Presence of e-EDCs in surface water and effluents of pollution sources in Sai Gon and Dong Nai river basin

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Abstract

This study aimed to assess the presence of estrogenic endocrine disrupting compounds (e-EDCs) including estriol, bisphenol A (BPA), atrazine (ATZ), octylphenol, octylphenol diethoxylate, octylphenol triethoxylate, nonylphenol, Nonylphenol triethoxylate (NPE3), nonylphenol diethoxylate (NPE2) and 17b- estradiol in: (i) Sai Gon and Dong Nai river waters which have been major raw water sources for drinking water supply for Ho Chi Minh City (HCMC) and neighbouring provinces, and (ii) water pollution sources located in their catchment basin. NPE3 and NPE2 were detected in most of the surface water samples. Concentrations of NPE3 were in a range of less than 5.9e235 ng L-1, whereas BPA was detected at significantly high concentrations in the dry season in canals in HCMC. In the upstream of Sai Gon and Dong Nai Rivers, ATZ concentrations were observed at water intake of water treatment plants served for HCMC water supply system. Similarly, high potential risk of NPE2 and NPE3 contamination at Phu Cuong Bridge near Hoa Phu water intake was identified. The significant correlation between NPE2, dissolved organic carbon and total nitrogen was found. Estrogenic equivalent or estrogenic activity of Sai Gon and Dong Nai Rivers was lower than those of the previous studies. Compared with other studies, e-EDCs of pollution in Sai Gon river basin were relatively low.

Keywrods: e-EDCs; LC-MS/MS; Surface water; Water pollution sources; EEQ

1. Introduction

Endocrine Disrupting Compounds (EDCs) are compounds of natural or synthetic origin. When EDCs enter the body, they cause negative effects on endocrine systems of humans and wildlife [1]. Estrogenic EDCs (e-EDCs) are subclass of EDCs. e-EDCs are chemicals which mimic or induce estrogen-like response in an organism [1]. Many e-EDCs could lead to an estrogenic response at very low concentrations (ppb to ppt) [1]. These e-EDCs have been found in wastewater, surface waters, sediments, groundwater, and even drinking water [2].

Vietnam has 68 water supply companies for civil activities, services and industries of urban areas with 70% of water supply companies using surface water and 30% of them groundwater [3]. Sai Gon and Dong Nai rivers play an important role in the water supply system for the cities in this basin. However, Sai Gon river is polluted by organic matters in terms of Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) [4] that exceed the limits of raw surface water quality standards for water supply (column A2 QCVN 08:2008/BTNMT [5]).

In addition, e-EDCs were observed by Le [6] and the concentrations of e-EDCs of water samples taken in Saigon river and canals in Ho Chi Minh City (HCMC) were 0.02e6.2 E2 (17b-estradiol) eq ng L^{-1} in the dry season and 0.33 to 1.17 E2 eq ng L^{-1} in the wet season. Caldwell et al. [7] determined a PNEC (Predicted No Effect Concentration) in surface water to be 0.35 ng EE2 (17a-ethynylestradiol) L^{-1}. Parrott and Blunt [8] proposed that an estrogen concentration of less than 1 ng L^{-1} in surface water could cause reproductive problems in some fish species. Thus, the Sai Gon river and canals in the HCMC may pose potential risks to aquatic organisms [6]. To date, information on e-EDCs in upstream and pollution point sources in Sai Gon and Dong Nai river basins is insufficient to assess potential risks. Hence, this study aimed: (i) to

investigate the concentrations of e-EDCs in the surface water and effluents from potential water pollution sources in Sai Gon and Dong Nai river basins; and (ii) to determine correlation among e-EDCs and physico-chemical parameters including dissolved organic concentration (DOC), total nitrogen (TN), dissolved oxygen (DO), Electrical Conductivity (EC), pH, ammonia, total phosphorus (TP) and turbidity.

