0 mL/min. The transmission line and the inlet temperature were maintained at 300°C and 250°C, respectively. The injection volume was 1.0 μL and the splitless injection mode was used. The oven program was set as follows: the initial temperature was maintained at 80°C (2 min), raised to 220°C at 20°C/min (10 min), then increased to 300°C at 2°C/min (5 min). The parameters of MS were optimized through the SIM mode.

2.3.3. Quality control

Quality control and quality assurance in the sample analysis were implemented according to the regulations for water environment monitoring of China (SL 219-2013). The quantitative standards for PAHs in the samples were determined using a combination of external standard methods. The linearity correlation coefficients were between 0.9987 and 0.9998 for 16 PAH monomers. The limits of detection (LOD) were determined based on the concentrations that existed at three times the signal-to-noise ratio. The LOD of water samples ranged from 0.04 to 0.39 ng/L, whereas the LOD of sediment samples ranged from 0.08 to 0.78 ng/g [13]. In total, 16 PAH monomers were quantitatively analyzed using Mass Hunter data acquisition software on an Agilent 7890B/5977A GC/MS instrument. To avoid the injection pollution caused by the analysis process, a sample blank was made after every 10 samples had been analyzed. The analysis value was the value after the blank had been deducted. Any datum that was under LOD was calculated as not detected.

3. Results and discussion

3.1. Distribution in water and sediment

Concentrations of the 16 US EPA priority PAHs were measured in all water and sediment samples through GC/MS. Ant, Nap, and Phe had high means in the TGR water, whereas Ant, Phe, BbF, and BkF had high means in the TGR sediments. The detection frequencies of the predominant PAH monomers were as follows: Nap 86.8%, Phe 83.5%, Ant 81.4%, Nap was the most frequently detected PAH monomer in water, whereas Phe 100%, Ant 100%, BbF 100%, and BkF 79.9% were the most frequently detected PAH monomers in sediment.

Fig. 2 illustrates the distribution characteristics of ΣPAHs in water and sediment in the TGR from 2015 to 2016. From the vicinity of Lidu Street in Chongqing (S1) to the front of the dam (S19), ΣPAHs in water ranged from 3.9 to 139.3 ng/L (mean 42.4 ng/L), and the minimum and maximum values appeared at the Daning River estuary (S14) and Meixi River estuary (S12). Meanwhile, during the wet season, fluctuations of the surface water of ΣPAHs were larger than those during the dry season.

ΣPAHs in sediment ranged from 185.5 to 2,055.6 ng/g (mean 726.1 ng/g), and the minimum and maximum values were found in the vicinity of Lidu Street in Chongqing (S1) and the upstream of Fengjie (S11). Due to different sources of deposited sediment in different seasons, the differences in the annual and seasonal variations of ΣPAHs were relatively large for both water and sediment. In general, the distribution of ΣPAHs had no significant consistency in the water and sediment of the TGR.

3.2. Composition of 16 PAH monomers

The 16 PAH monomers can be divided into three groups: LM-PAHs (containing two- to three-ring PAHs), MM-PAHs (containing four-ring PAHs), and M-PAHs (containing five- to six-ring PAHs) [14].

Of all the water samples from the TGR, three-ring PAHs were the predominant compounds, with a mean value of 23.9 ng/L, accounting for an average of 59.0% of the total PAHs in 2015, followed by two- and four-ring PAHs. The mean values of two- and four-ring PAHs were 11.1 and 4.6 ng/L, accounting for averages of 27.4% and 11.3% of the

