Ecotoxicology and Environmental Safety 180 (2019) 668–678

Contents lists available at ScienceDirect

Ecotoxicology and Environmental Safety

journal homepage: www.elsevier.com/locate/ecoenv

Persistent organic pollutants in typical lake ecosystems

Cui Li[a,b], Lili Yang[a,b], Miwei Shi[c], Guorui Liu[a,b,*]

[a] State Key Laboratory of Environmental Chemistry and Ecotoxicology, Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, Beijing, 100085, China
[b] College of Resources and Environment, University of Chinese Academy of Sciences, Beijing, 100190, PR China
[c] Hebei Engineering Research Center for Geographic Information Application, Institute of Geographical Sciences, Hebei Academy of Sciences, Shijiazhuang, 050051, China

ARTICLE INFO

Keywords:
Persistent organic pollutants
Lake
Water
Polychlorinated naphthalenes
Brominated flame retardants

ABSTRACT:

Persistent organic pollutants (POPs) are highly toxic organic chemicals. Lakes are one of the main sinks of POPs. POPs can be accumulated in multiple matrices in lake ecosystems and biomagnified through the food web, and thus pose a potential threat not only to lake ecosystems, but also to human health. Given their potential persistent risks, they have received much attention over the past decades. This review comprehensively summarizes the data on the levels and distributions of POPs in selected typical lake ecosystems in China and worldwide, involving water, sediments, organisms, and surrounding soils and atmosphere. It was found that current publications on POPs in Chinese lakes are mainly related to lakes in the developed eastern plain area, with only a few studies concerning the less-developed Qinghai-Tibet Plateau area. Similarly, around the world, there are more research on POPs in developed countries and less in relatively less-developed areas. Moreover, there are significant differences in the levels of POPs in different matrices in different lake ecosystems. Legacy POPs, such as polycyclic aromatic hydrocarbons (PAHs), organochlorine pesticides (OCPs), polychlorinated biphenyls (PCBs), polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs), and polybrominated diphenyl ethers (PBDEs), were commonly detected and reported in different lakes, while emerging POPs like perfluorinated compounds (PFCs), polychlorinated naphthalenes (PCNs), Tetrabromobisphenol A (TBBPA), and hexabromocyclododecane (HCBD) were relatively less detected or reported. A comprehensive summarization on the levels and distributions of traditional and emerging POPs in lake ecosystems could be significant for further understanding the behaviors and risks of POPs in lake ecosystems.

1. Introduction

Persistent organic pollutants (POPs) have received increased global attention over the past decades. In order to eliminate or reduce the release of POPs into the environment, several international treaties have been established calling for efforts and actions from the international community, such as the Protocol to the regional UNECE Convention on Long-Range Transboundary Air Pollution (CLRTAP) on POPs and the Stockholm Convention on POPs. These international treaties established strict international regimes for lists of POPs, including 16 chemicals in the UNECE Protocol and 12 initial and 16 newly added chemicals in the Stockholm Convention.

There are many lakes in China, some of which are important freshwater resources closely related to people's daily lives. As an important part of surface water systems, lakes are one of the main sinks of POPs and also important sources of secondary pollution in lake ecosystems. POPs in lakes can be accumulated in the fatty tissue of living organisms through the food web, and also pose potential risks to humans. In many instances, exposure to POPs can lead to serious health effects including certain cancers, birth defects, dysfunctional immune and reproductive systems, greater susceptibility to disease and damage to the central and peripheral nervous systems (UNEP, 2019).

There are many publications on POPs in lake ecosystems. Most of the studies only focus on the same contaminant in different lake mediums or different contaminants in the same lake medium. Overall reviews of different POPs in different regions covering different lake mediums have rarely been reported. In this review, we comprehensively summarize the data on the distribution of several POPs in selected typical lake ecosystems in China and worldwide, involving water, sediments, organisms, and surrounding soils and atmosphere. POPs included in this review are polycyclic aromatic hydrocarbons (PAHs), organochlorine pesticides (OCPs), polychlorinated biphenyls (PCBs), polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs), polybrominated diphenyl ethers (PBDEs), perfluorinated

* Corresponding author. College of Resources and Environment, University of Chinese Academy of Sciences, Beijing, 100190, PR China.
E-mail address: grliu@rcees.ac.cn (G. Liu).

https://doi.org/10.1016/j.ecoenv.2019.05.060
Received 28 March 2019; Received in revised form 19 May 2019; Accepted 20 May 2019
Available online 27 May 2019

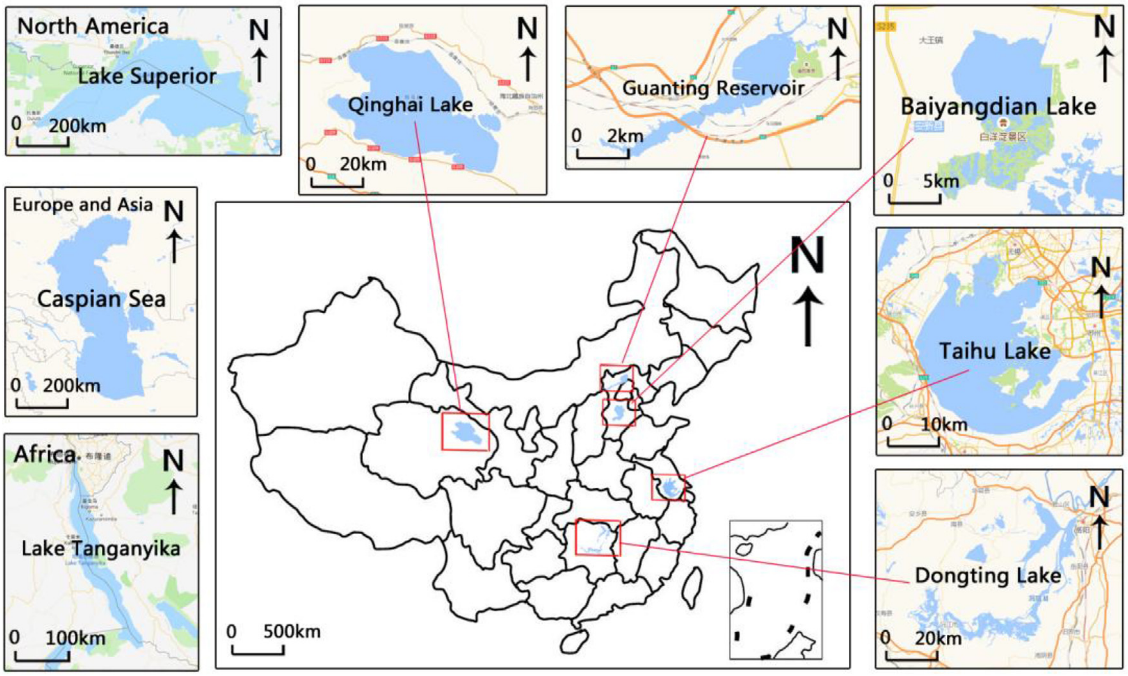

Fig. 1. Location of lakes studied in this review.

Table 1
Levels of POPs in sediment, organism and soil samples from the Caspian Sea.

Compounds	Year	Sample	Range (mean)	Reference
DDTs	2000–2001	sediments	0.006–13.401 (1.098)[a]	de Mora et al. (2004)
HCHs	2000–2001	sediments	0.004–3.46 (0.305)[a]	de Mora et al. (2004)
PCBs	2000–2001	sediments	0.00003–0.0064[a]	de Mora et al. (2004)
HCB	2000–2001	sediments	< 0.001–0.6 (0.0661)[a]	de Mora et al. (2004)
OCPs	2009	sediments	1.8–12.68[a]	Javedankherad et al. (2013)
PCBs	2009	sediments	0.39–2.64[a]	Javedankherad et al. (2013)
PAHs	2012	sediments	232.1–1014 [a]	Varnosfaderany et al. (2015)
PAHs	2005	sediments	830-3600 (1700) [a]	Boehm et al. (2005)
PAHs	*	sediments	3.8-4,800[a]	Nemirovskaya and Brekhovskikh, 2008
PAHs	2015	sediments	17.3–926.7[a]	Baniemam et al. (2017)
PAHs	2016	sediments	14.3–85.8[a]	Baniemam et al. (2017)
DDTs	2008	avian feathers	87[b]	Rajaei et al. (2011)
DDTs	2008	avian muscles	1089.5[b]	Rajaei et al. (2011)
HCHs	2008	avian muscles	20[b]	Rajaei et al. (2011)
HCB	2008	avian feathers	3.5 [b]	Rajaei et al. (2011)
PAHs	2011	Persian sturgeon	2095–6587 [a]	Mashroofeh et al. (2015)
PAHs	2011	Stellate sturgeon	1942–6206 [a]	Mashroofeh et al. (2015)
PCBs	2008	avian feathers	32[b]	Rajaei et al. (2011)
PCBs	2008	avian muscles	408.5[b]	Rajaei et al. (2011)
DDTs	1983–1992	Soils	58-1596 (573) [a]	Aliyeva et al. (2013)
HCHs	1983–1992	Soils	4-86 (28) [a]	Aliyeva et al. (2013)
DDTs	2008	Soils	37 [a]	Shahbazi et al. (2012)
HCHs	2008	Soils	21 [a]	Shahbazi et al. (2012)
PCBs	2008	Soils	4.7–34.7[a]	Aliyeva et al. (2012)
HCHs	2009	Soils	0.90–24.46 [a]	Aliyeva et al. (2012)
DDT	2009	Soils	1.43-1, 115.4 [a]	Aliyeva et al. (2012)
HCB	2009	Soils	0.02–1.63 [a]	Aliyeva et al. (2012)

*Lack of data.
[a] ng/g dry weight.
[b] ng/g wet weight.

compounds (PFCs), hexabromocyclododecane (HBCD), Tetrabromobisphenol A (TBBPA) and polychlorinated naphthalenes (PCNs). This comprehensive summarization of the levels and distributions of traditional and emerging POPs in lake ecosystems could be significant for further understanding the behaviors and risks of POPs in lake ecosystems.

2. Investigated lakes

Eight typical lakes in China and worldwide were selected in this study. The choice of these lakes was based on a combination of their significance to ecosystem and human health, geographical distribution, historical pollution and data availability. The distribution of these lakes is shown in Fig. 1. These selected lakes are geographically distributed all over the world, including both freshwater lakes and saltwater lakes. Taihu Lake, Qinghai Lake, Dongting Lake, Guanting Reservoir and Baiyangdian Lake were selected for the study of POPs in Chinese lakes while the Caspian Sea, Lake Superior and Lake Tanganyika were chosen for the study of POPs in worldwide lakes.