2. Materials and methods

2.1. Sampling

The surface water samples were collected from the upstream of Sai Gon River which originates from Dau Tieng reservoir to Hoa Phu water intake and Dong Nai River upstream which starts from Tri An reservoir to Hoa An Water Intake. These samples were collected in April 2013 (dry season) and September 2013 (wet season). Surface water samples were taken in the middle of the river or its branches or at the points far from the river bank with minimum distance of 5 m. The sampling locations are shown in Fig. 1.

EDCs of effluent from pollution point sources and non-point sources from agricultural activities in Sai Gon river basin were tested. The location of the pollution sources is presented in Fig. 2. The point sources included an industrial park, a tannery factory, a paper mill factory, two rubber latex processing factories and a municipal landfill. The non-point sources were from agricultural activities including effluent from a biogas digester of household-scale pig farm, surface run-off water from rice paddy field, and two irrigation canals at Thai My Commune e Cu Chi District. Samples were contained in amber glass bottles and stored in the ice box during transportation to the laboratory in HCMC University of Technology and preserved at 4 °C before analysis.

2.2. Analytical methods

The physico-chemical parameters including pH, EC, DO, turbidity and ammonium were analyzed according to Standard Methods [9]. DOC was measured using Shimadzu Total Organic Carbon Analyser (TOC-$V_{VPH/CPN}$ model). TN was determined using the TOC-$V_{VPH/CPN}$ analyser with Total Nitrogen Unit TNM-1.

To analyze e-EDCs, suspended solids in the samples were removed using paper filters with pore size of 0.7 mm (GF/F, Whatman). The volume for extraction depends on type of water sample. 250 mL of surface water and 100 mL of wastewater were used for extraction. pH value of water sample was adjusted to 6.0e8.0 by using 5% NaOH solution or 5% orthophosphoric acid solution [10].

The solid phase extraction procedure was similar to that described by Gomez et al. [11]. Oasis hydrophilicelipophilic balance cartridges (60 mg 3 mL^{-1}, from Waters, Guyancourt, France) installed on a vacuum manifold were used in this study. Cartridges were conditioned with 1 mL MeOH and 1 mL of ultra-pure water. Samples were passed through at a flow rate of 3 mL min^{-1}. The