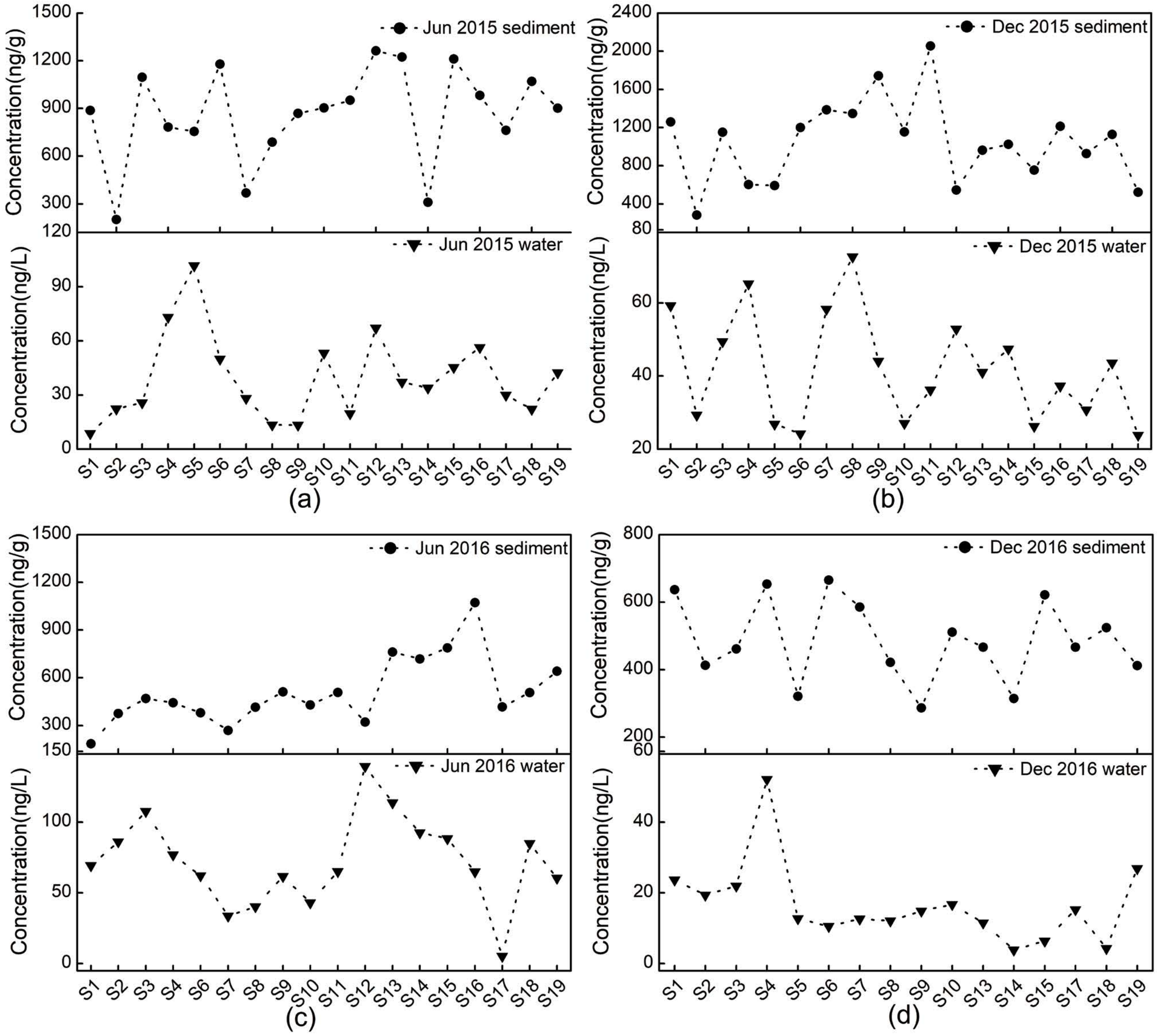

Fig. 2. Distribution characteristics of ΣPAHs in the water and sediment of the TGR.

total PAHs, respectively (Fig. 3a). In 2016, the proportions of PAH monomers of water samples were similar to those in 2015. The dominant PAH monomers were also three-ring PAHs with a mean value of 25.7 ng/L, which accounted for an average of 58.0% of the total PAHs, followed by two- and four-ring PAHs. The mean values of two- and four-ring PAHs were 14.9 and 2.8 ng/L, respectively, accounting for 33.6% and 6.2% of total PAHs (Fig. 3a). The percentages of five- and six-ring PAHs did not exceed 5% of the total PAHs in 2015 and 2016. In brief, LMW PAHs were the predominant compounds in TGR water.

As illustrated in Fig. 3b, the analysis of all the sediment samples from the TGR in 2015 and 2016 revealed that three- to five-ring PAHs were the predominant compounds, with a mean proportion of 84.4% of total PAHs, whereas two- PAHs accounted for only 2.1% of total PAHs. In 2016, the proportions of PAH monomers of sediment were similar to those in 2015. Three- to five-ring PAHs were also the dominant components, with a mean proportion of 86.6% of the total PAHs, whereas two-ring PAHs only accounted for 3.8% of the total PAHs. In general, three- to five-ring PAHs were the predominant compounds in the TGR.