The Caspian Sea is the largest lake in the world that is also an saltwater lake, and is located between Europe and Asia; Lake Superior is the largest freshwater lake in the world and also the largest of the Great Lakes in North America, shared by the United States and Canada. Its storage capacity accounts for more than half that the Great Lakes; Lake Tanganyika is a freshwater lake in central Africa, located in the western rift of the Great Rift Valley and is also the second oldest freshwater lake in the world; Taihu Lake resides in the Yangtze Delta plain of eastern China, one of the five largest freshwater lakes in China; Dongting Lake, located in southeastern China, is the second largest freshwater lake in China and also an important resource for grain, oil and aquatic products; Guanting Reservoir was once one of the main water sources in Beijing. However, it was seriously polluted in the late 1980s and finally withdrawn from the drinking water system in 1997; Baiyangdian Lake is the largest freshwater lake in northern China; Qinghai Lake is the largest lake in China classified as an saltwater lake, located in the northeastern of the Qinghai-Tibet Plateau in northwestern China.

In this review, we compiled nearly all the available publications, published within the last 30 years, reporting levels of POPs (PAHs, OCPs, PCBs, PCDD/Fs, PBDEs, PFCs, HBCD, TBBPA, and PCNs) in different lake matrices (sediments, water, organisms, surrounding soils and atmosphere) of these eight widely distributed typical lake ecosystems (see Tables 1–6). It was expected that the levels and distributions of traditional and emerging POPs in the lake ecosystems summarized in this review could be significant for further understanding the behaviors and risks of POPs in lake ecosystems.

3. POPs in typical lakes worldwide

3.1. Typical lake between Europe and Asia: the Caspian Sea

3.1.1. Sediments

PAHs, PCBs, DDTs and HCHs are the mainly studied POPs in the Caspian Sea sediments which were collected during 2000–2016. Reports on sediments collected during 2000–2001 show that the concentration of ΣDDTs ranges from 0.006 to 13.401 ng/g dw (mean 1.098); ΣHCHs ranges from 0.004 to 3.46 ng/g dw (mean 0.035); ΣPCBs ranges from 0.00003 to 0.0064 ng/g dw; HCB ranges from < 0.001 to 0.6 ng/g dw (mean 0.0661) (de Mora et al., 2004). Levels of ΣOCPs and ΣPCBs in sediments collected in 2009 were 1.8–12.68 ng/g dw and 0.39–2.64 ng/g dw, respectively (Javedankherad et al., 2013). Levels of ΣPAHs in sediments collected in 2012 from the southwestern Caspian Sea range from 232.1 to 1014 ng/g dw (mean 520) (Varnosfaderany et al., 2015), while the level of ΣPAHs in sediments collected in 2005 from the Absheron region of the Caspian Sea was 830-3600 ng/g dw (mean 1700) (Boehm et al., 2005); sediments from the northern Caspian Sea ranged from 3.8 to 4800 ng/g dw (Nemirovskaya and Brekhovskikh, 2008), and sediments collected in fall of 2015 and winter of 2016 from the southern Caspian Sea were 17.3–926.7 ng/g dw and 14.3–85.8 ng/g dw, respectively (Baniemam et al., 2017). Levels of PAHs showed a significant declining trend from 2005 to 2016 and the overall pollution of PAHs in sediments is at a low to moderate level.

3.1.2. Organisms

POPs studied in biota samples from the Caspian Sea are the same as POPs studied in sediments, which are PAHs, PCBs, DDTs and HCHs. The biota samples studied in previous researches are mainly fish and avian species. Concentrations of ΣPAHs in the various tissues of Persian sturgeon and Stellate sturgeon collected in 2011 from the Iranian coastline of the Caspian Sea were 2095–6587 ng/g dw and 1942–6206 ng/g dw, respectively (Mashroofeh et al., 2015). The high levels of PAHs in avian species may relate to the high lipid content in avian species. Rajaei et al. found that the average concentrations of PCBs in muscles and feathers of avian species were 408.5 ng/g ww and 32 ng/g ww respectively. DDTs were the dominate OCPs in both muscles and feathers, the average concentrations of which were 1089.5 ng/g ww, accounting for 89% of the total OCPs, and 87 ng/g ww, accounting for 53% of the total OCPs, respectively. The lowest OCPs in muscles were HCHs (20 ng/g ww) and in feathers it was HCB (3.5 ng/g ww) (Rajaei et al., 2011). Muscles contained significantly higher levels of PCBs and OCPs than feathers and this could be attributed to the high lipid content in muscles.

3.1.3. Surrounding soils

DDTs, HCHs, and PCBs are the mainly studied POPs in the Caspian

Table 2
Levels of POPs in organism and atmospheric samples from Lake Superior.

Compounds	Year	Sample	Range (mean)	Reference
DDE	1989–2001	bald eagle plasma	21.7[a]	Dykstra et al. (2005)
PCBs	1989–2001	bald eagle plasma	86.7[a]	Dykstra et al. (2005)
PBDEs	1989–2001	bald eagle plasma	7.9[a]	Dykstra et al. (2005)
PCBs	2004–2005	peregrinus plasma	3.52–368.21[b]	Fernie and Letcher, 2010
PBDEs	2004–2005	peregrinus plasma	0.87–195.79[b]	Fernie and Letcher, 2010
HBCD	2004–2005	peregrinus plasma	0–0.46[b]	Fernie and Letcher, 2010
PCNs	1996–1997	fish	0.019–3.400[b]	Kannan et al. (2000)
PFCs	2006–2011	bird plasma	7.37[d]	Route et al. (2014)
PFCs	2001	fish	13[a]	Furdui et al. (2007)
PFOS	2001	fish	5[a]	Furdui et al. (2007)
PBDEs	1997	fish	117–434[b]	Luross et al. (2002)
PAHs	*	atmosphere	2.9–3.9[e]	Fernandez et al. (2002)
PBDEs	1997–1999	atmosphere	0.008–0.11[e]	Strandberg et al. (2001)
HCB	1997–1999	atmosphere	0.086–0.14 [e]	Strandberg et al. (2001)
PCNs	1998	atmosphere	0.00178 [e]	Helm et al. (2003)
PCNs	2000	atmosphere	0.00146[e]	Helm et al. (2003)
PCBs	1990	atmosphere	0.089–0.37[e]	Hillery et al. (1997)

*Lack of data.
[c]ng/g lipid weight.
[a] ng/g dry weight.
[b] ng/g wet weight.
[d] ng/L.
[e] ng/m^3.

Table 3
Levels of POPs in sediment samples from Taihu Lake and Dongting Lake.

Compounds	Year	Range (mean)	Reference	Compounds	Year	Range (mean)	Reference
Taihu Lake				Taihu Lake			
DL-PCBs	2004	0.7–1.6 [b]	Xu et al. (2015)	PAHs	2007	1180 [a]	Liu et al. (2009)
PCDD/Fs	2004	2.7–6.9 [b]	Xu et al. (2015)	HCHs	2007	6.3 [a]	Liu et al. (2009)
PAHs	2004	11.1–22.9 [b]	Xu et al. (2015)	DDTs	2007	6.8 [a]	Liu et al. (2009)
PCDD/Fs	2009	0.91–4.8 (2.9) [b]	Zhou et al. 2012	PBDEs	2007	0.3 [a]	Liu et al. (2009)
PBDD/Fs	2009	0.16–1.6 (0.52) [b]	Zhou et al. 2012	BDE-209	2007	25 [a]	Liu et al. (2009)
PAHs	2003	1207–4754 [a]	Qiao et al. (2006)	PBDEs	2014	0.62–67 [a]	Yin et al. (2017)
PAHs	2009	436.6–1334.9 [a]	Tao et al. (2010)	PCBs	2014	0.018–0.82 [a]	Yin et al. (2017)
OCPs	2006	4.22–461 [a]	Zhao et al. (2009)	Dongting Lake			
DDTs	2006	0.25–375 (53.9) [a]	Zhao et al. (2009)	PCDD/Fs	1995	130–891 [b]	Gao et al. (2008)
HCHs	2006	0.07–5.75 (1.67) [a]	Zhao et al. (2009)	PCDD/Fs	2004	0.7–11 (4.5) [b]	Gao et al. (2008)
PBDEs	2009	3.77–347 (72.8) [a]	Wang et al. 2016	HCHs	2014	2.08–6.36 (3.21) [a]	Wei et al. (2019)
HBCD	2009	0.168–2.66 [a]	Wang et al. 2016	DDTs	2014	0.48–3.04 (1.31) [a]	Wei et al. (2019)
TBBPA	2009	0.012–1.30 [a]	Wang et al. 2016	OCPs	2014	6.37–12.88 (8.32) [a]	Wei et al. (2019)
TBBPA	2010	0.056–2.15 [a]	Xu et al. (2013)	PCBs	2014	7.47–18.69 (11.16) [a]	Wei et al. (2019)
HBCD	2010	0.046–2.56 [a]	Xu et al. (2013)	PBDEs	2014	2.70–5.23 (3.82) [a]	Wei et al. (2019)
DDT	2000	0.1–8.8 [a]	Feng et al. (2003)	HCHs	2004	0.21–9.59 [a]	Qian et al. (2006)
HCH	2000	0.3–66.5 [a]	Feng et al. (2003)	DDTs	2004	ND-10.15 [a]	Qian et al. (2006)
PCDD/Fs	2003–2004	0.17 [a]	Wen et al. (2008)	PCDD/Fs	2004	15.4–38.9 [b]	Xiao et al. (2013)
PCDD/Fs	2002	0.12–1.315 [a]	Zhang and Jiang (2005)	PCDD/Fs	2016	0.0799–3.449 [a]	Cui, 2018
PCBs	2002	0.89–29.75 [a]	Zhang and Jiang (2005)	PCBs	2016	0.1226–4.4538 [a]	Cui, 2018
PCBs	2014	0.018–0.82 [a]	Yin et al. (2017)				

[a] ng/g dry weight.
[b] pgTEQ/g dry weight.

Sea surrounding soils. Research during 1983–1992 revealed that the level of DDTs in the agricultural soil from Azerbaijan, a country on the west coast of the Caspian Sea, ranged from 58 to 1596 ng/g dw (mean 573); HCHs ranged from 4 to 86 ng/g dw (mean 28) (Aliyeva et al., 2013). Shahbazi et al. conducted a study on the levels of DDTs, HCHs and PCBs in agricultural soils collected in 2008 near the Caspian Sea. The results show that the average concentrations of DDTs and HCHs are among the largest levels ever reported for soil samples, which are 37 ng/g dw for DDTs and 21 ng/g dw for HCHs, and 4.7–34.7 ng/g dw for PCBs (Shahbazi et al., 2012). Concentrations of selected OCPs and

Table 4
Levels of POPs in organism and water samples from Taihu Lake.