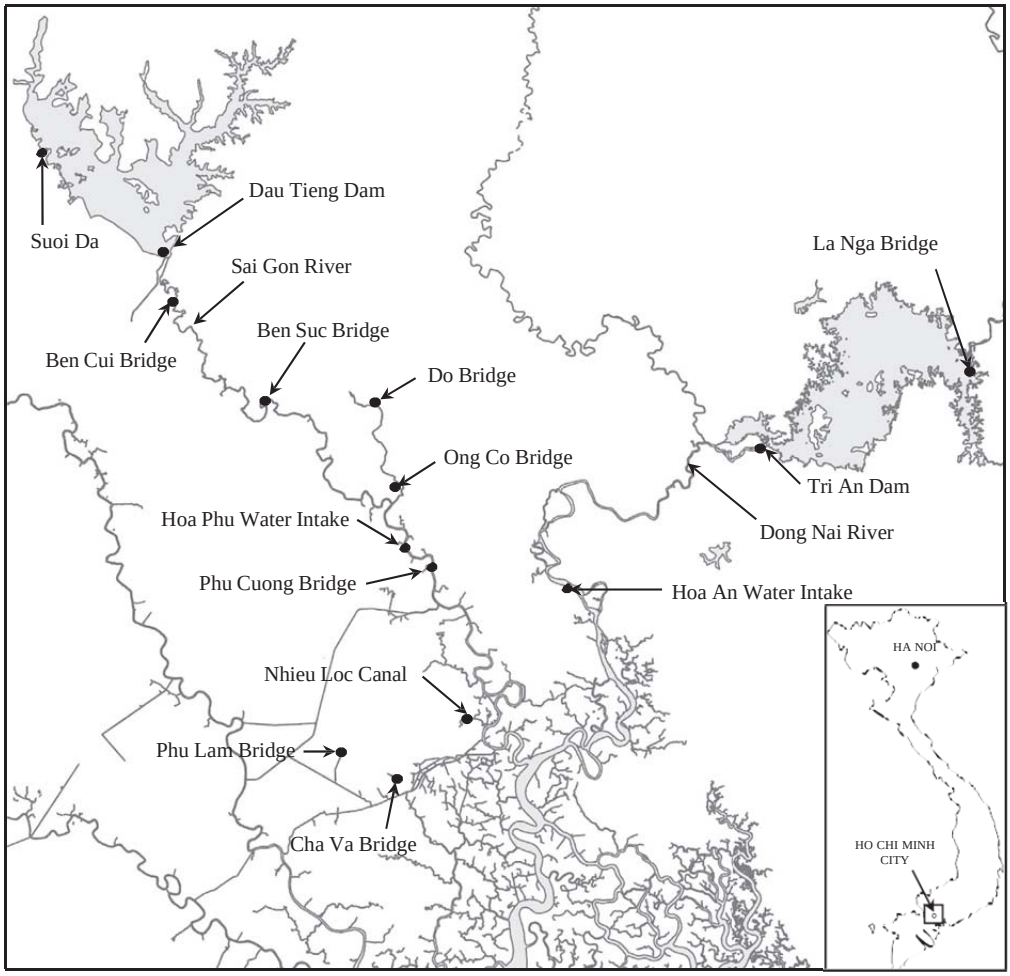
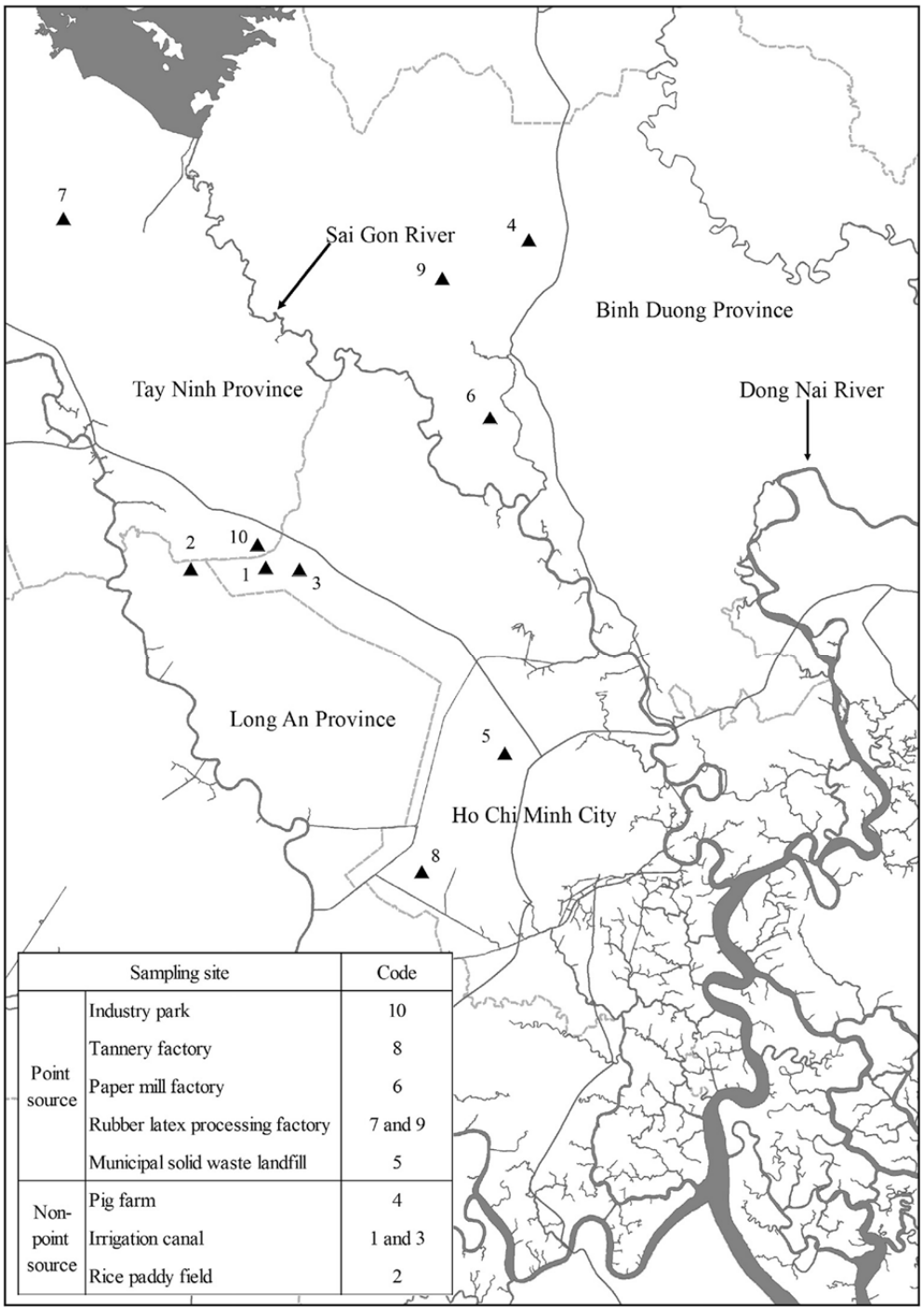


