Environ Sci Pollut Res (2015) 22:17644–17652
DOI 10.1007/s11356-015-4980-y

RESEARCH ARTICLE

Occurrence and distribution of endocrine-disrupting compounds in the Honghu Lake and East Dongting Lake along the Central Yangtze River, China

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Received: 23 April 2015 / Accepted: 29 June 2015 / Published online: 7 July 2015

Abstract Lakes along the Yangzte River are very important for inhabitants due to their ecosystem service values. In this study, the level of eight endocrine-disrupting compounds (EDCs) was studied in the Honghu Lake and East Dongting Lake. In each lake, 21 water samples and 21 sediment samples were collected. The total concentrations of eight EDCs in surface water (47.60–419.82 ng L^{-1}, mean value: 225.65 ng L^{-1}) and sediments (202.71–635.36 ng g^{-1} dry weight (dw), mean value 371.90 ng g^{-1} dw) of Honghu Lake were significantly higher than those in surface water (43.52–394.21 ng L^{-1}, mean value 153.03 ng L^{-1}) and sediment (70.01–464.63 ng g^{-1} dw, mean value 238.42 ng g^{-1} dw) in East Dongting Lake. 4-Nonylphenol (NP), 4-octylphenol (OP), and bisphenol A (BPA) in surface water and sediments were main EDCs in two lakes. No correlation relationships were found between concentrations of EDCs in water and sediment from two lakes. The concentrations of OP and 17α-ethinylestradiol (EE2) in sediments of Honghu Lake had significant positive correlation with the content of total organic carbon (TOC). The concentrations of EDCs in outlet of Honghu Lake were comparable to those in the main lake, whereas the EDCs in outlet of East Dongting Lake were lower than those in the main lake. The EDCs in Honghu Lake and East Dongting Lake may have a significant potential biological effect on fish based on the estimation of EDC estrogenicity.

Keywords Surface water · Sediment · LC-MS · Endocrine-disrupting compounds (EDCs) · Spatial distribution

Responsible editor: Ester Heath

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Introduction

Lakes along the Yangtze River in China play a very important role as drinking, agricultural and industrial water sources, and aquaculture site. Most lakes by the Central Yangtze River used to link with Yangtze, but these lakes had lost their linkages since 1950s except Dongting Lake and Poyang Lake because of hydraulic projects (Wan et al. 2014). Hence, the water exchange and migration of aquatic organisms between the lakes and Yangtze River were cut off by dam and sluice gates (Pan et al. 2011). Unfortunately, the disconnection between the lake and Yangtze River can result in serious degrading of wetland ecosystem, great loss of biodiversity, eutrophication, depletion of aquatic resource, and so on. Linkage between the lakes and Yangtze River has been shown to have positive significant impacts on fish species diversity and environmental pollution in lake systems (Ru et al. 2008). The number of fish species and species diversity index in the Dongting lake (Yangtze-connected Lake) were 69 and 2.53, which were higher than those in the Honghu Lake (Yangtze-isolated lake) (57 and 2.19) (Ru et al. 2008). These lakes also undergo serious environmental pollution along with the rapid economic development in China since 1980s (Ruili et al. 2007; Yang et al. 2010).

East Dongting Lake and Honghu Lake in this study were Yangtze-connected and Yangtze-isolated lakes, respectively. East Dongting Lake, the largest part of Dongting Lake, is naturally connected to the Yangtze River and of great socio-economic and cultural importance (Boekhorst et al. 2010). But, pollution level of this lake is very serious and has threatened the aquatic organism and health of local people around the lake. Total nitrogen and total phosphorus were found to be the main pollutants in East Dongting Lake (Huang et al. 2013; Qin et al. 2012). Honghu Lake, the seventh largest freshwater lake in China, is cut off with Yangtze River by hydraulic projects since 1950s. Total nitrogen and total phosphorus were also the main pollutants in Honghu Lake (Ban et al. 2014). Besides, toxic organic pollutants were also detected in two lakes, such as organochlorine pesticides (Qian et al. 2006; Yuan et al. 2013), pharmaceuticals, and personal care products (Wu et al. 2014).

Endocrine-disrupting compounds (EDCs), as toxic organic pollutants, have also gained more and more attention due to their impact to reproductive organs, thyroid gland, and brain tissues, and the compounds were recently associated with cancer development in humans (Chouhan et al. 2014; Pinto et al. 2014). The EDCs in the water environment have posed threats to human health via drinking and/or food chain (Chang et al. 2009; Falconer et al. 2006). The EDCs were also widely detected in some lakes, such as Donghu Lake (Jin et al. 2013), Lake Malta (Zgola-Grzeskowiak et al. 2010), Dianchi Lake (Wang et al. 2012), and Lake Taihu (Lu et al. 2011). In this study, bisphenol A (BPA), 4-nonylphenol (NP), 4-octylphenol (OP), 17α-ethinylestradiol (EE2), estrone (E1), 17α-estradiol (αE2), 17β-estradiol (βE2), and estriol (E3) were selected for study of the occurrence and distribution of estrogens in the East Dongting Lake and Honghu Lake. There is a lot of literature pertaining to the impacts of estrogens on humans and wildlife, and it appears that there is no information about the presence of estrogens in these two specific lakes.