3.3. Pollution levels

3.3.1. ΣPAHs in other rivers around the world

The pollution levels of the TGR were compared with the pollution levels of relevant rivers in China and abroad (Table 1). The concentrations of ΣPAHs in the TGR were approximately 2–3.5 times higher than those in the Seine River [15] and the York River [16], and were approximately equal to those in the Mississippi River [17]. Pollution levels in TGR water are much higher than those of developed

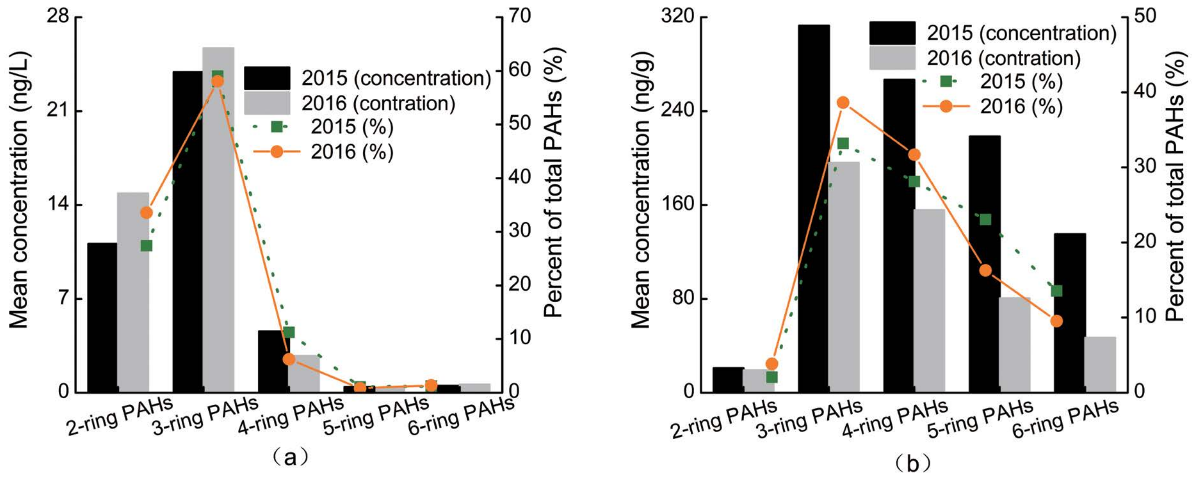

Fig. 3. Mean concentrations and percentages of two- to six-ring PAHs in TGR surface water (a) and sediment (b).

Table 1
PAHs concentrations in surface water and sediment from various sites in China and abroad

Phase	Country	Locations	Sampling time	PAHs number	Range	Mean	S.D.	Sources
Water (ng/L)	France	Seine River	1993	12	4.0–36.0	20.0	13.0	[15]
	United States	York River	1998–1999	20	2.09–122.85	13.1	24.5	[16]
		Mississippi River	1999	18	5.6–68.5	40.8	32.9	[17]
	Iran	Soltan Abad River	2013–2014	16	47.3–385.0	–	–	[18]
	China	Yellow River	2004	15	179.0–369.0	248.0	78.0	[19]
		Tonghui River	2002	16	192.9–2,651.0	762.3	777.4	[20]
		Taizi River	2010	16	1,802.0–5,869.0	3,235.0	–	[21]
		Wuhan section of the Yangtze River	2005	16	242.0–6,235.0	–	–	[22]
		Wangyang River	2013	16	416.7–4,907	–	–	[23]
		Maozhou River	2012–2013	16	13–1,212	292	–	[24]
		Rivers in Shanghai	2015	16	46.53–460.53	145.1	–	[25]
		TGR	2015–2016	16	3.9–139.3	42.4	20.4	This study
Sediment (ng/g)	United States	Savannah River	2001	16	29.0–5,375.0	1,216.0	–	[26]
	India	Gomti River	2010	16	5.24–3,365.13	687.1	–	[33]
	Mexico	Todos Santos Bay	1995	16	7.6~813	96.0	–	[34]
	South Africa	Klip River	2013–2014	–	270–5,400	–	–	[27]
	China	Peal estuary	2001	15	156.3–9,219.8	1,863.0	–	[28]
		Tonghui River	2002	16	127.1~927.7	540.4	291.8	[20]
		Yangtze River Estuary	2009	16	316.0–792.0	–	–	[35]
		Haihe River	2006	16	775.0–255,372.0	27,074.0		[30]
		Middle and lower reaches of Yangtze River	2015	16	221.0–2,418.8	751.5	–	[29]
		Wangyang River	2013	16	545.1–134,054.7	–	–	[23]
		Maozhou River	2012–2013	16	28–1,051	458	–	[24]
		Moshui River	2015	16	196.51–8,549.33	3,320.03	–	[31]
		Upper reach of the Huai River	2013–2014	15	3.96–379	65.3	–	[36]
		Songhua River	2014	16	34–4,456	–	–	[32]
		TGR	2015–2016	16	185.5–2,055.6	726.1	270.0	This study