Compounds	Year	Sample	Range (mean)	Reference
OCPs	2006	B. aeruginosa	4.16–26.74 [a] 133.4–14.1 [c]	Zhao et al. (2009)
DDTs	2006	B. aeruginosa	0.08–1.42 [a]	Zhao et al. (2009)
HCHs	2006	B. aeruginosa	0.89–1.14 [a]	Zhao et al. (2009)
OCPs	2006	C. fluminea	85.89–1032 [a] 386.6–4526 [c]	Zhao et al. (2009)
DDTs	2006	C. fluminea	1.42–69.98 [a]	Zhao et al. (2009)
HCHs	2006	C. fluminea	6.29–976[a]	Zhao et al. (2009)
PBDEs	2007	fish	ND-77 [c]	Su et al. (2010)
PBDEs	2014	fish	25–200 [c]	Yin et al. (2017)
PCBs	2014	fish	90–680 [c]	Yin et al. (2017)
PCDD/Fs	2008	aquatic organism	0.005–0.036 [b]	Zhang and Jiang (2005)
PCBs	2008	aquatic organism	1.517–27.648 [b]	Zhang and Jiang (2005)
PCDD/Fs	2003–2004	bivalve	0.58 [a] 7.24 [d]	Wen et al. (2008)
PBDEs	2009	fish	8.59–74.28 [c]	Yu et al. (2012)
PCBs	2009	fish	10.30–165.2 [c]	Yu et al. (2012)
PBDEs	2010	fish	0.098–0.269 [b]	Zhang et al. (2012)
PCBs	2010	fish	279–1071[b]	Zhang et al. (2012)
DDTs	1999–2000	fish	3.7–23.5[a]	Feng et al. (2003)
HCHs	1999–2000	fish	3.7–123[a]	Feng et al. (2003)
PFOS	2013	water	32 [g]	Gao et al. (2016)
TBBPA	2010	water	ND-1.12 [g]	Xu et al. (2013)
HBCD	2010	water	ND-0.37 [g]	Xu et al. (2013)
PFCs	2009	water	17.8–448 (51.8) [g]	Yang et al. (2011)
DDTs	2009–2000	water	200-9300 (1000) [g]	Feng et al. (2003)
HCHs	2009–2000	water	20-36100 (5600) [g]	Feng et al. (2003)

[e]ngTEQ/g wet weight.
[f]ngTEQ/g lipid weight.
[a] ng/g dry weight.
[b] ng/g wet weight.
[c] ng/g lipid weight.
[d] ngTEQ/g dry weight.
[g] ng/L; ND: not detected.

Table 5
Levels of POPs in organism and water samples from Dongting Lake.

Compounds	Year	Sample	Range (mean)	Reference
PCDD/Fs	2004	serum	0.005–0.109 (0.026) [f]	Xiao et al. 2010a
PCDD/F	2004	breast milk	0.0004–0.01 (0.0055) [f]	Xiao et al. 2010a
PCDD/Fs	2004	tissue extracts of cormorants	0.421–5.696 [c]	Gao et al. (2011)
PCDD/Fs	2004	avian eggs	0.011–0.182 [c]	Fang et al. (2007)
PCDD/F	2004	fish	0.002–0.018 [b]	Gao et al. (2014)
PCBs	1998–2004	Yangtze finless porpoises	60–1890 [c]	Yang et al. (2008)
PBDEs	1998–2004	Yangtze finless porpoises	5.32–72.76 [c]	Yang et al. (2008)
PCDD/Fs	1998–2004	Yangtze finless porpoises	0.006–1.563 [c]	Yang et al. (2008)
PCDD/Fs	wet season	fish	0.006–0.198 (0.03) [b] 0.05–5.552 (0.67) [e]	Hu et al. (2018)
PCDD/Fs	dry season	fish	0.0004–0.003 (0.001) [b] 0.054–0.699 (0.186) [e]	Hu et al. (2018)
DL- PCBs	wet season	fish	0.012–0.411 (0.088) [b] 0.019–0.593 (0.172) [e]	Hu et al. (2018)
DL- PCBs	dry season	fish	0.008–0.238 (0.0583) [b] 0.02–0.396 (0.128) [e]	Hu et al. (2018)
PBDEs	wet season	fish	0.021–0.488 (0.144) [b]	Hu et al. (2018)
PBDEs	dry season	fish	0.01–0.42 (0.129) [b]	Hu et al. (2018)
PCDD/Fs	2005	vegetation tissue	0.14–1.64 (0.67) [d]	Fang et al. (2008)
HCHs	2014	water	0.96–2.57 (1.33) [g]	Wei et al. (2019)
DDTs	2014	water	0.05–2.12 (0.54) [g]	Wei et al. (2019)
OCPs	2014	water	1.25–6.02 (2.91) [g]	Wei et al. (2019)
PCBs	2014	water	0.50–2.84 (1.13) [g]	Wei et al. (2019)
PBDEs	2014	water	0.06–2.03 (0.66) [g]	Wei et al. (2019)
PAHs	2015	water	17.33–77.12 [g]	Wang et al. 2016
PCDD/Fs	2004	water	0.036–0.345 (0.0003) [g]	Gao et al. (2014)
PCDD/Fs	2016	water	ND	Cui, 2018
PCBs	2016	water	0.077–10.321 [g]	Cui, 2018
PCNs	2016	water	0.007–0.854 [g]	Cui, 2018

[a] ng/g dry weight.
[b] ng/g wet weight.
[c] ng/g lipid weight.
[d] ngTEQ/g dry weight.
[e] ngTEQ/g wet weight.
[f] ngTEQ/g lipid weight.
[g] ng/L; ND: not detected.

Table 6
Levels of POPs in sediment samples from Baiyangdian Lake and Guanting Reservoir.

Compounds	Year	Range (mean)	Reference
Baiyangdian Lake			
PAHs	2016	163.20–861.43 [a]	Gao et al. (2018)
OCPs	2016	2.25–6.07[a]	Gao et al. (2018)
PBDEs	2016	0.231–1.224[a]	Gao et al. (2018)
HCHs	2008	1.75–5.70 [a]	Dai et al. (2011)
DDTs	2008	0.91–6.48 [a]	Dai et al. (2011)
PCBs	2008	5.96–29.61 [a]	Dai et al. (2011)
Guanting Reservoir			
OCPs	2008	8.48–24.40 [a]	Wan and Kang, 2012
HCHs	2008	1.11–7.73 [a]	Wan and Kang, 2012
DDTs	2008	2.97–10.52 [a]	Wan and Kang, 2012

[a] ng/g dry weight.

PCBs in soils collected in 2009 from an extensive spatial survey across Azerbaijan were reported; HCHs ranged from 0.90 to 24.46 ng/g dw, DDT ranged from 1.43 to 1115.4 ng/g dw, and HCB ranged from 0.02 to 1.63 ng/g dw. It was surprising that the concentrations of PCBs in most soil samples were below the method detection limit (Aliyeva et al., 2012). Concentrations of DDTs and HCHs in 2009 slightly declined compared to that in 1980s, this might relate to the government`s efforts in controlling these contaminants.

3.1.4. Water and atmosphere

Levels of OCPs and PCBs in water samples collected in 2009 from the Caspian Sea were reported. The total concentration of OCPs was 71.75–315.16 ng/L, and PCBs nd-141.09 ng/L. In addition, the results also indicated that β-HCH and DDE were the most common OCPs, and the ratio of ΣPCB/ΣDDT also reflected that agriculture was an important source of OCPs and PCBs in this area (Javedankherad et al., 2013). Concentrations of OCPs and PCBs were measured in atmospheric samples collected during October–November 2008 from the Azerbaijan region of Caspian Sea. The results show that the concentration of PCBs ranges from 0.011 to 0.209 ng/m^3, HCHs ranges from 0.169 to 3.744 ng/m^3, DDTs ranges from 0.045 to 2.545 ng/m^3 and HCB ranges from 0.025 to 0.075 ng/m^3 (Aliyeva et al., 2012).

3.2. Typical lake in North America: Lake Superior

3.2.1. Sediments

PCDD/Fs, PCBs and PBDEs are the mainly studied POPs. Concentrations of 2,3,7,8-PCDD/Fs and DL-PCBs in sediments from Lake Superior and Lake Huron were reported in 2012. The concentrations of PCDD/Fs ranged from 0.005 to 18 ng/g dw for Lake Superior and 0.003–6.1 ng/g dw for Lake Huron. The concentrations of DL-PCBs ranged from 0.009 to 11 ng/g dw for Lake Superior and 0.009-27 pg/g dw for Lake Huron (Shen et al., 2009). Song et al. studied the concentration of PBDEs and PCBs in sediments collected during 2001–2002 from Lake Superior, and the results show that the concentration of PBDEs ranges from 0.49 to 3.1 ng/g dw (mean 1.4) and PCBs ranges from 2 to 27 ng/g dw (mean 3.6). Compared to previous studies, PCBs showed a declining or leveling-off trend, while PBDEs showed a significant upward trend (Song et al., 2004). There is also a report on the atmospheric accumulation rates of PCDDs and PCDFs in sediments from the Great Lakes region. It shows that the accumulation rates of PCDDs in Lake Superior and Lake Ontario are 0.0075 ng/cm^2/yr and 0.22 ng/cm^2/yr, respectively, and the accumulation rates of PCDFs are

0.00078 ng/cm^2/yr and 0.23 ng/cm^2/yr, respectively (Pearson et al., 1998). The pattern of PBDEs in Lake Superior sediments differed from those in air and fish, and there were obvious enhanced fractions of heavier congeners in the sediments. It is because heavier congeners have higher sediment-water distribution ratio (Song et al., 2004).

3.2.2. Organisms

POPs, including OCPs, PCBs, PBDEs, PFCs, HBCD and PCNs, in biota samples from Lake Superior are studied. Concentrations of DDE, PCBs and PBDEs in plasma samples collected during 1989–2001 from Lake Superior bald eagles were reported by Dykstra`s team. They found that the average concentration of DDE was 21.7 ng/g ww, PCBs was 86.7 ng/g ww and PBDEs was 7.9 ng/g ww. Their results suggested that reproduction of the Lake Superior eagle population was no longer limited by DDE and PCBs, at least in Wisconsin. However, reproduction at individual nests located in contaminant "hotspots" potentially might be affected by DDE or PCBs. (Dykstra et al., 2005). Fernie et al. studied the levels of PCBs, PBDEs and HBCD in plasma samples of Falco peregrinus collected during 2004–2005 from the Great Lakes. The concentration of PCBs was 3.52–368.21 ng/g ww, PBDEs was 0.87–195.79 ng/g ww and HBCD was 0–0.46 ng/g ww (Fernie and Letcher, 2010). A study by Kannan et al. show that the concentration of PCNs in fish samples collected during 1996–1997 from Lake Superior ranges from 0.019 to 3.4 ng/g ww (Kannan et al., 2000). Route et al. found that PFCs in plasma samples collected during 2006–2011 from Lake Superior birds was at a high level of 7.37 ng/L and the contributions of PFOS and PFDS to total PFCs were 67% and 23%, respectively (Route et al., 2014). Furdui et al. studied the concentration of PFCs in fish samples collected in 2001 from the Great Lakes region. The results show that the level of PFCs is 13 ng/g ww in Lake Superior, 152 ng/g ww in Lake Erie, 60 ng/g ww in Lake Ontario and 58 ng/g ww in Lake Huron. PFOS was found to be the major perfluoroalkyl contaminant, with a concentration of 121 ng/g ww in Lake Erie, 46 ng/g ww in Lake Ontario, 39 ng/g ww in Lake Huron, 16 ng/g ww in Lake Michigan and 5 ng/g ww in Lake Superior (Furdui et al., 2007). Luross et al. found that the average concentration of PBDEs in fish samples collected in 1997 from the Great Lakes ranged from 117 to 434 ng/g lw (Luross et al., 2002).