Materials and method

Reagents and chemicals

The eight target EDCs (BPA, NP, OP, E1, EE2, αE2, βE2, and E3) were purchased from Sigma (St. Louis, MO, USA), which were dissolved in methanol to prepare standard solutions for chemical analysis. HPLC-grade water, acetonitrile, and methanol were used for sample processing and liquid chromatography–mass spectrometry (LC-MS) analysis.

Studied area and sample collection

Rural area and small city area (Honghu City, 57 km^2) are surrounding the Honghu Lake. Rural area, industrial region, and city area (Yueyang City, 120 km^2) are around the East Dongting Lake. Aquaculture is the main human activity in Honghu Lake, in which enclosure culture is one of the main fishing methods. In East Dongting Lake, aquaculture, shipping, tourism, and sand dredging are the main human activities. East Dongting Lake (N 28° 59′–29° 38′, E 112° 43′–113° 15′), located in northeastern Hunan province, is naturally connected to Yangtze River (Fig. 1). The average runoff of East Dongting Lake to Yangtze River is 10,600 $m^3\ s^{-1}$. East Dongting Lake spreads wide on an area of 1900 km^2. The maximum and average depths of East Dongting Lake were 18.67 and 6.39 m, respectively. Honghu Lake (N 29° 39′–30° 12′; E 113° 7′–114° 05′) with an area of 348 km^2 was disconnected with Yangtze River by hydraulic projects since 1950s. The maximum and average depths of Honghu Lake were 2.32 and 1.35 m, respectively. Twenty-one surface water (0–15 cm) and 21 sediment (0–10 cm) samples were collected in each lake during May 2014. Three subsamples were collected at each site and combined before analysis. Prior to sample collection, the glass bottles were precleaned three times with Milli-Q water and methanol. All water samples were collected, stored in refrigerating chamber at a temperature of 4 °C, and analyzed in 7 days. Surface sediment samples were collected with a stainless steel sampler and placed into polytetrafluoroethylene bags. The sediment samples were freeze-dried, ground, and sieved through 60 mesh and stored at −20 °C before extraction.

Sample preparation and extraction

Water samples were passed through 0.45-μm filters under vacuum to remove the particles before extraction. Solid-phase extraction (SPE) method was used for extraction of EDCs in water (Chang et al. 2009). Briefly, 1-L water samples were passed through hydrophilic–lipophilic balanced (HLB) cartridge (6 mL, 500 mg, Waters, Milford, MA, USA) which was pretreated with dichloromethane (DCM), methanol, and Milli-Q water. After loading, each cartridge was washed with deionized water, dried under vacuum, and eluted with methanol. The collection was evaporated under gentle nitrogen stream and finally reconstituted with 100 μL of methanol for analysis.

The EDCs in sediments were extracted by ultrasonic-assisted solvent extraction and SPE method. Briefly, 5 g of the sediments was ultrasonically extracted in triplicate with 30 mL of solvent (methanol/DCM, 1:1) for 20 min. The extracts were reduced to 5 mL by rotary evaporation and dissolved in 500 mL Milli-Q water for SPE as above.

Sample analysis

The targeted EDCs in water and sediment samples were targeted by liquid chromatography–mass spectrometry using atmospheric pressure chemical ionization (LC-MS, Thermo Fisher Scientific). The analytical method was performed according to the reference (Viglino et al. 2008). Samples were