Note: "–" denotes "no data".

countries. However, pollution levels of ΣPAHs in the TGR are lower than those of some rivers in developing countries, such as the Soltan Abad River [18], the Yellow River [19], the Tonghui River [20], the Taizi River [21], the Wuhan section of the Yangtze River [22], the Wangyang River [23], the Maozhou River [24] and rivers in Shanghai [25]. Overall, ΣPAHs pollution levels are relatively low in the TGR.

In comparison with other large rivers around the world (Table 1), the sediment pollution level of ΣPAHs found in TGR was lower than levels in some locations, such as the Wangyang River [23], the Savannah River [26], the Klip River [27], the Peal Estuary [28], the middle and lower reaches of the Yangtze River [29], the Haihe River [30], the Moshui River [31], and the Songhua River [32]. Nevertheless, the sediment pollution level was higher than that of the Gomti River [33], Todos Santos Bay [34], the Tonghui River [20], the Yangtze River estuary [35] and the upper reach of the Huai River [36]. On the whole, the ΣPAH sediment pollution level was moderate in the TGR.

3.3.2. PAH monomers with different water quality standards

Based on several water environmental quality standards, guidelines, and criteria (Table 2) [2], the water environment quality in the surface waters of the TGR was assessed in regard to PAHs. For the TGR, based on PAH monomer data from 2015, the concentrations of Ant at 26.3% of the sampling points exceeded the Canadian Environmental Quality Guidelines, simultaneously, the levels of BaP and InP at 26.3% and 31.6% of the sampling points, exceeded USEPA water quality standards in June 2015. The level of Ant at 52.6% of the sampling points exceeded the standard from the Canadian environmental quality guidelines, whereas the level of DahA at 47.3% of the sampling points exceeded the USEPA water quality standard in December 2015.

Table 2
Standards for water quality of PAHs by different countries/organization (ng/L)

Country/Organization	China	USA	European Union	Canada
Nap	–	–	2.4×10^3	1.1×10^3
Ace	–	7×10^4	–	5.8×10^3
Acy	–	–	–	–
Flu	–	5×10^4	–	3×10^3
Phe	–	–	–	400
Ant	–	3×10^5	100	12
Fla	–	2×10^4	100	40
Pyr	–	2×10^4	–	25
BaA	–	1.2	–	18
Chr	–	120	–	–
BbF	–	1.2	30[a]	–
BkF	–	12	30[a]	–
BaP	2.8	0.12	50	15
InP	–	1.2	2[b]	10
BghiP	–	–	2[b]	–
DahA	–	0.12	–	–
∑PAHs	–	–	–	–

Note: "—" denotes "no data".
[a]Means the sum of BbF and BkF.
[b]Means the sum of InP and BghiP.

In June 2016, InP and DahA levels at 5.6% and 16.7% of the sampling points exceeded the USEPA standard limits of water quality, respectively. Additionally, Ant levels at 27.7% of the sampling points, exceeded the standard limits of the Canadian environmental quality guidelines. Analyzing the monitoring data of December 2016, Ant, BaP, and DahA levels at 5.9%, 41.2%, and 35.3% of the sampling points, severally, exceeded the USEPA standard limits of water quality.

3.4. Source apportionment

According to various compositional characteristics of PAHs from different sources, isometric ratios of PAHs are frequently used to determine the sources of PAHs. Due to the relatively stable characteristics of Ant, Phe, Fla, Pyr, BaA, Chr, and others, the isometric ratios of Ant/(Phe + Ant), Fla/(Pyr + Fla), and 0.2 are often used to identify the source of PAHs [25,37], the specific analysis was shown in Fig. 4.