3.2.3. Atmosphere

The concentration of ΣPAHs in atmospheric samples from Lake Superior is in the range of 2.9–3.9 ng/m^3, which is similar to the levels in remote mountain regions in Europe (1.3–2.6 ng/m^3, 2.0–3.7 ng/m^3) and the Chesapeake Bay (2.7–5.3 ng/m^3), and is between the levels of urban atmospheres (about 2-3 orders of magnitude) and Arctic atmospheres (0.19–0.47 ng/m^3) (Fernandez et al., 2002). Strandberg et al. investigated air samples collected during 1997–1999 from Lake Superior. The results show that the concentration of ΣPBDEs ranges from 0.006 to 0.052 ng/m^3, ΣHCHs ranges from 0.14 to 0.2 ng/m^3, ΣDDTs ranges from 0.008 to 0.11 ng/m^3, and HCB is in the range of 0.086–0.14 ng/m^3 (Strandberg et al., 2001). Reports on the PCN concentrations of atmospheric samples from Lake Superior collected in 1998 and 2000 and Lake Ontario collected in 1996 and 1997 show that the average concentration of PCNs in Lake Superior is 0.002 ng/m^3 in 1998, and 0.001 ng/m^3 in 2000; the average concentration of PCNs in Lake Ontario is 0.006 ng/m^3 in 1996, and 0.006 ng/m^3 in 1997 (Helm et al., 2003). Barbar et al. found that concentrations of ΣPCBs in atmospheric samples collected in 1990 from the Great Lakes region ranged from 0.089 to 0.37 ng/m^3 (Hillery et al., 1997).

3.2.4. Water

Concentrations of Σ_{25}PCBs in water samples collected during 1980–1992 from Lake Superior were reported; the level of Σ_{25}PCBs was about 2.4 ng/L in 1980, but decreased to 0.18 ng/L by 1992. These results indicated that during the 12-year period of 1980–1992, Σ_{25}PCBs in Lake Superior had declined by approximately 26,500 kg and was decreasing with a first-order rate constant of 0.20 yr^{-1}. Predictions based on the theory of quality balance revealed that volatilization rather than precipitation was the main loss process of PCBs in Lake Superior (Jeremiason et al., 1994). Ruge et al. investigated the concentrations of PCBs and OCPs in water samples from Lake Superior. The results show that ΣPCBs ranges from 0.007 to 0.04 ng/L, and α-HCH, HCB are the main OCPs in water samples; the average concentration of α-HCH was 0.25 ng/L and HCB was 0.017 ng/L (Ruge et al., 2018). Concentrations of PCBs in water samples declined significantly from 1980 to 2018. It was speculated that volatilization and precipitation were the important factors, but volatilization might contribute more than precipitation, which lead to the decline of PCBs in water samples.

3.3. Typical lake in Africa: Lake Tanganyika

Studies related to POPs in Lake Tanganyika mainly involved lake organisms. Mahugija et al. investigated concentrations of DDTs in fish samples from eastern Lake Tanganyika. The results show that the concentration of ΣDDTs ranges from 23 to 339 ng/g ww or 1736-25,552 ng/g lw (Mahugija et al., 2018). Concentrations of OCPs, PCBs, PBDEs and HBCD in different wild fish samples collected in 2011 from Lake Tanganyika were investigated. The concentration of ΣDDTs was 207-319 ng/g lw (mean 273), ΣHCHs was in the range of 0.8–1.5 ng/g lw (mean 1.1), Σ_7PCBs ranged from 13.8 to 20.6 ng/g lw (mean 17.2), ΣPBDEs was 2.8–6.7 ng/g lw (mean 4.1), and HBCD was not detected in any samples (Polder et al., 2014). Manirakiza et al. reported concentrations of OCPs and PCBs in seven fish samples collected in 2009 from northern Lake Tanganyika. The results show that ΣDDTs ranges from 95.4 to 909.1 ng/g lw, ΣHCHs ranges from 21.2 to 288.2 ng/g lw and ΣPCBs ranges from 35.7 to 166.7 ng/g lw, which indicated that the POPs pollution in Lake Tanganyika was lower than or comparable to that of other regions of Africa (Manirakiza et al., 2002). Concentrations of DDTs in fish samples from eastern Lake Tanganyika were higher than northern Lake Tanganyika, and levels of POPs in wild fish samples were significantly lower than other fish samples. This could be attributed to human activities concerning use of pesticides.

4. POPs in typical Chinese lakes

4.1. Eastern China: Taihu Lake and Dongting Lake

4.1.1. Sediments

Various POPs, including PCBs, PCDD/Fs, PBDD/Fs, PAHs, DDTs, HCHs, PBDEs, HBCD and TBBPA, in Taihu Lake sediments are studied. Xu et al. studied sediment samples collected in 2004 from Taihu Lake. Their results showed that concentrations of DL-PCBs, PCDD/Fs and PAHs in sediments from Taihu Lake were 0.7–1.6 pgTEQ/g dw, 2.7–6.9 pgTEQ/g dw and 11.1–22.9 pgTEQ/g dw, respectively (Xu et al., 2015). Concentrations of PCDD/Fs and PBDD/Fs in sediment collected in 2009 were 0.91–4.8 pgTEQ/g dw (mean 2.9) and 0.16–1.6 pgTEQ/g dw (mean 0.52), respectively (Zhou et al. 2012). Historical usage of pentachlorophenol and sodium pentachlorophenate was the dominant source of PCDD/Fs and specific sources of PBDD/Fs were unclear, it was suspected to be effects of atmospheric deposition. The concentration of ΣPAHs in surface sediment collected in 2003 is 1207-4754 ng/g dw (Qiao et al., 2006), while the concentration of Σ_{15}PAHs in sediments collected in 2009 ranged from 436.6 to 1334.9 ng/g dw (Tao et al., 2010). The concentration of ΣOCPs in sediment collected in 2006 ranged from 4.22 to 461 ng/g dw, ΣDDTs ranged from 0.25 to 375 ng/g dw (mean 53.9) and ΣHCHs ranged from 0.07 to 5.75 ng/g dw (mean 1.67) (Zhao et al., 2009). PBDEs in sediment collected in 2009 are in the range of 3.77-347 ng/g dw (mean 72.8), HBCD ranged from 0.168 to 2.66 ng/g dw, and TBBPA ranged from 0.012 to 1.30 ng/g dw (Wang et al. 2016b). TBBPA in sediments collected in 2010 is 0.056–2.15 ng/g dw and HBCD range from 0.046 to 2.56 ng/g dw (Xu et al., 2013). The concentration of DDT in sediments collected in 2000 range from 0.1 to

8.8 ng/g dw and HCH was in the range of 0.3–66.5 ng/g dw (Feng et al., 2003). Concentrations and toxicity equivalent (TEQ) concentrations of ΣPCDD/Fs in sediments collected during 2003–2004 are 0.17 ng/g dw and 0.81 pgTEQ/g dw, respectively (Wen et al., 2008). Concentrations of PCDD/Fs and PCBs in sediments collected in 2002 are 0.12–1.315 ng/g dw and 0.89–29.75 ng/g dw, respectively (Zhang and Jiang, 2005). Liu et al. studied surface sediment samples collected in 2007 from Meiliang Bay and Xukou Bay in Taihu Lake, they found that concentrations of ΣPAHs, ΣHCHs, ΣDDTs, Σ_9PBDEs and BDE-209 in Meiliang Bay were 1180 ng/g dw, 6.3 ng/g dw, 6.8 ng/g dw, 0.3 ng/g dw and 25 ng/g dw, respectively and in Xukou Bay were 530 ng/g dw, 1.8 ng/g dw, 2.5 ng/g dw, 0.2 ng/g dw and 5.3 ng/g dw, respectively (Liu et al., 2009). Σ_{24}PBDEs in sediments collected in 2014 ranged from 0.62 to 67 ng/g dw and Σ_{22}PCBs ranged from 0.018 to 0.82 ng/g dw (Yin et al., 2017).

PCDD/Fs, PCBs, DDTs, HCHs and PBDEs in Dongting Lake sediments were intensively studied. Technical sodium pentachlorophenate (Na-PCP) had been used in the Dongting Lake area since 1960s. PCDD/Fs are by-products of Na-PCP. It was reported that concentrations of PCDD/Fs in sediments from Dongting Lake were 130-891 pg I-TEQ/g in 1995. Total I-TEQ values for sediments collected in 2004 were in the range of 0.7-11 pg I-TEQ/g (mean 4.5) (Gao et al., 2008). Concentrations of ΣHCHs, ΣDDTs, ΣOCPs, ΣPCBs and ΣPBDEs in sediments collected in 2014 from Dongting Lake ranged from 2.08 to 6.36 ng/g dw (mean 3.21), ΣDDTs ranged from 0.48 to 3.04 ng/g dw (mean 1.31), ΣOCPs ranged from 6.37 to 12.88 ng/g dw (mean 8.32), ΣPCBs ranged from 7.47 to 18.69 ng/g dw (mean 11.16) and ΣPBDEs ranged from 2.70 to 5.23 ng/g dw (mean 3.82) (Wei et al., 2019). The concentrations of ΣHCHs in sediments collected in 2004 ranged from 0.21 to 9.59 ng/g dw, while DDTs were in the range of ND-10.15 ng/g dw (Qian et al., 2006). The concentrations of ΣPCDD/Fs ranged from 15.4 to 38.9 pg I-TEQ/g in surface sediments collected in 2004 and 0.55–38.9 pg I-TEQ/g for sediment cores (Xiao et al., 2013). PCDD/F concentrations in sediment collected in 2016 ranged from 79.9 to 3449 pg/g dw, while PCBs ranged from 122.6 to 4453.8 pg/g dw (Cui, 2018).

4.1.2. Organisms

PCDD/Fs, PCBs, DDTs, HCHs and PBDEs in several aquatic organisms from Taihu Lake were studied. Zhao et al. investigated macrobenthos samples collected in 2006 from Taihu Lake. They found that the concentration of ΣOCPs in B. aeruginosa samples ranged from 4.16 to 26.74 ng/g dw or 133.4–14.1 ng/g lw, ΣDDTs ranged from 0.08 to 1.42 ng/g dw and ΣHCHs ranged from 0.89 to 1.14 ng/g dw. As for C. fluminea samples, the concentration of ΣOCPs was in the range of 85.89-1032 ng/g dw or 386.6-4526 ng/g lw, ΣDDTs ranged from 1.42 to 69.98 ng/g dw and ΣHCHs ranged from 6.29 to 976 ng/g dw (Zhao et al., 2009). Concentrations of ΣPBDEs in fish samples collected in 2007 ranged from ND-77 ng/g lw (Su et al., 2010). Σ_{24}PBDEs in fish samples collected in 2014 ranged from 25 to 200 ng/g lw and Σ_{22}PCBs ranged from 90 to 680 ng/g lw (Yin et al., 2017). PCDD/Fs and PCBs in aquatic organism samples collected in 2008 ranged from 0.005 to 0.036 ng/g ww and 1.517–27.648 ng/g ww, respectively (Zhang and Jiang, 2005). Concentrations and toxic equivalent concentrations of ΣPCDD/Fs in bivalve samples collected during 2003–2004 were 0.58 ng/g dw and 7.24 pgTEQ/g dw, respectively (Wen et al., 2008). PBDEs and PCBs in fish samples collected in 2009 were 8.59–74.28 ng/g lw and 10.30–165.20 ng/g lw, respectively (Yu et al., 2012), whereas those in fish samples collected in 2010 were 0.098–0.269 ng/g ww and 0.279–1.071 ng/g ww, respectively (Zhang et al., 2012). DDTs in fish samples collected during 1999–2000 ranged from 3.7 to 23.5 ng/g ww and HCHs ranged from 3.7 to 123 ng/g ww (Feng et al., 2003). Concentrations of DDTs and HCHs in fish samples were far below the National Food Standards of China. This indicated that banning the use of DDT and HCH has might reduce the amounts of DDT and HCH residues in the ecosystem.