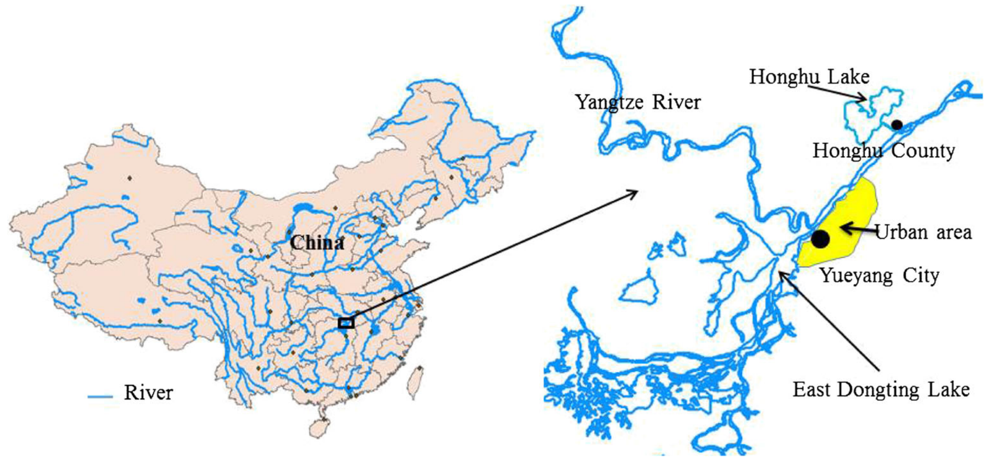

Fig. 1 The sketch map of location of East Dongting Lake and Honghu Lake

spiked with eight corresponding isotope internal standards at a concentration of 50 ng L^{-1} prior to analysis. Each sample was analyzed in triplicate. Total organic carbon (TOC) content in sediments from two lakes was determined using $K_2Cr_2O_7$-H_2SO_4 wet oxidation method described in Yeomans and Bremner (1988).

Quality assurance and quality control

External calibration for the determination of EDCs (Céspedes et al. 2004; Esteban et al. 2014) was applied in surface waters and sediments. 17β-E2-D2 was added to all the samples to monitor matrix effects with recoveries of 75–120 %. If the surrogate recoveries are beyond the range of 75–120 %, the samples were reanalyzed. The calibration curves obtained for the analytes presented good linear relationship ($R^2>0.99$) between limit of detection (LOD) to 5000 ng L^{-1} for the samples. For every set of ten samples, a procedural blank and spike sample consisting of all reagents were run to check for interference and cross contamination. No target compounds were detected in the blanks. The average recoveries of the target EDCs ranged from 63 to 124 %. The LODs of EDCs were defined as three times of the signal to noise ratio (S/N). Not detected (nd) was used to symbol non-detects and calculated as zero values in the statistics. All results were corrected with the recovery, and pollutants in sediments were reported on dry weight (dw). The LODs of the target EDCs ranged from 0.4 to 3.2 ng L^{-1} and 0.7 to 4.2 ng g^{-1} dw in water and sediment, respectively.

Calculation of the estrogenic equivalents

The estradiol equivalent concentration (EEQ) is the total amount, E2-normalized, of estrogenic compounds contained in a sample. It was calculated by the following equation: $EEQ=\sum C_i\times EEF_i$, where C and EEF are the concentration and estradiol equivalency factor of individual EDCs, respectively. EEF values of BPA, NP, OP, E1, EE2, αE2, βE2, and E3 were 0.00011, 0.00063, 0.00093, 0.3, 2.2, 0.03, 1, and 0.11, respectively, which were previously reported in the literature (Gutendorf and Westendorf 2001; Pojana et al. 2004).

Statistical analysis

Statistical analysis was performed using SPSS software (IBM, USA). Independent samples *t* test was performed to test the difference between the EDCs in different environmental media. Pearson correlation analysis was also performed to determine the relationship between the concentrations of EDCs and TOC in sediments. Statistical tests were considered significant at $p<0.05$. ArcGIS software (ESRI, USA) was applied to investigate the spatial distribution of EDCs in two lakes.

Results and discussion

Profiles of endocrine-disrupting compounds in two lakes

The EDCs in surface water of two lakes are summarized in Table 1. In East Dongting Lake, OP had the highest average concentrations among the tested EDCs with a mean value of 59.47 ng L^{-1}, followed by BPA (31.13 ng L^{-1}) and E3 (20.69 ng L^{-1}). In Honghu Lake, OP also had the maximum concentration with a mean value of 60.97 ng L^{-1}, followed by BPA (44.78 ng L^{-1}) and NP (44.31 ng L^{-1}). In East Dongting Lake, only two compounds (OP and NP) had more than 90 % of detection frequencies, whereas four compounds (OP, NP, BPA, and E3) had more than 90 % of detection frequencies in Honghu Lake. Hence, independent samples *t* test was carried out to test the difference of OP and NP in surface water of East Dongting Lake and Honghu Lake. The levels of OP in surface water between the two lakes were not significantly different. But, concentrations of NP in surface water of Honghu Lake were significantly higher than those in East Dongting Lake. BPA, EE2, E3, and E1 in surface water of Honghu Lake had higher detection frequencies and average values than those in

Table 1 The mean concentration (ng L^{-1}), ranges, and detection frequencies of EDCs in surface water of two lakes

Compounds	East Dongting Lake (*n*=21)				Honghu Lake (*n*=21)			
	Min	Max	Mean	DF (%)	Min	Max	Mean	DF (%)
OP	21.94	115.51	59.47	100	nd	185.32	60.97	95.24
NP	nd	38.43	19.53	95.24	nd	104.02	43.31	95.24
BPA	nd	140.90	30.13	38.10	15.80	110.38	44.78	100
E1	nd	41.01	5.63	14.29	nd	83.52	17.64	38.10
αE2	nd	33.18	4.21	23.81	nd	74.71	6.25	14.28
βE2	nd	52.81	10.32	28.57	nd	58.94	7.26	14.28
EE2	nd	24.88	3.04	14.29	nd	43.93	17.73	66.67
E3	nd	51.43	20.69	66.67	nd	56.35	27.70	90.48

n number of samples, *Min* minimum value, *Max* maximum value, *DF* detection frequency

East Dongting Lake. The total concentrations of eight EDCs in surface water of Honghu Lake ranged from 47.60 to 419.82 ng L^{-1} with a mean value of 225.65 ng L^{-1}, which were significantly higher than those in East Dongting Lake (43.52–394.21, mean value of 153.03 ng L^{-1}).