Fig. 1. Map of surface water sampling sites in Sai Gon e Dong Nai river basin.



Sampling site		Code
Point source	Industry park	10
	Tannery factory	8
	Paper mill factory	6
	Rubber latex processing factory	7 and 9
	Municipal solid waste landfill	5
Non-point source	Pig farm	4
	Irrigation canal	1 and 3
	Rice paddy field	2

Fig. 2. Map of sampling sites of water pollution sources in Sai Gon river basin.

cartridges were then rinsed with 2 mL of H_2O/MeOH mixture (95%/5%) and vacuum dried for 10 min to remove excess water. The cartridges were eluted with 5 mL of MeOH. Samples were dried under a gentle nitrogen stream. After that, ultra-pure water/ CH_3CN mixture (90/10) acidified with 0.01% formic acid was added to the dried samples to reach a volume of 0.5 mL. Samples were conserved at 4 ^oC before analysis by liquid chromatography-tandem mass spectrometer with LC 1260 Infinity Þ MS 6420 Triple Quad model (Agilent, Singapore). The recovery rates of this procedure were over 80% for e-EDCs and limit of detection (LOD) ranged from 0.9 to 13 ng L^{-1}.

3. Results and discussion

3.1. Surface water quality

3.1.1. Physico-chemical parameters

Fig. 3a shows that pH of the Sai Gon River water decreased at downstream in both seasons. pH value of Dau Tieng reservoir was slightly different in wet and dry seasons, ranging from 6.5 to 6.8. All pH values in wet season were lower than those in dry season. pH values at downstream sites were below 6.0 in the wet season. This can be explained by surface run-off which brought acidity