PCDD/Fs, PCBs and PBDEs in several biota samples from Dongting Lake were reported. An investigation on serum and breast milk samples from the Dongting Lake area collected in 2004 shows that the WHO-TEQ concentration of PCDD/Fs in serum samples ranges from 0.005 to 0.109 ngTEQ/g lw (mean 26). In breast milk samples, it ranged from 0.0004 to 0.01 ngTEQ/g lw (mean 5.5) (Xiao et al. 2010a). Levels of PCDD/Fs in tissue extracts of cormorants, eggs of avian species and fish samples collected from Dongting Lake in 2004 were determined. ΣPCDD/Fs ranged from 0.421 to 5.696 ng/g lw or 14.8–2021 pgWHO-TEQ/g lw in tissue extracts. PCDD/Fs may have been bio-accumulated through food-web and the levels of PCDD/Fs in the cormorant collected from Dongting Lake were still relatively high (Gao et al., 2011). 2,3,7,8-PCDD/Fs in eggs of avian species were in the range of 0.011–0.182 ng/g lw (Fang et al., 2007), and in the fish samples were 0.002–0.018 ng/g ww or 0.1–0.92 ww (3.3–65.3 lw) pgWHO-TEQ/g (Gao et al., 2014). Concentrations of PCBs, PBDEs and PCDD/Fs in tissue extracts of Yangtze finless porpoises collected from Dongting Lake during 1998–2004 were 60-1890 ng/g lw, 5.32–72.76 ng/g lw and 0.006–1.563 ng/g lw, respectively (Yang et al., 2008). In the vegetation tissue samples collected in 2005, the concentrations of PCDD/Fs ranged from 0.14 to 1.64 pgTEQ/g dw (mean 0.67) (Fang et al., 2008). In the wet season, the levels of ΣPCDD/Fs in fish samples ranged from 0.006 to 0.198 ng/g ww (mean 0.03) or 0.05–5.552 pgTEQ/g ww (mean 0.67), ΣDL-PCBs ranged from 0.012 to 0.411 ng/g ww (mean 0.088) or 0.019–0.593 pgTEQ/g ww (mean 0.172) and PBDEs ranged from 0.021 to 0.488 ng/g ww (mean 0.144). In the dry season, ΣPCDD/Fs ranged from 0.0004 to 0.003 ng/g ww (mean 0.001) or 0.054–0.699 pgTEQ/g ww (mean 0.186), ΣDL-PCBs ranged from 0.008 to 0.238 ng/g ww (mean 58.285) or 0.02–0.396 pgTEQ/g ww (mean 0.128) and PBDEs ranged from 0.01 to 0.412 ng/g ww (mean 0.129) (Hu et al., 2018). Levels of PCDD/Fs in wet season fish samples was considerably higher than dry season, this could be attributed to the use of Na-PCP in the past and/or to the migration of PCDD/Fs from sediments to water in the wet season.

4.1.3. Surrounding soils

Concentrations of DDTs in surrounding soil samples collected during 1999–2000 from Taihu Lake ranged from 0.3 to 5.3 ng/g dw for 0–15 cm surface soils, 0.5–4.0 ng/g dw for 16–30 cm and 0–2.7 ng/g dw for 31–50 cm; HCHs levels were similar to those of DDTs (Feng et al., 2003). Concentrations of DDTs in soil samples collected in 2003 from Taihu Lake ranged from 10 to 989 ng/g dw and HCHs ranged from 10 to 37 ng/g dw (Shen et al., 2005). Fang et al. studied the concentration of Σ_{13}OCPs in soil samples collected in 2004 from Taihu Lake; their results show that ΣDDX (DDD, DDE and DDT) has the highest concentrations, which ranges from 3.10 to 66.55 ng/g dw (mean 57.04); it was followed by ΣHCHs, which ranged from 0.73 to 60.97 ng/g dw (mean 24.06). Besides, dieldrin, endrin, hexchlorobenzene and alpha-endosulfan were also found in these soil samples, but their concentrations were less than 15 ng/g dw (Wang et al., 2007). The average concentration of PCDD/Fs in soil samples from Dongting Lake ranged from 5.53 to 75.6 pgI-TEQ/g dw (mean 30.3). Differences in the congener profiles between soil samples and sodium pentachlorophenate reflected the variety of PCDD/F sources to the environment (Xiao et al., 2010b). PCDD/Fs and DDTs contamination was not only confined to the surface soil, but extended into the subsoil.

4.1.4. Water

PFCs, TBBPA, HBCD, DDTs and HCHs in water samples from Taihu Lake were studied. Gao et al. found that the average concentration of PFOS in water samples collected in 2013 from Taihu Lake was 32 ng/L. However, it was not detected in samples from other regions in China, such as the Bohai Sea, Yellow Sea and Lake Qinghai (Gao et al., 2016). TBBPA in water samples collected in 2010 ranged from ND-1.12 ng/L and HBCD ranged from ND-0.37 ng/L (Xu et al., 2013). Yang et al. analyzed the concentrations of 4 PFSAs and 10 PFCAs in water samples collected in 2009 from Taihu Lake and Liaohe River. The results show that the concentration of ΣPFCs in Taihu Lake is in the range of 17.8-448 ng/L (mean 51.8 ng/L) and PFOA and PFOS are the main PFCs; ΣPFCs in Liaohe river ranges from 1.4 to 131 ng/L (mean 43.6 ng/L), and PFHxS and PFOA are the main PFCs. Concentrations of PFOS and PFOA in water samples from these two regions were similar to those of rivers in Japan, but significantly lower than in the Great Lakes (Yang et al., 2011). DDTs in water samples collected during 2009–2000 ranged from 200 to 9300 ng/L (mean 1.0) and HCHs ranged from 20 to 36100 ng/L (mean 5.6) (Feng et al., 2003).

PCBs, PAHs, DDTs, HCHs, PCDD/Fs, PBDEs and PCNs in water samples from Dongting Lake were summarized. Reports on water samples from Dongting Lake collected in 2014 show that the concentration of ΣHCHs ranges from 0.96 to 2.57 ng/L (mean 1.33), ΣDDTs ranges from 0.05 to 2.12 ng/L (mean 0.54), ΣOCPs ranges from 1.25 to 6.02 ng/L (mean 2.91), ΣPCBs ranges from 0.50 to 2.84 ng/L (mean 1.13), and ΣPBDEs ranges from 0.06 to 2.03 ng/L (mean 0.66) (Wei et al., 2019). The concentration of ΣPAHs in water and SPM samples collected in 2015 ranged from 17.33 to 77.12 ng/L and 595.91–2473.74 ng/g, respectively. PAH levels in water samples were relatively lower than in SPM samples (Wang et al. 2016a). PCDD/Fs in water samples collected in 2004 from Dongting Lake ranged from 0.036 to 0.345 ng/L (mean 0.191) or 0.17–0.37 pgWHO-TEQ/L (mean 0.28) and Octachlorodibenzo-p-dioxin was the most abundant PCDD/F (Gao et al., 2014). Water samples from Dongting Lake collected in 2016 were investigated and the concentrations of PCBs ranged from 0.077 to 10.321 ng/L, PCNs ranged from 0.007 to 0.854 ng/L and PCDD/Fs were not detected (Cui, 2018).

4.1.5. Atmosphere

The average concentrations of α-HCH, γ-HCH, HCB, HEPT, α-endosulfan, p,p'-DDT, p,p'-DDE in atmospheric samples collected during July 23 to August 11, 2002 from Taihu Lake are 0.074 ng/m^3, 0.046 ng/m^3, 0.047 ng/m^3, 0.053 ng/m^3, 0.307 ng/m^3, 0.124 ng/m^3, 0.212 ng/m^3 and 0.767 ng/m^3, respectively (Qiu et al., 2004). In 2004, the annual average concentration of PBDEs in atmospheric samples from Taihu Lake is 0.22 ng/m^3. BDE-209, BDE-47 and BDE-28 accounted for 41%, 17% and 15% of the total PBDEs, respectively. In addition to PBDEs, the average annual concentrations of other brominated and chlorinated flame retardants are mostly under 0.004 ng/m^3 (Yu et al., 2012).

4.2. Northern China: Baiyangdian Lake and Guanting Reservoir

4.2.1. Sediments

PCBs, PAHs, DDTs, HCHs and PBDEs in sediment samples from Baiyangdian Lake were reviewed. Gao et al. studied sediment samples collected in 2016 from Baiyangdian Lake. Their results show that the concentrations of PAHs, OCPs and PBDEs range from 163.2 to 861.43 ng/g dw, 2.25–6.07 ng/g dw and 0.231–1.224 ng/g dw, respectively (Gao et al., 2018). Dai et al. found that the concentrations of HCHs, DDTs and PCBs in sediments collected in 2008 range from 1.75 to 5.70 ng/g dw, 0.91–6.48 ng/g dw and 5.96–29.61 ng/g dw, respectively (Dai et al., 2011). As a tributary river of Baiyangdian Lake, Fuhe has a significantly higher concentration of PBDEs than Baiyangdian Lake (Hu et al., 2010) and the distribution of DDTs showed a similar trend of decreasing from Fuhe to Baiyangdian (Hu et al., 2009). Guo et al. analyzed the concentrations of PAHs in sediments core from Baiyangdian Lake. They found that high concentrations of PAHs occurred mainly in the 1940s and 1990s, and decreased significantly since 1990. It could be attributed to the implemented measures for pollution control in this region since 1990, which reduced point source input of PAH in some degree (Guo et al., 2011). Concentrations of OCPs, HCHs and DDTs in sediments collected in 2008 from Guanting Reservoir are 8.48–24.40 ng/g dw, 1.11–7.73 ng/g dw and 2.97–10.52 ng/g dw, respectively (Wan and Kang, 2012).