For sediment samples in East Dongting Lake (Table 2), BPA had the highest concentration among the tested EDCs with a mean value of 101.74 ng g^{-1} dw, followed by NP (73.42 ng g^{-1} dw), E1 (20.44 ng g^{-1} dw), and OP (18.78 ng g^{-1} dw). Interestingly, BPA, NP, E1, and OP were also the main EDCs in sediments of the Honghu Lake. Four (BPA, NP, E1, and OP) and five EDCs (BPA, NP, E1, OP, and EE2) had more than 80 % of detection frequencies in East Dongting Lake and Honghu Lake, respectively. Results of independent samples *t* test indicated that the levels of NP, OP, and E1 were significantly higher in sediment samples of the Honghu Lake than those in the East Dongting Lake. But, there was no significantly difference between the concentrations of BPA in sediments of two lakes. The total concentrations of eight EDCs in Honghu Lake were in the range 202.71–635.36 ng g^{-1} dw with a mean value of 371.90 ng g^{-1} dw, which were significantly higher than those in the East Dongting Lake (70.01–464.63 ng g^{-1} dw, mean value of 238.42 ng g^{-1} dw). In East Dongting Lake and Honghu Lake, the concentrations of NP, OP, and BPA accounted for more than 68 % of total EDCs detected in the surface water and sediment samples, respectively, indicating that the concentrations of alkylphenols (NP and OP) and BPA were more higher than those of steroid estrogens (E1, E1, EE2, αE2, βE2, and E3).

The difference in EDC levels between the two lakes could be due to the following reasons. Firstly, the water flows from Xiangjiang River and South Dongting Lake to East Dongting Lake, then to the Yangtze River. Hence, there exists huge water exchange in East Dongting Lake, whereas water exchange between Honghu Lake and Yangtze River was cut off because of hydraulic projects. The water exchange may dilute the pollutants and enhance the degradation of EDCs, because oxygen is an important factor for EDC degradation (Soares et al. 2008). Secondly, enclosure culture for fishing still exists in Honghu Lake, whereas no enclosure culture is found for East Dongting Lake. The embanked pens and net enclosures are two main forms of pen culture in fish farming. The enclosure culture had been shown to have serious effects on water quality (Tao et al. 2009). The improper and abuse of fish bait for enclosure culture in the lake may be an important

Table 2 The mean concentration (ng g^{-1} dw), ranges, and detection frequencies of EDCs in surface sediments of two lakes

Compounds	East Dongting Lake (*n*=21)				Honghu Lake (*n*=21)			
	Min	Max	Mean	DF (%)	Min	Max	Mean	DF (%)
OP	3.98	56.63	18.78	100	2.59	95.97	32.83	100
NP	nd	197.05	73.42	95.24	nd	242.85	115.90	85.71
BPA	nd	251.65	101.74	85.71	nd	380.70	131.08	80.95
E1	nd	111.93	20.44	80.95	nd	170.05	49.97	85.71
αE2	nd	5.01	0.38	9.52	nd	45.73	3.72	23.81
βE2	nd	36.17	2.20	14.29	nd	38.23	4.38	42.86
EE2	nd	27.39	5.82	71.43	nd	33.28	12.32	90.48
E3	nd	66.67	15.64	61.90	nd	125.31	21.70	47.62

n number of samples, *Min* minimum value, *Max* maximum value, *DF* detection frequency source for EDC contamination. *Limnodilus* spp., a water earthworm used as fish bait, have been found to contain BPA, OP, and NP at microgram per gram levels (Dong 2014).