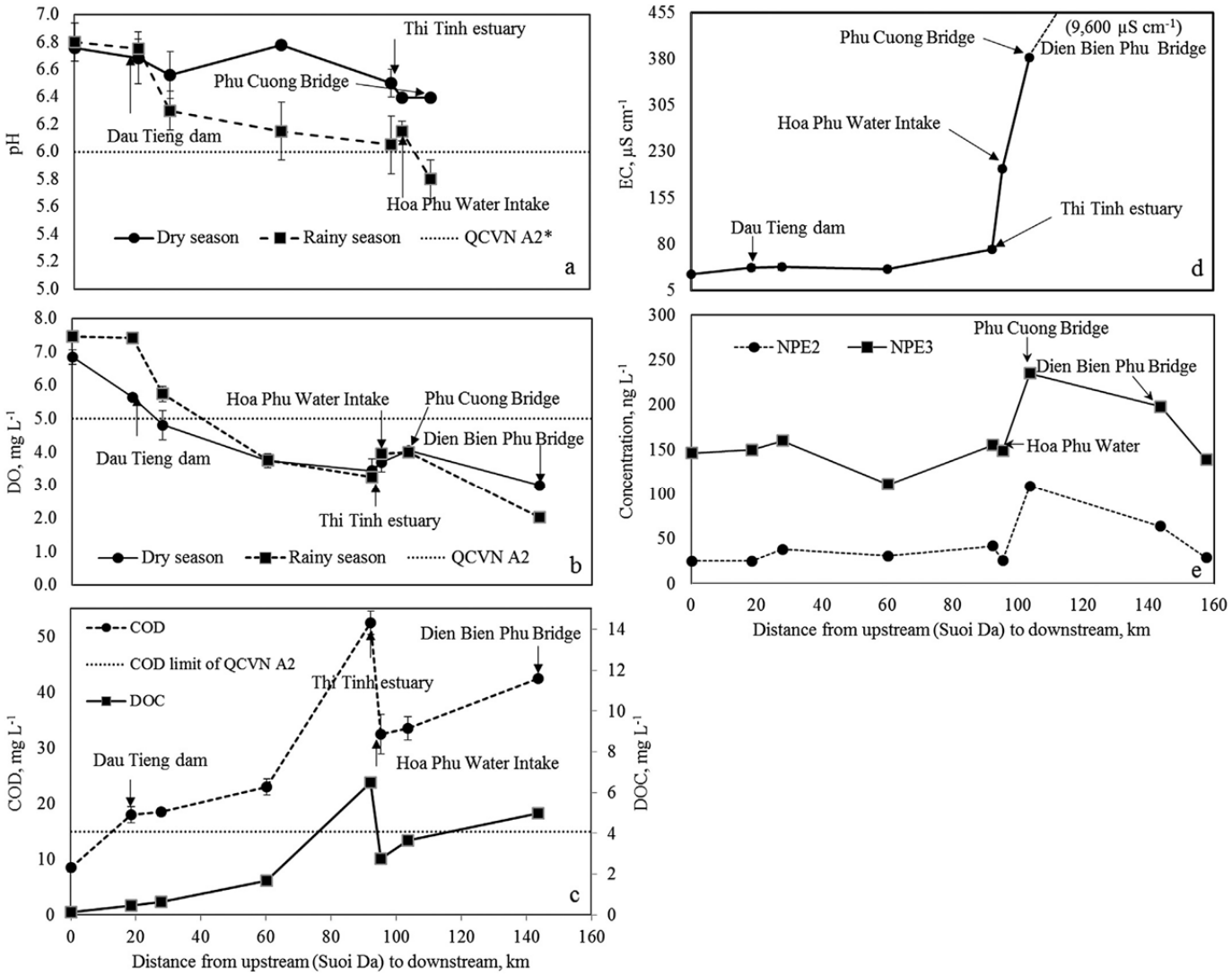


Fig. 3. Variation of pH, DO, COD, DOC, EC, NPE2 and NPE3 along the Sai Gon River from Dau Tieng reservoir to the downstream. *QCVN A2: National technical regulation on surface water quality column A2.

from acid sulphate soils in the downstream area of Sai Gon river basin [12].

Fig. 3b shows the DO was high at Dau Tieng reservoir (above 6 mg L^{-1}). However, DO values rapidly decreased at downstream sites (less than 4 mg L^{-1}). This may be due to: (i) DO consumption of heterotrophic bacteria and nitrifiers for degradation of biodegradable organic matter and ammonia or nitrite from pollution sources, and (ii) the reaction of iron and manganese in water runoff from acid sulphate soils and sediment [12].

Fig. 3c shows that COD and DOC increased at downstream sites. COD and DOC were quite high at the junction of the Sai Gon and Thi Tinh rivers. The result was similar to those of the study of DST [12]. Thus, water pollution from Thi Tinh River adversely affect raw water quality at Hoa Phu water intake.

EC is a parameter related to salinity or chloride content. The result showed that EC increased at sampling site in Hoa Phu water intake in April 2013 (Fig. 3d). Other study [13] showed chloride level in Hoa Phu Water Intake was 250 mg L^{-1}. This value is higher than the allowable values of Vietnamese technical regulation on drinking water quality [14]. However, chloride concentration in this study was 62 mg L^{-1} at Hoa Phu water intake. This value is below the threshold of regulation on drinking water quality.