4.2.2. Organisms

Hu et al. studied the concentrations of HCHs and DDTs in aquatic organism samples collected in 2007 from Baiyangdian Lake. Their results show that concentrations of HCHs and DDTs range from 58 to 563 ng/g dw and 21–401 ng/g dw, respectively (Hu et al., 2010). Guo et al. found that PAHs were more accumulated in SPM than aquatic plants, and that some low molecular weight PAHs could accumulate and transfer in different lake mediums (Guo et al., 2011). Concentrations of Σ_{13}OCPs, HCB, ΣHCHs, ΣDDTs, ΣChlordanes and ΣHeptachlors in fish samples from Guanting Reservoir are 8.76–44.7 ng/g ww, 0.23–1.36 ng/g ww, 1.51–9.45 ng/g ww, 7.22–35.08 ng/g ww, 0.04–0.26 ng/g ww and 0.01–0.13 ng/g ww; the average values are 22.35 ng/g ww, 0.76 ng/g ww, 4.71 ng/g ww, 16.64 ng/g ww, 0.17 ng/g ww and 0.07 ng/g ww, respectively (Wang et al., 2006).

4.2.3. Surrounding soils

The concentration of PAHs in the surface and subsurface soil samples collected in 2007 around Baiyangdian Lake ranged from 146 to 645.9 ng/g dw (mean 417.4) (Zhao et al., 2009) and in agricultural soil samples collected in 2008 surrounding Guanting Reservoir was 14 ng/g dw (Li et al., 2013). Concentrations of 16 priority PAHs in soil samples collected in 2007 ranged from 62.8 to 4110 ng/g dw (mean 94) (Jiao et al., 2013). High-level PAH contamination (4110 ng/g dw) near steel and cement factories around Guanting Reservoir was identified, and low to medium levels (mean 394.2 ng/g dw) were evident throughout the Guanting Reservoir region (Jiao et al., 2009). Levels of HCHs and DDTs in soil samples collected in 2003 range from 0 to 7.33 ng/g dw (mean 0.69) and 0–76.01 ng/g dw (mean 9.46) (Wang and Lu 2008).

4.2.4. Water

Concentrations of PAHs, OCPs and PBDEs in water samples collected in 2016 from Baiyangdian Lake range from 71.32 to 228.27 ng/L, 2.62–6.13 ng/L and 0–6.5 ng/L, respectively (Gao et al., 2018). Concentrations of HCHs, DDTs and PCBs in water samples collected in 2008 range from 3.13 to 0.6 ng/L, 4.05–20.59 ng/L and 19.46–131.62 ng/L, respectively (Dai et al., 2011). Compared to other regions around the world, such as the Bohai Sea (Tan et al., 2009), Yangtze River (Jiang et al., 2000), India (Dua et al., 1996) and Spain (Fernandez et al., 1999), levels of HCHs and DDTs in Baiyangdian Lake were relatively low, but levels in suspended particulates were comparable to or higher than those in other regions (Wang et al., 2013). PFOA, PFOS and PFBA were the main PFCs in water samples from Baiyangdian Lake, with concentrations ranging from 6.8 to 56.8 ng/L, 0.1–17.5 ng/L and 3.0–14.6 ng/L, respectively (Zhou et al. 2012). Concentrations of HCHs, DDTs, and OCPs in water samples collected in 2012 from Guanting reservoir range from 6.20 to 12.81 ng/L (mean 6.80), 10.94–14.40 ng/L (mean 2.06) and 278.32–942.63 ng/L (mean 446.35), respectively (Liu et al., 2014). The concentration of OCPs in water samples collected in 2000 from Guanting reservoir range from 4.2 to 96.9 ng/L and DDTs range from ND-46.8 ng/L (Kang et al. 2003).

4.3. Qinghai-Tibet Plateau: Qinghai Lake

4.3.1. Sediments and surrounding soils

Levels of OCPs in surface sediment samples collected in 2012 from Qinghai Lake ranged from 0.26 to 1.73 ng/g dw, HCHs ranged from 0.02 to 1.00 ng/g dw, DDTs were in the range of ND-0.86 ng/g dw and PAHs ranged from 366 to 966 ng/g dw (Wu et al., 2014). Li et al. conducted a large-scale investigation of PAHs, OCPs and PCBs in sediments collected during 2011–2012 from 52 lakes in China, and their results show that the concentrations of ΣPAHs, ΣOCPs and ΣPCBs ranges from 17.00 to 6633 ng/g dw, 0.12–45.24 ng/g dw and 0.03–13.99 ng/g dw, respectively. Levels of these pollutants in China are in the following trend: eastern plains > Yungui Plateau > Northeast China > Qinghai-Tibet Plateau > Mongolia > Xinjiang Plateau (Li et al., 2017). Han et al. found that the average concentration of Σ_{27}PCDD/Fs in surrounding soil samples collected in 2014 from Qinghai Lake was 15.108 ng/g dw, the total concentration of low-chlorinated PCDD/Fs was 15.104 ng/g dw and 2,3,7,8-PCDD/Fs was only 0.003 ng/g dw (Han et al., 2016).

4.3.2. Organisms

To the best of our knowledge, POPs in organisms from Qinghai Lake have rarely been reported. Liu et al. synthesized the data published from July 1997 to July 2017 of POPs in lake organisms in China. They found that reports on the Qinghai-Tibet Plateau and Yunnan-Guizhou Plateau were very limited; most reports were related to organisms from the eastern plain lakes in China. Concentrations of POPs in organisms from different lakes were quite different. DDTs and HCHs were generally detected in various lake organisms, but their concentrations were quite different. PCBs and PBDE concentrations in lake organisms from the eastern plain were higher than those in other regions. The average concentrations of DDTs, HCHs, PAHs, PCBs, PBDEs, PCDD/Fs, PFCs, PFOAs and HBCD in organisms from different lakes in China were 454.56 ng/g lw, 153.57 ng/g lw, 2849.49 ng/g lw, 118.40 ng/g lw, 18.40 ng/g lw, 17.43 ng/g lw, 147.17 ng/g lw, 1542.18 ng/g lw and 2.19 ng/g lw, respectively (Liu et al. 2018).

5. Conclusion

In summary, lakes in China and worldwide are contaminated to different extents by various POPs, including both traditional POPs and emerging POPs. There are great differences in the levels of POPs between different lake ecosystems and different matrices. Contamination levels of POPs in developed regions in both China and worldwide tend to be higher than those in regions that are less developed. Compared to the levels of POPs in regions around the world, some POPs in certain regions of China may be lower, while some may be comparable or higher.

Lake ecosystems are important freshwater resources closely related to human life, but our understanding of POPs pollution in lake ecosystems is still not sufficient. Although many studies on multiple POPs in different matrices from different lake ecosystems have been carried out, these previous studies usually focused on certain pollutant or certain matrix, especially on traditional POPs. Available publications associated with emerging POPs are relatively rarely reported. Systematic research involving different pollutants and different matrices, as well as the risk assessments is still needed for a better understanding of POPs in lake ecosystems.

Acknowledgments

This work was supported by the Beijing Natural Science Foundation (8182052); the Youth Innovation Promotion Association of the Chinese Academy of Sciences (2016038) and Collaborative Project supported by Chinese Academy of Sciences and Hebei Academy of Sciences (181602).