Lakes with a low rate of water exchange and oxygen content are often more polluted. The levels of NP in Shihwa Lake were 10.4–5054.1 ng g^{-1} dw in sediments and 17.4–130.2 ng L^{-1} in water, and the lake was probably one of the most polluted areas in Korean Peninsula concerning alkylphenol contamination (Li et al. 2004). East Lake of China is a classical urban and domestic sewage-holding lake, having the concentrations of NP, OP, BPA, and βE2 in the range 260–4042, 10–133, 20–534, and nd–12.0 ng L^{-1} in surface water, respectively (Jin et al. 2013). Taihu Lake, the third largest freshwater and semi-enclosed lake in China, had high concentrations of NP with 262–1443 ng L^{-1}, followed by BPA (9.15–33.47 ng L^{-1}), EE2 (nd–16.37 ng L^{-1}), E1 (nd–15.77 ng L^{-1}), βE2 (nd–10.75 ng L^{-1}), and OP (nd–5.22 ng L^{-1}) in surface water (Lu et al. 2011). Dianchi Lake is a semi-enclosed ecosystem with a very low rate of water exchange, and the levels of NP, BPA, and OP in surface water/sediment were 12.55–45.28 ng L^{-1}/1.94–4.58 ng g^{-1} dw, 50.62–530.33 ng L^{-1}/2.69–166.87 ng g^{-1} dw, and 2.72–21.37 ng L^{-1}/ng g^{-1} dw, respectively (Wang et al. 2012). In this study, the OP levels in surface water of East Dongting Lake (21.94–115.51 ng L^{-1}) and Honghu Lake (nd–185.32 ng L^{-1}) were higher than those in Taihu Lake and Dianchi Lake, but comparable to those in East Lake of China. The NP levels in surface water of East Dongting Lake (nd–38.43 ng L^{-1}) and Honghu Lake (nd–104.02 ng L^{-1}) were lower than those in Taihu Lake, East Lake, and Shihwa Lake, but higher than those in Dianchi Lake. The BPA concentrations in surface water of East Dongting Lake (nd–140.90 ng L^{-1}) and Honghu Lake (15.80–110.37 ng L^{-1}) were lower than those in East Lake and Dianchi Lake, but higher than those in Taihu Lake. E1, βE2, and EE2 concentrations in water of two lakes were higher than those in East Lake and Taihu Lake. The results about EDCs in sediments of lakes were scarce, but the EDC levels in two studied lakes were higher than those corresponding in East Lake.

The relationships between endocrine-disrupting compound levels in surface water and sediments and total organic carbon and endocrine-disrupting compound levels in sediments

EDCs entering into the aquatic environment can distribute into different media, such as water, sediment, and suspended particles. OP and NP in two lakes with both high detection frequencies in surface water and sediments were selected for Pearson

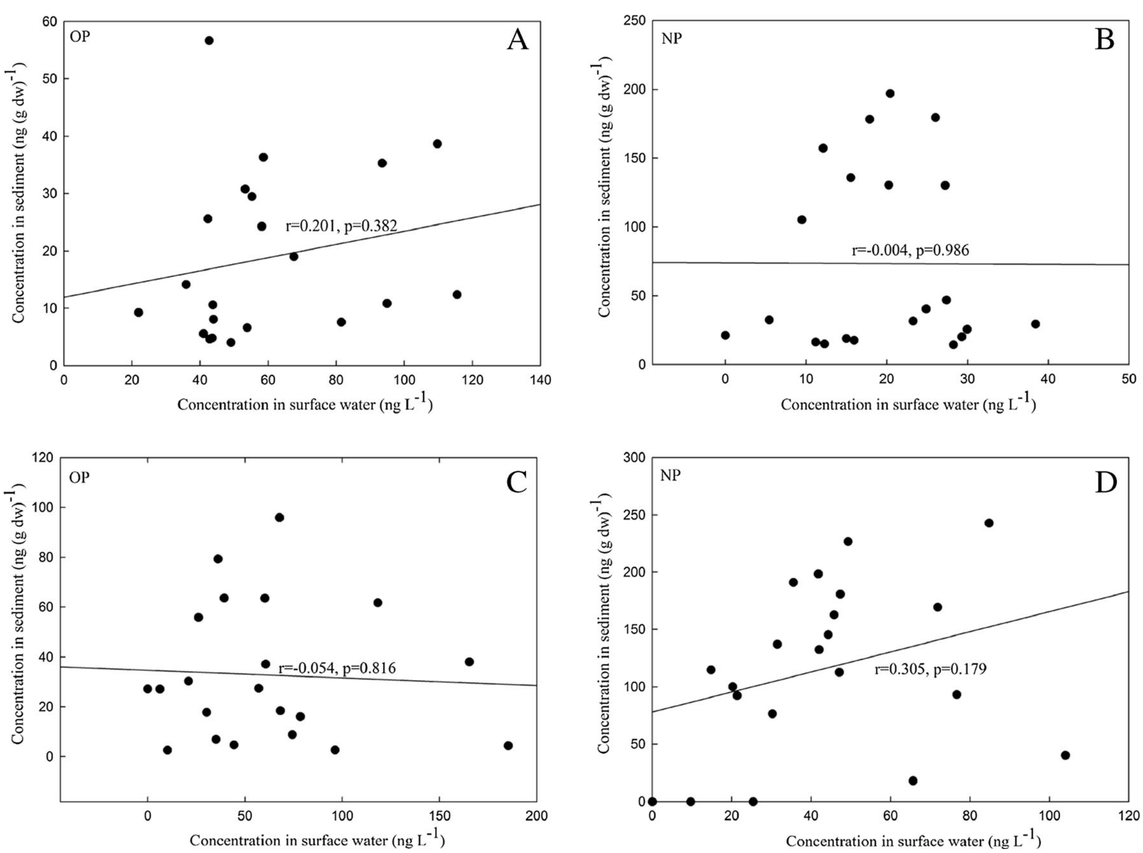

Fig. 2 The Pearson correlation analysis between the OP and NP concentrations in water and sediment of East Dongting Lake (**a**, **b**) and Honghu Lake (**c**, **d**)