In surface water from the TGR from 2015 to 2016, Ant/(Phe + Ant) ratios in all water samples (Ant, Phe were detected) were above 0.1, which indicated that PAHs mainly originated from biomass, coal, and petroleum combustion. Fla/(Pyr + Fla) ratios in 70.5% of water samples (Fla, Pyr were detected) in 2015 and in 84.1% of water samples (Fla, Pyr were detected) in 2016 were above 0.5, which suggested that PAHs primarily originated from biomass and coal combustion. The Fla/(Pyr + Fla) ratios in 16.2% of water samples (Fla, Pyr were detected) in 2015 and in 10.9% of water samples (Fla, Pyr were detected) in 2016 were between 0.4 and 0.5, indicating that PAHs originated from petroleum combustion and vehicular emissions. Of total water samples (BaA, Chr were detected), 77.8% in 2015 had BaA/(BaA + Chr) ratios above 0.35, which indicated origins from biomass, coal,

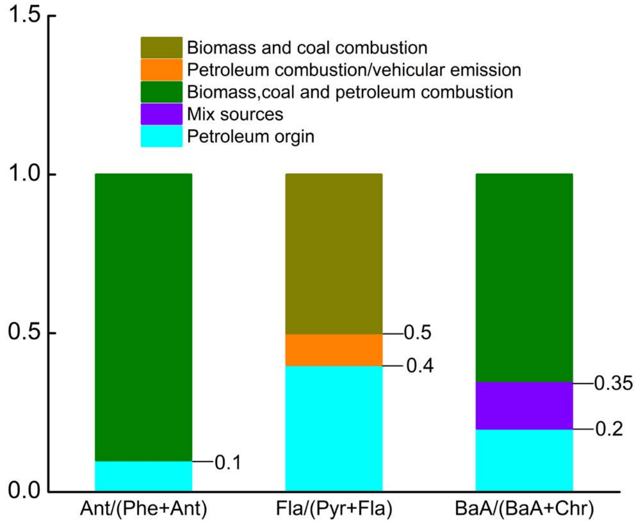

Fig. 4. Diagnostic ratios of potential PAHs sources.

and petroleum combustion. Due to the low detection rates of BaA and Chr (2% and 3%, respectively) in 2016, source apportionment was not carried out. Therefore, biomass, coal, petroleum combustion, and vehicular emissions constituted the major contributors to the PAHs that entered surface water of the TGR.

Similarly, the diagnostic ratios also indicated that biomass, coal, and petroleum combustion were the major sources of PAHs that contaminated the sediment of the TGR. The TGR sediment source apportionment results resembled the TGR water source apportionment results.

3.5. Ecological risk assessment

3.5.1. Water

Several countries and international organizations have established safety standards for aquatic organisms exposed to PAH-contaminated water through a large amount of toxicological data and a series of inferential methods (Table 3) [38]. Safety standards data indicated that PAHs might pose a threat to human health by the bioaccumulation of toxins through the food chain of aquatic organisms. As presented in Table 3, comprehensive analysis of TGR surface water

Table 3
Safety guidelines for exposure of aquatic organisms to PAHs in surface water (μg/L)

PAHs	Netherlands (Maximum permissible concentration)	Canada (Environmental quality guidelines)	Denmark (Water quality criteria)	United States (Environmental quality criteria)	European Union (Maximum admissible concentration)	This study	
						(June/December, 2015) × 10^{-3}	(June/December, 2016) × 10^{-3}
Nap	–	11.0	1.0	–	–	ND-24.9/ND-39.8	ND-50.1/ND-14.6
Phe	2.0	0.8	–	4.6	–	ND-15.2/ND-21.3	ND-6.3/0.2-16.9
Ant	–	0.12	0.01	–	0.4	2.5-37.9/1.4-17.4	ND-37.2/ND-9.6
Fla	0.5	–	–	–	1	0.7-4.8/ND-2.1	ND-2.4/ND-4.9
BaA	0.2	–	–	–	–	ND-4.7/ND-1.1	ND/ND-0.8
BkF	0.1	–	–	–	–	ND-0.9/ND-0.7	ND-0.8/ND-1.0
BaP	0.1	0.008	–	–	0.1	ND-0.7/ND-0.1	ND/ND-0.6
BghiP	0.02	–	–	–	–	ND-0.2/ND-0.7	ND-0.6/ND-0.9
∑PAHs	–	–	–	0.03	–	8.7-101.7/23.9-72.6	5.2-139.3/3.9-52.1

Note: "—" denotes "no data".
"ND" denotes "not detected".