3.1.2. e-EDCs

Tables 1 and 2 show target e-EDCs levels in Sai Gon and Dong Nai River in 2013. Sai Gon River upstream from Dau Tieng reservoir to Hoa Phu water intake, bisphenol A (BPA) concentrations were below limit of detection (BDL < 0.9 ng L^{-1}). BPA is an e-EDCs and has an acute toxicity to aquatic organisms in the range of 1.1e10 mg L^{-1} for freshwater and marine species [15]. For urban canals in HCMC, BPA concentration was detected at relatively high level (0.14 mg L^{-1}) in Phu Lam Bridge in April 2013.

Octylphenol (OP) was not found in Dau Tieng reservoir in both seasons. In dry season, the concentration of OP was in the range of 25e27 ng L^{-1} from Ben Suc Bridge to Phu Cuong Bridge and OP level (35 ng L^{-1}) in Phu Lam Bridge located in HCMC inner was higher than in other sites. Thus, OP concentrations at Ben Suc Bridge and Phu Lam Bridge sites in this study were higher than another study [16].

Octylphenol ethoxylates (OPEs) are one of the most common surfactants in the market place [17]. Octylphenol triethoxylate (OPE3) and octylphenol diethoxylate (OPE2) concentrations in Sai Gon River upstream in the dry season were in the ranges of BDL-32 and BDL-37 ng L^{-1}, respectively. OPE3 and OPE2 were not detected in Dong Nai River upstream. In Phu Cuong Bridge, OPE2 and OPE3

Table 1
Concentration of the target e-EDCs in Sai Gon and Dong Nai river basin in wet season (ng L^{-1}).

Location	Sample Number	Concentration (ng L^{-1})[a]									
		E3	BPA	Atrazine	OP	OPE3	OPE2	NP	NPE3	NPE2	E2
SG.up	6	BDL	BDL	6.4e6.8 (3.3)	BDL	15.1e15.7 (5.1)	BDL	BDL	37.8e53.2 (46.2)	27.6e29.3 (23.8)	BDL
SG.PS	1	BDL	BDL	6.1	BDL	BDL	BDL	14.8	52.1	30.4	BDL
SG.down	2	17.2e21.6 (19.4)	BDL	5.7e5.9 (5.8)	BDL	BDL	BDL	16.8e18.4 (17.6)	48.7e63.7 (56.2)	26.4e28.4 (27.4)	BDL-13 (6.4)
CityCanal	3	BDL	24.8e66.8 (30.5)	6.2e48.5 (21.8)	BDL	BDL	BDL	BDL	43.9e54.9 (48.8)	28.9e43.2 (34.7)	17.0e27.0 (14.7)
DN.up	2	BDL	BDL	8.2e9.8 (9)	BDL	BDL	BDL	BDL	44.3e48.0 (46.2)	27.7e29.1 (28.4)	BDL
DN.PS	7	BDL	BDL	5.9e7.7 (4.5)	BDL	15.3e15.7 (8.9)	BDL	BDL	32.3e54.8 (46.4)	28.0e29.4 (28.7)	BDL
LOD		1.3	0.9	1.5	2.0	1.6	2.7	1.9	5.9	3.4	3.5

SG.up: Sampling sites in the upstream of Sai Gon River Water Pump Station; SG.PS: Site at Sai Gon River Water Pump Station; SG.down: Sites in the downstream of Sai Gon River Water Pump Station; CityCanal: Canals in the Center of Ho Chi Minh City; DN.up: Sites in the upstream of Dong Nai River Water Pump Station; DN.PS: Site at Dong Nai River Water Pump Station.

[a] Concentration range and mean value in parentheses.

Table 2
Concentration of the target e-EDCs in Sai Gon and Dong Nai river basin dry season (ng L^{-1}).