correlation analysis. The p values of Pearson correlation analysis between the EDCs in water and sediments of two lakes were all above 0.15 and not significant (Fig. 2). Hence, no correlation relationships were found between EDCs in water and sediments in the two lakes. These results were different from those in East Lake, an enclosed and domestic sewage-holding lake, in which high correction coefficients were observed between the EDC levels in water and sediments (Jin et al. 2013). The EDCs in the water and sediment of Anoia River and Cardener River (Spain) also observed no correlation relationships (Petrovic et al. 2002).

Sediment properties are important for the distribution of contaminants in sediments, such as organic carbon and particle size distribution (Lai et al. 2000). The EDC compounds with detection rates more than 90 % in sediment samples of East Dongting Lake (OP and NP) and Honghu Lake (OP and EE2) were selected for the Pearson correlation analysis. Figure 3 shows that OP and NP levels in sediments of the East Dongting Lake had no correlation with the TOC content, whereas OP and EE2 in sediments of Honghu Lake had significant positive correlation relationship with the TOC content. The water with high speed flows from Xiangjiang River and South Dongting Lake to East Dongting Lake, then to Yangtze River, so organic carbon was not easy to deposit to the sediments. Honghu Lake was isolated from Yangtze River as an enclosure lake with low water exchange, so the TOC was abundant in sediments. The TOC contents in Honghu Lake ranged from 1.16 to 15.95 %, which was significantly higher than those in sediments of East Dongting Lake (0.08–2.38 %). No correlation relationship was found between concentrations of OP and NP and content of TOC in sediments in East Dongting Lake, which may be due to the low TOC content in this lake. The results also suggested that OP and EE2 in sediments of Honghu Lake could be mainly associated with organic-rich sediments through hydrophobic interaction, in virtue of their higher hydrophobicity with a log Kow value of 4.12 (Ahel and Giger 1993) and 4.15 (Lai et al. 2000) for OP and EE2, respectively. To sum up, the organic carbon may play a key factor in controlling the distributions of OP and EE2 in the sediment of Honghu Lake.

Spatial distribution of endocrine-disrupting compounds in surface water and sediments

Figure 4 shows the spatial distribution of EDCs in surface water and sediments in two lakes. The levels of EDCs in surface water in northeastern part of Honghu Lake were higher than those in the southwestern part of Honghu Lake (Fig. 4a). But, EDC levels in sediments of Honghu Lake showed the opposite trend (Fig. 4b). Sewage treatment plant has also been regarded as a significant EDC point source,