References

Aliyeva, G., Kurkova, R., Hovorkova, I., Klanova, J., Halsall, C., 2012. Organochlorine pesticides and polychlorinated biphenyls in air and soil across Azerbaijan. Environ. Sci. Pollut. Control Ser. 19 (6), 1953–1962.
Aliyeva, G., Halsall, C., Alasgarova, K., Avazova, M., Ibrahimov, Y., Aghayeva, R., 2013. The legacy of persistent organic pollutants in Azerbaijan: An assessment of past use and current contamination. Environ. Sci. Pollut. Control Ser. 20 (4), 1993–2008.
Baniemam, M., Moradi, A.M., Bakhtiari, A.R., Fatemi, M.R., Khanghah, K.E., 2017. Seasonal variation of polycyclic aromatic hydrocarbons in the surface sediments of the southern Caspian Sea. Mar. Pollut. Bull. 117 (1–2), 478–485.
Boehm, P.D., Brown, J.S., Maxon, C.L., Newton, F.C., Galperin, Y., 2005. Aspects of Polycyclic Aromatic Hydrocarbons in Offshore Sediments in the Azeri Sector of the Caspian Sea. Battelle Press, Columbus.
Cui, L.L., 2018. Polllution Characteristics Study in the Dongting Lake of PCDD/Fs, PCBs and PCNs. Thesis, Hebei Normal University (In Chinese).
Dai, G., Liu, X., Liang, G., Han, X., Shi, L., Cheng, D., Gong, W., 2011. Distribution of organochlorine pesticides (OCPs) and poly chlorinated biphenyls (PCBs) in surface water and sediments from Baiyangdian Lake in North China. J. Environ. Sci. 23 (10), 1640–1649.
de Mora, S., Villeneuve, J.P., Sheikholeslami, M.R., Cattini, C., Tolosa, I., 2004. Organochlorinated compounds in Caspian sea sediments. Mar. Pollut. Bull. 48 (1–2), 30–43.
Dua, V.K., Kumari, R., Sharma, V.P., 1996. HCH and DDT contamination of rural ponds of India. Bull. Environ. Contam. Toxicol. 57 (4), 568–574.
Dykstra, C.R., Meyer, M.W., Rasmussen, P.W., Warnke, D.K., 2005. Contaminant concentrations and reproductive rate of Lake Superior bald eagles, 1989-2001. J. Gt. Lakes Res. 31 (2), 227–235.
Fang, L.P., Zheng, M.H., Zhang, B., Gao, L.R., Liu, W.B., Zhao, X.R., 2007. Polychlorinated dibenzo-p-dioxins and dibenzofurans in eggs of eight avian species from Dongting Lake, China. Chemosphere 69 (3), 411–421.
Fang, U., Zheng, M.H., Xiao, K., Yang, Y.B., 2008. Tissue-dependent distribution and bioaccumulation of polychlorinated dibenzo-p-dioxins and dibenzofurans in vegetation samples collected from Dongting Lake, China. Environ. Toxicol. Chem. 27 (1), 49–56.
Feng, K., Yu, B.Y., Ge, D.M., Wong, M.H., Wang, X.C., Cao, Z.H., 2003. Organo-chlorine pesticide (DDT and HCH) residues in the Taihu Lake Region and its movement in soil-water system I. Field survey of DDT and HCH residues in ecosystem of the region. Chemosphere 50 (6), 683–687.
Fernandez, M.A., Alonso, C., Gonzalez, M.J., Hernandez, L.M., 1999. Occurrence of organochlorine insecticides, PCBs and PCB congeners in waters and sediments of the Ebro River (Spain). Chemosphere 38 (1), 33–43.
Fernandez, P., Grimalt, J.O., Vilanova, R.M., 2002. Atmospheric gas-particle partitioning of polycyclic aromatic hydrocarbons in high mountain regions of Europe. Environ. Sci. Technol. 36 (6), 1162–1168.
Fernie, K.J., Letcher, R.J., 2010. Historical contaminants, flame retardants, and halogenated phenolic compounds in peregrine falcon (Falco peregrinus) nestlings in the Canadian great lakes basin. Environ. Sci. Technol. 44 (9), 3520–3526.
Furdui, V.I., Stock, N.L., Ellis, D.A., Butt, C.M., Whittle, D.M., Crozier, P.W., Reiner, E.J., Muir, D.C.G., Mabury, S.A., 2007. Spatial distribution of perfluoroalkyl contaminants in lake trout from the Great Lakes. Environ. Sci. Technol. 41 (5), 1554–1559.
Gao, L.R., Zheng, M.H., Zhang, B., Liu, W.B., Zhao, X.R., Zhang, Q.H., 2008. Declining polychlorinated dibenzo-p-dioxins and dibenzofurans levels in the sediments from Dongting Lake in China. Chemosphere 73 (1), S176–S179.
Gao, L.R., Zheng, M.H., Zhang, B., Liu, W.B., Xiao, K., Su, G.J., Zhang, Q.H., 2011. Polychlorinated dibenzo-p-dioxins and dibenzofurans in different tissues of the cormorants (Phalacrocorax carbo) from Dongting Lake, China. J. Environ. Sci. 23 (10), 1709–1713.
Gao, L.R., Zhang, Q., Zhang, B., Liu, W.B., Xiao, K., 2014. Polychlorinated dibenzo-p-dioxins and dibenzofurans in water and six fish species from Dongting Lake, China. Chemosphere 114, 150–157.
Gao, L.R., Zheng, M.H., Lv, Y.B., Fu, Q., Tan, L., Zhu, Q.Q., 2016. In: Loganathan, B.G., Khim, J.S., Kodavanti, P.R.S., Masunaga, S. (Eds.), Persistent Organic Chemicals in the Environment: Status and Trends in the Pacific Basin Countries Ii: Temporal Trends. Amer Chemical Soc, Washington, pp. 73–102.
Gao, Q.S., Qiao, L.X., Yang, L., Tian, Z.Q., Yang, S.W., An, Y.X., Jian, H.B., Cui, Z.D., 2018. Occurrence and ecological risk Assessment of typical persistent organic pollutants in Baiyangdian Lake. Environ. Sci. 39 (04), 1616–1627 (In Chinese).
Guo, W., Pei, Y., Yang, Z., Chen, H., 2011. Historical changes in polycyclic aromatic hydrocarbons (PAHs) input in Lake Baiyangdian related to regional socio-economic development. J. Hazard Mater. 187 (1–3), 441–449.
Han, Y., Liu, W.B., Hansen, H.C.B., Chen, X.B., Liao, X., Li, H.F., Wang, M.J., Yan, N., 2016. Influence of long-range atmospheric transportation (LRAT) on mono- to octa-chlorinated PCDD/Fs levels and distributions in soil around Qinghai Lake, China. Chemosphere 156, 143–149.
Helm, P.A., Jantunen, L.M., Ridal, J., Bidleman, T.F., 2003. Spatial distribution of polychlorinated naphthalenes in air over the great lakes and air-water gas exchange in Lake Ontario. Environ. Toxicol. Chem. 22 (9), 1937–1944.
Hillery, B.R., Basu, I., Sweet, C.W., Hites, R.A., 1997. Temporal and spatial trends in a long-term study of gas phase PCB concentrations near the Great Lakes. Environ. Sci. Technol. 31 (6), 1811–1816.
Hu, G.C., LI, F.C., Dai, J.Y., Luo, X.J., Mai, B.X., Cheng, S.J., Cao, H., XU, M.Q., 2009. Characteristics of distribution and risk assessment of DDTs in surface sediments from Fuhe River and Baiyangdian Lake. Environ. Sci. Res. 22 (08), 891–896 (In Chinese).
Hu, G., Xu, Z., Dai, J., Mai, B., Cao, H., Wang, J., Shi, Z., Xu, M., 2010. Distribution of polybrominated diphenyl ethers and decabromodiphenylethane in surface sediments from Fuhe River and Baiyangdian Lake, North China. J. Environ. Sci. 22 (12), 1833–1839.
Hu, Y.M., Yi, C.Z., Li, J.G., Shang, X.H., Li, Z.M., Yin, X.C., Chen, B., Zhou, Y.C., Zhang, Y.Y., Wu, Y.N., 2018. Seasonal variations of PCDD/Fs in fishes: Inferring a hidden exposure route from Na-PCP application for schistosomiasis control. Environ. Monit. Assess. 190 (4), 11.
Javedankherad, I., Esmaili-Sari, A., Bahramifar, N., 2013. Levels and distribution of organochlorine pesticides and polychlorinated biphenyls in water and sediment from the international anzali wetland, North of Iran. Bull. Environ. Contam. Toxicol. 90 (3), 285–290.
Jeremiason, J.D., Hornbuckle, K.C., Eisenreich, S.J., 1994. PCBS in lake-superior, 1978-1992 - decreases in water concentrations reflect loss by volatilization. Environ. Sci. Technol. 28 (5), 903–914.
Jiang, X., Xu, S.F., D, M., Wang, L.S., 2000. Polychlorinated organic contaminants in water, suspended solids and sediments of the Nanjing section, Yangtze River. China Environ. Sci. 03, 193–197 (In Chinese).
Jiao, W.T., Lu, Y.L., Wang, T.Y., Li, J., Han, J.Y., Wang, G., Hu, W.Y., 2009. Polycyclic aromatic hydrocarbons in soils around Guanting Reservoir, Beijing, China. Chem.