Table 4
Ecological risk assessment of PAHs in sediments from the TGR (ng/g)

PAHs	ERL	ERM	This study	
			June/December, 2015	June/December, 2016
Nap	160	2,100	ND-38.3/7.4-72.7	8.9-33.9/ND-74.9
Ace	16	500	ND-5.68/0.9-10.4	1.0-3.5/ND
Acy	44	640	ND-34.3/ND-21.8	6.3-31.2/ND
Flu	19	540	ND-81.9/15.3-116.1	19.4-112.5/ND-10.1
Phe	240	1,500	50.9-254.9/4.3-223.2	3.6-383.4/4.6-13.8
Ant	85.3	1,100	23.9-195.27/66.3-376.1	68.1-372.7/24.6-64.9
Fla	600	5,100	25.6-96.4/16.5-133.6	10.0-68.5/34.8-125.6
Pyr	665	2,600	24.1-85.8/12.5-112.2	7.5-48.1/32.0-98.7
BaA	261	1,600	34.9-90.7/20.7-127.9	ND-4.2/28.0-83.1
Chr	384	2,800	ND-102.91/30.9-129.6	ND-35.1/33.5-84.4
BbF	—	—	32.7-196.4/9.5-237.9	12.0-56.8/33.6-83.8
BkF	—	—	ND-127.4/12.8-194.5	5.8-52.2/ND-57.4
BaP	430	1,600	9.8-65.4/4.7-137.9	ND-1.7/22.7-67.7
InP	—	—	ND-63.5/7.0-143.1	3.7-32.5/ND-55.6
DahA	63.4	260	ND-22.27/6.8-131.9	ND-9.6/ND-21.8
BghiP	—	—	ND-65.36/26.7-128.0	ND-18.4/ND-39.7

Note: "—" denotes "no data".
"ND" denotes "not detected".

PAH components from 2015 to 2016 proved that Ant levels exceeded the criteria from Denmark at some sampling points. The total concentrations of PAHs exceeded the USEPA threshold. The result indicated that the consumption of aquatic organisms posed potential risks to human health, on account of bioaccumulation of PAHs, particularly Ant.

3.5.2. Sediment

Long et al. [39] proposed the most widely used method of potential ecological risk assessment of PAHs in sediments. The two guideline values, which are named the effects range-low (ERL) and the effects range-median (ERM), delineate three concentration ranges for particular PAH monomers. The concentrations below the ERL value represent a minimal-effects range; a range intended to estimate conditions in which effects would be rarely observed. Concentrations equal to and above the ERL, but below the ERM, represent a possible-effects range within which effects may occasionally occur. Finally, the concentrations equivalent to and above the ERM value represent a probable-effects range within which effects frequently tend to occur. Based on the monitoring data from 2015 to 2016 (Table 4), the PAH monomer concentrations in all sediments of the TGR were lower than those of the ERM, whereas the PAH monomers (such as Flu, Phe, Ant, DahA, etc.) of some sampling points exceeded ERL. In conclusion, the PAHs in the sediments of the TGR have potentially toxic effects on the surrounding organisms, especially Flu, Phe, Ant, and DahA, which must be monitored intensively.

4. Conclusion

The paper systematically studied the distribution of PAHs in the water and sediment of the TGR during the wet season and the dry season from 2015 to 2016. Distribution, composition, levels, source, and risk assessment of PAHs in surface water and sediment from the mainstream Three Gorges Reservoir were investigated through systematic survey. The main conclusions are as follows:

- ΣPAHs ranged from 3.9 to 139.3 ng/L (mean 42.4 ng/L) in surface water, while ΣPAHs ranged from 185.5 to 2,055.6 ng/g (mean 726.1 ng/g) in sediment. Water samples collected during the wet season showed larger ΣPAHs fluctuations than those collected during the dry season. The distribution of ΣPAHs had no significant regularity for TGR water and sediment.
- Ant, Nap, and Phe are high-mean PAH monomers in the water of the TGR, whereas Ant, Phe, BbF, and BkF are high-mean PAH monomers in the sediments of the TGR. PAH monomers with two and three rings were predominant in water samples, whereas PAH monomers with three to five rings were the main pollutants in sediment.
- Surface water levels pollution of ΣPAHs in the TGR were lower than those of other rivers in China and higher than those of some rivers abroad, whereas the concentrations of PAH monomers such as Ant, BaP, InP, and DahA at some sampling points exceeded the limits of several water environmental quality standards from abroad. In comparison with other large rivers around the world, the sediment pollution levels of ΣPAHs in the TGR were moderate.
- PAHs pollution of water and sediment in the TGR mainly originated from pyrogenic sources, such as the combustion of biomass, coal, petroleum, and other fuels. The PAHs in water of the TGR pose a potential threat to human health due to their bioaccumulation, particularly Ant, in aquatic organisms. The PAH monomers in the sediment of the TGR also have potentially toxic effects on the surrounding organisms, especially Flu, Phe, Ant, and DahA. Therefore, the PAH monomers in the water and sediment of the TGR must be monitored intensively.

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