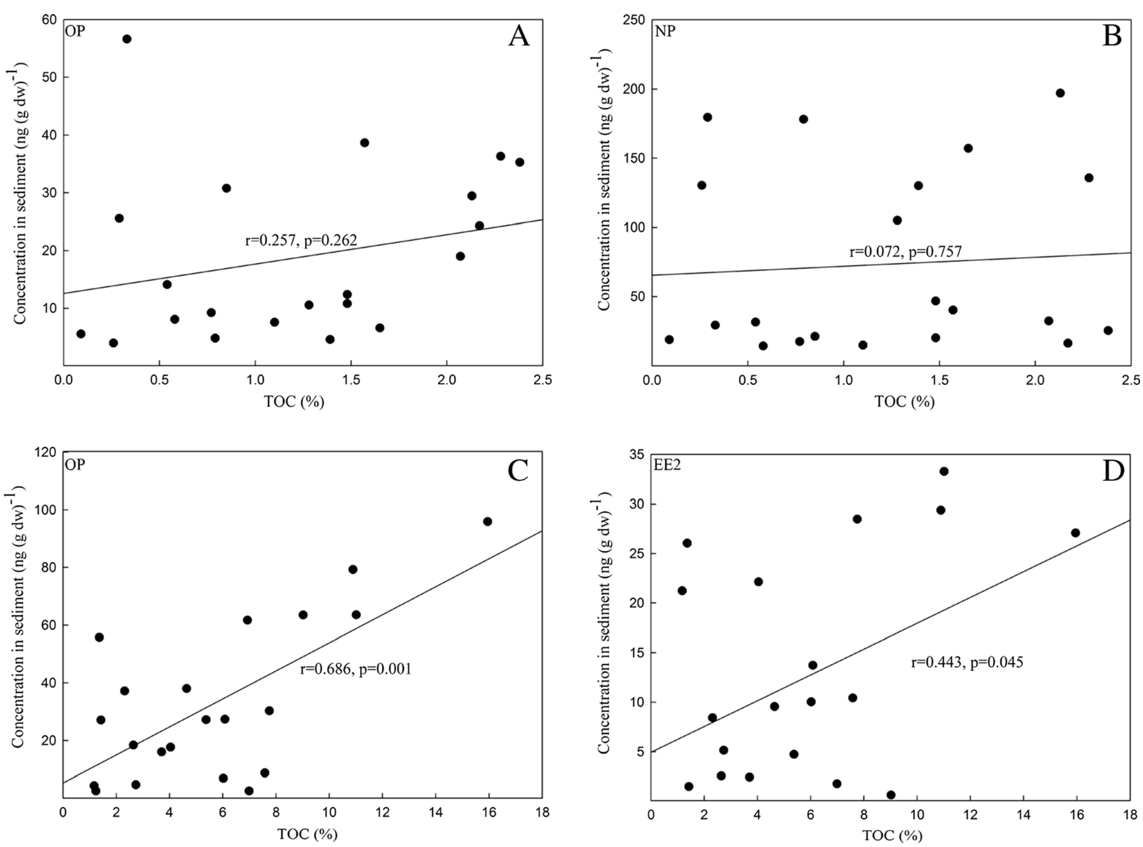

Fig. 3 The correlation relationships between EDCs and TOC in sediments of East Dongting Lake (**a**, **b**) and Honghu Lake (**c**, **d**)

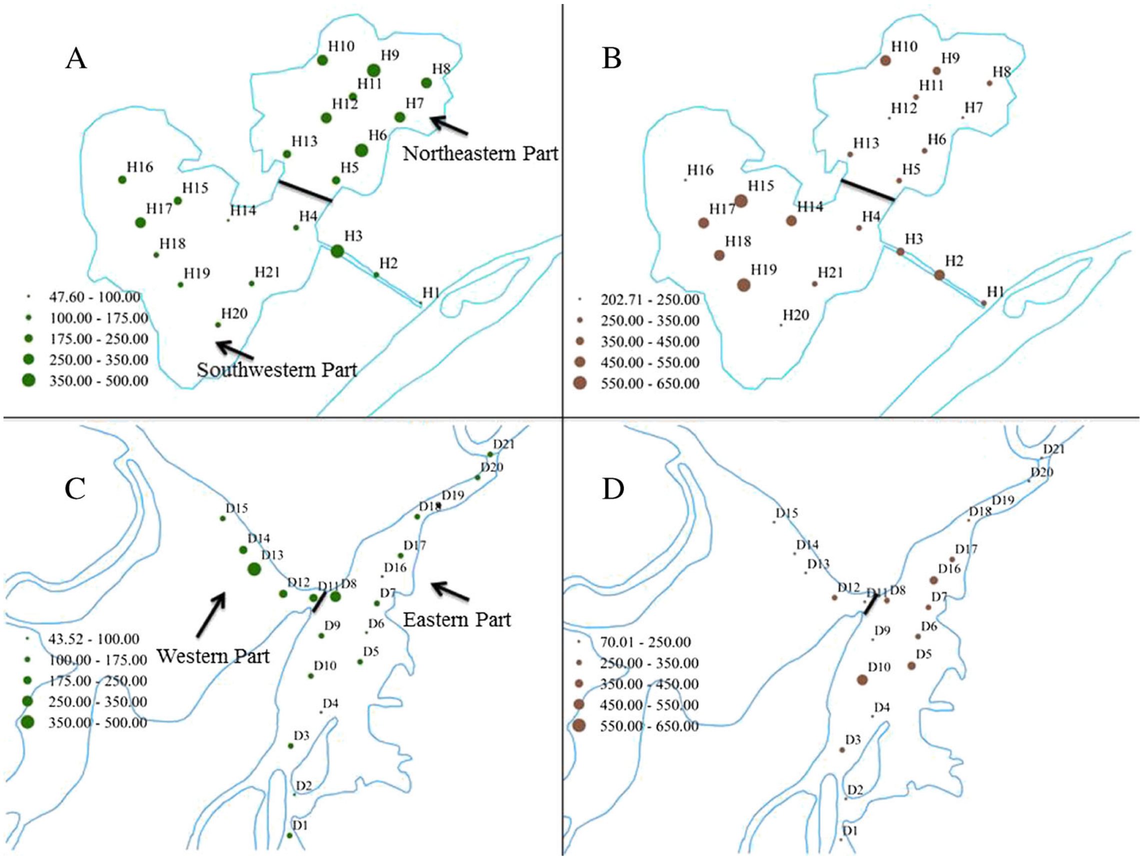

Fig. 4 The spatial distribution of EDCs in Honghu Lake (**a**, **b**) and East Dongting Lake (**c**, **d**) (**a**, **c** EDC concentrations in water; **b**, **d** EDC concentrations in sediment)

particularly for surface water and underground water (Auriol et al. 2006). The sewage treatment plant in Honghu City located near the Yangtze River, so the effluent from sewage treatment plant may not the point source for EDC pollution in Honghu Lake. Surrounding the Honghu Lake is the main agricultural area, so agricultural and livestock practices may be one of the important non-point sources for EDC pollution in Honghu Lake.