Ecol. 25 (1), 39–48.
Jiao, W.T., Wang, T.Y., Lu, Y.L., Chang, A., Chen, W.P., 2013. Multi-factors influencing the spatial distribution of polycyclic aromatic hydrocarbons in soils surrounding drinking water protection zone. J. Environ. Sci. 25 (8), 1643–1648.
Kang, Y.H., Liu, P.B., Wang, Z.J., Lu, Y.B., Li, Q.J., 2003. Persistent Organochlorinated Pesticides in Water from Guanting Reservoir and Yongdinghe River, Beijing. Journal of Lake Sciences 15 (7), 125–132 (In Chinese).
Kannan, K., Yamashita, N., Imagawa, T., Decoen, W., Khim, J.S., Day, R.M., Summer, C.L., Giesy, J.P., 2000. Polychlorinated naphthalenes and polychlorinated biphenyls in fishes from Michigan waters including the Great Lakes. Environ. Sci. Technol. 34 (4), 566–572.
Li, X.R., Zhao, T.K., Zhang, C.J., Li, P., Li, S.J., Zhao, L.P., 2013. Source apportionment of polycyclic aromatic hydrocarbons in agricultural soils of Yanqing county in Beijing, China. Environ. Forensics 14 (4), 324–330.
Li, C.C., Huo, S.L., Yu, Z.Q., Xi, B.D., Yeager, K.M., He, Z.S., Ma, C.Z., Zhang, J.T., Wu, F.C., 2017. National investigation of semi-volatile organic compounds (PAHs, OCPs, and PCBs) in lake sediments of China: Occurrence, spatial variation and risk assessment. Sci. Total Environ. 579, 325–336.
Liu, G.Q., Zhang, G., Jin, Z.D., Li, J., 2009. Sedimentary record of hydrophobic organic compounds in relation to regional economic development: A study of Taihu Lake, East China. Environ. Pollut. 157 (11), 2994–3000.
Liu, L.L., Li, J., Li, M.R., Reng, S.J., Wang, Y.F., Tang, Y.D., 2014. Residues and health risk assessment of organochlorine pesticides in waters of Guanting Reservoir. J. Beijing Normal Univ. (Nat. Sci.) 50 (06), 657–661 (In Chinese).
Liu, D.H., Tao, Y.Q., Zhou, W.Z., 2018. Distribution and accumulation of persistent organic pollutants in aquatic organisms of Chinese lakes. Journal of Lake Sciences 30 (3), 581–596 (In Chinese).
Luross, J.M., Alaee, M., Sergeant, D.B., Cannon, C.M., Whittle, D.M., Solomon, K.R., Muir, D.C.G., 2002. Spatial distribution of polybrominated diphenyl ethers and polybrominated biphenyls in lake trout from the Laurentian Great Lakes. Chemosphere 46 (5), 665–672.
Mahugija, J.A.M., Nambela, L., Mmochi, A.J., 2018. Determination of dichlorodiphenyltrichloroethane (DDT) and metabolites residues in fish species from eastern Lake TanganyikaDetermination of dichlorodiphenyltrichloroethane (DDT) and metabolites residues in fish species from eastern Lake Tanganyika. South African Journal of Chemistry-Suid-Afrikaanse Tydskrif Vir Chemie 71, 86–93.
Manirakiza, P., Covaci, A., Nizigiymana, L., Ntakimazi, G., Schepens, P., 2002. Persistent chlorinated pesticides and polychlorinated biphenyls in selected fish species from Lake Tanganyika, Burundi, Africa. Environ. Pollut. 117 (3), 447–455.
Mashroofeh, A., Bakhtiari, A.R., Pourkazemi, M., 2015. Distribution and composition pattern of polycyclic aromatic hydrocarbons in different tissues of sturgeons collected from Iranian coastline of the Caspian Sea. Chemosphere 120, 575–583.
Nemirovskaya, I.A., Brekhovskikh, V.F., 2008. Origin of hydrocarbons in the particulate matter and bottom sediments of the northern shelf of the Caspian Sea. Oceanology 48 (1), 43–53.
Pearson, R.F., Swackhamer, D.L., Eisenreich, S.J., Long, D.T., 1998. Atmospheric inputs of polychlorinated dibenzo-p-dioxins and dibenzofurans to the Great Lakes: Compositional comparison of PCDD and PCDF in sediments. J. Gt. Lakes Res. 24 (1), 65–82.
Polder, A., Muller, M.B., Lyche, J.L., Mdegela, R.H., Nonga, H.E., Mabiki, F.P., Mbise, T.J., Skaare, J.U., Sandvik, M., Skjerve, E., Lie, E., 2014. Levels and patterns of persistent organic pollutants (POPs) in tilapia (Oreochromis sp.) from four different lakes in Tanzania: Geographical differences and implications for human health. Sci. Total Environ. 488, 252–260.
Qian, Y., Zheng, M.H., Zhang, B., Gao, L.R., Liu, W.B., 2006. Determination and assessment of HCHs and DDTs residues in sediments from Lake Dongting, China. Environ. Monit. Assess. 116 (1–3), 157–167.
Qiao, M., Wang, C.X., Huang, S.B., Wang, D.H., Wang, Z.J., 2006. Composition, sources, and potential toxicological significance of PAHs in the surface sediments of the Meiliang Bay, Taihu Lake, China. Environ. Int. 32 (1), 28–33.
Qiu, X.H., Zhu, T., Jing, L., Pan, H.S., Li, Q.L., Miao, G.F., Gong, J.C., 2004. Organochlorine pesticides in the air around the Taihu Lake, China. Environ. Sci. Technol. 38 (5), 1368–1374.
Rajaei, F., Sari, A.E., Bahramifar, N., Savabieasfahani, M., Ghasempouri, M., 2011. Persistent organic pollutants in muscle and feather of ten avian species from Mazandaran province of Iran, on the coast of the Caspian Sea. Bull. Environ. Contam. Toxicol. 87 (6), 678–683.
Route, W.T., Key, R.L., Russell, R.E., Lindstrom, A.B., Strynar, M.J., 2014. Spatial and temporal patterns in concentrations of perfluorinated compounds in bald eagle nestlings in the upper Midwestern United States. Environ. Sci. Technol. 48 (12), 6653–6660.
Ruge, Z., Muir, D., Helm, P., Lohmann, R., 2018. Concentrations, trends, and air-water exchange of PCBs and organochlorine pesticides derived from passive samplers in lake superior in 2011. Environ. Sci. Technol. 52 (24), 14061–14069.
Shahbazi, A., Bahramifar, N., Smolders, E., 2012. Elevated concentrations of pesticides and PCBs in soils at the southern Caspian Sea (Iran) are related to land use. Soil Sediment Contam. 21 (2), 160–175.
Shen, G.Q., Lu, Y.T., Wang, M.N., Sun, Y.Q., 2005. Status and fuzzy comprehensive assessment of combined heavy metal and organo-chlorine pesticide pollution in the Taihu Lake region of China. J. Environ. Manag. 76 (4), 355–362.
Shen, L., Gewurtz, S.B., Reiner, E.J., MacPherson, K.A., Kolic, T.M., Khurana, V., Helm, P.A., Howell, E.T., Burniston, D.A., Brindle, I.D., Marvin, C.H., 2009. Occurrence and sources of polychlorinated dibenzo-p-dioxins, dibenzofurans and dioxin-like polychlorinated biphenyls in surficial sediments of Lakes Superior and Huron. Environ. Pollut. 157 (4), 1210–1218.
Song, W.L., Ford, J.C., Li, A., Mills, W.J., Buckley, D.R., Rockne, K.J., 2004. Polybrominated diphenyl ethers in the sediments of the great lakes. 1. Lake superior. Environ. Sci. Technol. 38 (12), 3286–3293.
Strandberg, B., Dodder, N.G., Basu, I., Hites, R.A., 2001. Concentrations and spatial variations of polybrominated diphenyl ethers and other organohalogen compounds in Great Lakes air. Environ. Sci. Technol. 35 (6), 1078–1083.
Su, G.Y., Gao, Z.S., Yu, Y.J., Ge, J.C., Wei, S., Feng, J.F., Liu, F.Y., Giesy, J.P., Lam, M.H.W., Yu, H.X., 2010. Polybrominated diphenyl ethers and their methoxylated metabolites in anchovy (Coilia sp.) from the Yangtze River Delta, China. Environ. Sci. Pollut. Control Ser. 17 (3), 634–642.
Tan, L., He, M.C., Men, B., Lin, C.Y., 2009. Distribution and sources of organochlorine pesticides in water and sediments from daliao river estuary of Liaodong Bay, Bohai Sea (China). Estuar. Coast Shelf Sci. 84 (1), 119–127.
Tao, Y.Q., Yao, S.C., Xue, B., Deng, J.C., Wang, X.L., Feng, M.H., Hu, W.P., 2010. Polycyclic aromatic hydrocarbons in surface sediments from drinking water sources of Taihu Lake, China: Sources, partitioning and toxicological risk. J. Environ. Monit. 12 (12), 2282–2289.
UNEP, 2019. http://www.pops.int/TheConvention/Overview/tabid/3351/Default.aspx.
Varnosfaderany, M.N., Bakhtiari, A.R., Gu, Z.Y., Chu, G.Q., 2015. Distribution and characteristic of PAHs in sediments from the southwest Caspian Sea, Guilan province, Iran. Water Sci. Technol. 71 (11), 1587–1596.
Wan, Y.W., Kang, T.F., 2012. Distribution of organochlorine pesticides in surface sediments from Guanting Reservoir and its risk evaluation. Environ. Monit. Manag. Technol. 24 (03), 35–40 (In Chinese).
Wang, X.T., Sun, Y.S., Li, X.H., Liu, X.F., Xu, X.B., 2006. Persistent organochlorine pesticides in fish from Guanting Reservoir, China. Proc. Org. Pollut. Environ. Chem. Front. Environ. Sustain. Dev. Strategy 16 (In Chinese).
Wang, F., Jiang, X., Bian, Y.R., Yao, F.X., Gao, H.J., Yu, G.F., Munch, J.C., Schroll, R., 2007. Organochlorine pesticides in soils under different land usage in the Taihu Lake region, China. J. Environ. Sci. 19 (5), 584–590.
Wang, Y., Wu, W.J., He, W., Qin, N., He, Q.S., Xu, F.L., 2013. Residues and ecological risks of organochlorine pesticides in lake small Baiyangdian, North China. Environ. Monit. Assess. 185 (1), 917–929.
Wang, T.Y., Lu, Y.L., 2008. Spacial distribution and countermeasures of pesticidal POPs in soils around Guanting Reservoir in Beijing. In: Soil Science Society of China. Proceedings of the 11th National Congress of Soil Science Society of China, pp. 7 (In Chinese).
Wang, C.L., Zou, X.Q., Zhao, Y.F., Li, B.J., Song, Q.C., Li, Y.L., Yu, W.W., 2016a. Distribution, sources, and ecological risk assessment of polycyclic aromatic hydrocarbons in the water and suspended sediments from the middle and lower reaches of the Yangtze River, China. Environ. Sci. Pollut. Control Ser. 23 (17), 17158–17170.
Wang, J.Z., Jia, X.W., Gao, S.T., Zeng, X.Y., Li, H.R., Zhou, Z., Sheng, G.Y., Yu, Z.Q., 2016b. Levels and distributions of polybrominated diphenyl ethers, hexabromocyclododecane, and tetrabromobisphenol A in sediments from Taihu Lake, China. Environ. Sci. Pollut. Control Ser. 23 (11), 10361–10370.
Wei, L.F., Tadesse, A.W., Wang, J., 2019. Organohalogenated contaminants (OHCs) in surface sediments and water of east Dongting Lake and hong lake, China. Arch. Environ. Contam. Toxicol. 76 (2), 157–170.
Wen, S., Hui, Y., Yang, F.X., Liu, Z.T., Xu, Y., 2008. Polychlorinated dibenzo-p-dioxins (PCDDs) and dibenzofurans (PCDFs) in surface sediment and bivalve from the Changjiang Estuary, China. Chin. J. Oceanol. Limnol. 26 (1), 35–44.
Wu, C.X., Xiong, X., Huang, X.L., Xing, X.L., Liu, J.T., 2014. Occurrence and distribution of organochlorine pesticides and polycyclic aromatic hydrocarbons in surface sediments from Qinghai Lake, northeast Qinghai-Tibet plateau, China. J. Gt. Lakes Res. 40 (3), 675–683.
Xiao, K., Zhao, X.R., Liu, Z.T., Zhang, B., Fang, L.P., Liu, W.B., Zheng, M.H., 2010a. Polychlorinated dibenzo-p-dioxins and dibenzofurans in blood and breast milk samples from residents of a schistosomiasis area with Na-PCP application in China. Chemosphere 79 (7), 740–744.
Xiao, K., Zheng, M.H., Fang, L.P., Yang, Y.B., 2010b. Concentrations and profiles of polychlorinated dibenzo-p-dioxins and dibenzofurans in bank soils collected from Dongting Lake, China. Bull. Environ. Contam. Toxicol. 85 (2), 174–178.
Xiao, K., Zheng, M.H., Zhang, B., Liu, W.B., Zhao, X.R., Gao, L.R., 2013. Polychlorinated dibenzo-p-dioxins and dibenzofurans in the sediment core from a schistosomiasis area with Na-PCP application in China. Bull. Environ. Contam. Toxicol. 90 (2), 160–164.
Xu, J., Zhang, Y., Guo, C.S., He, Y., Li, L., Meng, W., 2013. Levels and distribution of tetrabromobisphenol A and hexabromocyclododecane in Taihu Lake, China. Environ. Toxicol. Chem. 32 (10), 2249–2255.
Xu, Y., Wei, S., Qin, Q.D., Lam, M.H.W., Giesy, J.P., 2015. AhR-mediated activities and compounds in sediments of Meiliang Bay, Taihu Lake, China determined by in vitro bioassay and instrumental analysis. RSC Adv. 5 (69), 55746–55755.
Yang, F.X., Zhang, Q.H., Xu, Y., Jiang, G.B., Wang, Y.W., Wang, D., 2008. Preliminary hazard assessment of polychlorinated biphenyls, polybrominated diphenyl ethers, and polychlorinated dibenzo-p-dioxins and dibenzofurans to Yangtze finless porpoise in Dongting Lake, China. Environ. Toxicol. Chem. 27 (4), 991–996.
Yang, L.P., Zhu, L.Y., Liu, Z.T., 2011. Occurrence and partition of perfluorinated compounds in water and sediment from Liao River and Taihu Lake, China. Chemosphere 83 (6), 806–814.
Yin, G., Zhou, Y.H., Strid, A., Zheng, Z.Y., Bignert, A., Ma, T.W., Athanassiadis, I., Qiu, Y.L., 2017. Spatial distribution and bioaccumulation of polychlorinated biphenyls (PCBs) and polybrominated diphenyl ethers (PBDEs) in snails (Bellamya aeruginosa) and sediments from Taihu Lake area, China. Environ. Sci. Pollut. Control Ser. 24 (8), 7740–7751.
Yu, Y.X., Zhang, S.H., Huang, N.B., Li, J.L., Pang, Y.P., Zhang, X.Y., Yu, Z.Q., Xu, Z.G., 2012. Polybrominated diphenyl ethers and polychlorinated biphenyls in freshwater fish from Taihu Lake, China: Their levels and the factors that influence

biomagnification. Environ. Toxicol. Chem. 31 (3), 542–549.
Zhang, Q.H., Jiang, G.B., 2005. Polychlorinated dibenzo-p-dioxins/furans and polychlorinated biphenyls in sediments and aquatic organisms from the Taihu Lake, China. Chemosphere 61 (3), 314–322.
Zhang, D.P., Zhang, X.Y., Yu, Y.X., Li, J.L., Yu, Z.Q., Wang, D.Q., Wu, M.H., Sheng, G.Y., Fu, J.M., 2012. Intakes of omega-3 polyunsaturated fatty acids, polybrominated diphenyl ethers and polychlorinated biphenyls via consumption of fish from Taihu Lake, China: A risk-benefit assessment. Food Chem. 132 (2), 975–981.
Zhao, Z.H., Zhang, L., Wu, J.L., Fan, C.X., 2009. Distribution and bioaccumulation of organochlorine pesticides in surface sediments and benthic organisms from Taihu Lake, China. Chemosphere 77 (9), 1191–1198.
Zhou, L., Li, H.R., Yu, Z.Q., Ren, M., Zeng, X.Y., Peng, P.A., Sheng, G.Y., Fu, J.M., 2012a. Chlorinated and brominated dibenzo-p-dioxins and dibenzofurans in surface sediment from Taihu Lake, China. J. Environ. Monit. 14 (7), 1935–1942.
Zhou, Z., Shi, Y.L., Li, W.H., Xu, L., Cai, Y.Q., 2012b. Perfluorinated compounds in surface water and organisms from Baiyangdian Lake in north China: Source profiles, bioaccumulation and potential risk. Bull. Environ. Contam. Toxicol. 89 (3), 519–524.