Location	Sample number	Concentration (ng L^{-1})[a]									
		E3	BPA	Atrazine	OP	OPE3	OPE2	NP	NPE3	NPE2	E2
SG.up	5	BDL-11 (2.75)	BDL	BDL-27 (11.5)	BDL-28 (13.75)	BDL-34 (11.5)	BDL-37.1 (15.5)	BDL	111–160 (140.5)	25–42 (30.8)	BDL-34 (21)
SG.PS	1	BDL	BDL	28	36.6	BDL	24.3	BDL	149	26	BDL
SG.down	2	BDL-11 (5.5)	BDL	BDL-20 (10)	BDL-26 (12.8)	BDL-35 (17.5)	BDL-19.5 (10)	BDL	128–235 (181)	36–109 (72.5)	BDL-31 (15.5)
CityCanal	3	BDL-16 (9.7)	BDL-144 (56.6)	BDL	BDL-35 (11.7)	15.2–36 (23.3)	BDL-31.3 (17.3)	BDL	105–198 (147.3)	29–159 (84)	49–63 (54)
DN.up	2	BDL	3-6 (4.6)	16–30 (23)	BDL-7 (3.6)	BDL	BDL	BDL	34–55 (44.5)	BDL	BDL-22 (11)
DN.PS	2	BDL-6 (3)	BDL-9 (4.5)	14–25 (17.5)	15.6–19 (17.5)	BDL-7 (3.4)	BDL	BDL	68–109 (88.5)	BDL-13 (6.5)	BDL
LOD		1.3	0.9	1.5	2.0	1.6	2.7	1.9	5.9	3.4	3.5

[a] Concentration range and mean value in parentheses.

levels were 20 and 35 ng L^{-1}, respectively. Ferguson et al. [16] reported that OPE3 and OPE2 levels in Jamaica Bay, Long Island, New York ranged from BDL to 10.3 (mean of 2.4 ng L^{-1}) and from BDL to 15.6 ng L^{-1} (mean of 5.4 ng L^{-1}), respectively; significantly lower than those of Phu Cuong Bridge. In addition, in urban canals in HCMC, OPEs levels were in the range of 15e36 ng L^{-1}. This indicates that urban canals in HCMC are heavily polluted by domestic and/or industrial wastewater that contains high OPEs.

Nonylphenol (NP) is highly toxic to aquatic life, causing reproductive effects on aquatic organisms at concentrations ranging from 0.13 mg L^{-1} up to the mg L^{-1} [18]. In wet season, NP was found at Hoa Phu water intake site (14.8 ng L^{-1}) and the downstream sites (16.8e18.4 ng L^{-1}). NP was not observed in water samples of Sai Gon and Dong Nai Rivers in the dry season.

Nonylphenol ethoxylates (NPEs) were commonly used in industrial applications and consumer products [19]. NPEs are less toxic than NP, but they are quite high toxic to aquatic organisms, and decompose to more persistent NP in the environment. Except upstream sites and water intakes of Dong Nai River, nonylphenol diethoxylate (NPE2) and nonylphenol triethoxylate (NPE3) were exposed in all other sites in the dry season. NPE2 and NPE3 were found in almost of all canal samples in Sai Gon and Dong Nai Rivers' upstream in the rainy season and dry season. NPE3 and NPE2 concentrations were in the range of 111e160 and 25e42 ng L^{-1} in Sai Gon River's upstream in dry season, respectively. NPE3 and NPE2 levels especially were up to 235 and 109 ng L^{-1} at Phu Cuong Bridge in dry season, respectively. Difference in level of NPE2 and NPE3 between upstream and downstream in Sai Gon and Dong Nai Rivers is shown in Fig. 3e. The results indicate that the highest NPE2 and NPE3 concentrations are observed at Phu Cuong Bridge. Sai Gon River at Phu Cuong Bridge site was the place which received about 56,000 m^3 d^{-1} discharged domestic wastewater from Thu Dau Mot Town in Binh Duong Province. However, only 32% of total discharge was treated by a central wastewater treatment plant (17,650 m^3 d^{-1}) [20]. Thus, huge quantity of untreated wastewater led to deteriorated water quality at the Hoa Phu water intake. Indeed, NPE3 (149 ng L^{-1}) and NPE2 (26 ng L^{-1}) levels at Hoa Phu water intake site were quite high in dry season. Generally, compared with other locations in Sai Gon and Dong Nai basins, the potential risks of NPE2 and NPE3 at Phu Cuong Bridge should be considered in terms of safe drinking water supply.