For East Dongting Lake, the pollution levels of EDCs in surface water at sampling sites (D1–D7, D9–D10, D16, and D17) of eastern part of East Dongting Lake except for D8 were relatively lower compared with the western part of East Dongting Lake (D11–D15) (Fig. 4c). Site D13 had the highest EDC concentration and near to the boat mooring, where fisherman lived in. This may account for the distribution of EDCs in water. The levels of EDCs in sediment samples of eastern part of East Dongting Lake (D1–D10; D16 and D17) were relatively higher than those in western part of East Dongting Lake (D11–D15) (Fig. 4d). The levels of EDCs in water and sediments of sampling sites (D18–D21) in the lake outlet were relatively lower than those in the main lake (D1–D17). This result was similar with the spatial distribution of heavy metals in East Dongting Lake (Zhu et al. 2008). The eastern part of East Dongting Lake was close to the intensive population and industrial region of Yueyang City. Four sewage treatment plants in Yueyang City located near the lake, and more than 1.5 million tons of wastewater was discharged into the lake every year. The western part of East Dongting Lake was close to the nature reserve and agricultural region with less wastewater discharged. This could be explained for the difference of EDC levels in sediments of the two parts of the East Dongting Lake.

EDCs in sediment may reflect the long-term pollution of EDCs in the two lakes. By comparison of spatial distribution of EDCs in sediments between East Dongting Lake and Honghu Lake, it was obvious that the EDCs in lake outlet (H1–H3) of Honghu Lake were comparable to those in the main lake, whereas the EDCs in lake outlet (D18–D21) of East Dongting Lake were lower than those in the main lake. This may be caused by the TOC and difference of outlet water exchange between lake and Yangtze River in the two lakes.

Estimation of endocrine-disrupting compound estrogenicity

The EEQ values in water and sediment of East Dongting Lake were in the range 0.0024–37.66 ng L^{-1} and 0.0046–36.21 ng g^{-1}, respectively, and more than 66 % of the sampling sites had EEQ less than 10 ng L^{-1} or ng g^{-1}. The EEQ values in water and sediment of Honghu Lake were in the range 0.0010–30.59 ng L^{-1} and 0.24–50.07 ng g^{-1}, respectively, and more than 55 % of the sampling sites had EEQ more than 10 ng L^{-1} or ng g^{-1}. When the EEQ values between 2.5 and 10 ng L^{-1}, an increase of plasma vitellogenin levels can occur in fish (Solé et al. 2000). A decrease of testicular growth in male trout can be observed at the EEQ values in the range 10–100 ng L^{-1} (Harries et al. 1997). The production of testis-ova in the testes of male medaka can be noticed at EEQ >100 ng L^{-1} level (Seki et al. 2002). Hence, the EDCs in East Dongting Lake and Honghu Lake at specific sites may induce biological effects on the endocrine system of aquatic organisms, if the exposure to these levels is of sufficient duration. Furthermore, the aquatic organisms in Honghu Lake could experience more serious biological effect caused by EDCs based on the EEQ values. Further research will be needed to investigate the influence of EDC pollution on the aquatic life like fish or frogs. Then, based on the EDC levels in aquatic products, the potential risk to humans via consuming aquatic products could be assessed in the future research.

Conclusion

East Dongting Lake and Honghu Lake are important lakes along the Central Yangtze River, China. Occurrence and distribution of eight EDCs were investigated in this study, in which NP, OP, and BPA were main EDCs in two lakes. The EDC levels in surface water and sediments of Honghu Lake were significantly higher than those in East Dongting Lake. Compared to the levels of other lakes worldwide, the EDC levels in East Dongting Lake and Honghu Lake were not desirable. No correlation relationship was found between the EDCs in water and sediments. The organic carbon may play a key factor in controlling the distributions of OP and EE2 in the sediment of Honghu Lake, whereas no correlation was found between the TOC and concentrations of OP and NP in sediments of East Dongting Lake. Estimation of EDC estrogenicity indicated that the EDCs in Honghu Lake and East Dongting Lake may have a significant potential biological effect on fish.

Acknowledgments This project was supported in part by the Foundation of Key Laboratory of Yangtze River Water Environment, Ministry of Education (Tongji University), China (No. YRWEF201402), Foundation of the State Key Laboratory of Water Resources and Hydropower Engineering Science (Wuhan University), China (No. 2013B115), Natural Science Foundation of Hubei Province (2014CFA114), National Natural Science Foundation of China (No. 31400113), Youth Innovation Promotion Association of Chinese Academy of Sciences (No. 2015282), and the Hundred Talents Program of the Chinese Academy of Sciences (Y329671K01).

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