The concentration of NPE3 at Phu Cuong bridge was similar to those of the samples (26e328 ng L^{-1}) in USA [16]. However, NPE3 concentration in this study was significantly lower than these reported in Taiwan (2800e25,700 ng L^{-1}) [21]. The concentration for total NPEs in Ohio were in the ranges of 0.13e1.0 mg L^{-1} for surface water [22]. Generally, NPE3 and NPE2 in this study were similar to those reported in Ohio and Great lakes (USA). Comparison of NPE2

and NPE3 levels in surface waters in Vietnam and other countries are shown in Table 3. It is indicated that e-EDCs contamination in Sai Gon River water is lower than those of other studies. Low trace contamination may be due to: (i) high discharge of Sai Gon River (minimum 22.5 $m^3 s^{-1}$ with average 54 $m^3 s^{-1}$) [23] which may dilute trace pollutants from effluent of pollution sources including 800,000 $m^3 d^{-1}$ of domestic wastewater and 80,000 $m^3 d^{-1}$ of industrial wastewater [4], and (ii) availability of wastewater treatment plant for all industrial parks and industries in Sai Gon river basin.

Total estrogen equivalent concentration (EEQ) of a sample is determined by the formula: EEQi ¼ Ci X EEFi, and EEQt ¼ $\sum$ EEQi [1], where EEF is estrogenic potency factor. The highest values of EEF of BPA, OP, NP, NPE3, NPE2, OPE2, OPE3, E2 and E3 are listed in Table 4.

Fig. 4 shows that total EEQ of Sai Gon and Dong Nai Rivers upstream was low (17 pg L^{-1}) in dry season. EEQ in canals in the inner HCMC of in dry season was significantly higher than that in wet season. EEQ at Hoa Phu Water Intake in Sai Gon River was higher than that Hoa An and Binh An water intakes in Dong Nai River in dry season. This indicates that raw water of Sai Gon River is at higher risk than that of Dong Nai River. However, compared with EEQ in other countries, EEQs of both rivers in this study were lower (Table 5). This may be because: (i) high average temperature of tropical monsoon climate in the South of Vietnam can promote heterotrophic bacterial activity that may utilize slowly biodegradable trace organics [24]; (ii) high discharge of Sai Gon River (maximum 86 $m^3 s^{-1}$) and Dong Nai River (maximum 100 $m^3 s^{-1}$) [23] may dilute trace pollutants; and (iii) E2 with the highest EEF among natural estrogens was not detected in most of the samples.

3.2. Water pollution sources

The target e-EDC concentrations in wastewater samples are listed in Table 6. The results show the concentrations of BPA, E3, NPE3 and E2 are in the range of BDL-51, BDL-29, 55.1e176 and BDL-16 ng L^{-1} in surface runoff from agricultural area, respectively.

Table 3
Concentration of NPE2 and NPE3 in surface water in this study and other studies.

Location	Concentration (ng L^{-1})		Reference
	NPE2	NPE3	
USA	38e398	26e328	[16]
Taiwan	e	2800e25700	[21]
USA	e	130e1000	[22]
Canada	BDL-10000	e	[28]
Switzerland	800e21000	e	[29]
Vietnam (Sai Gon - Dong Nai river)	25e42[a] 28e29[b]	111e160[a] 38e51[b]	This study

[a] Data for the dry season in Sai Gon river upstream.
[b] Data in the rainy season in Sai Gon river upstream.

Table 4
The highest values of estrogenic potency of BPA, OP, NP, NPE3, NPE2, OPE2, OPE3, E2 and E3.

No	Chemical	EEF	Reference
1	BPA	2.5×10^{-3}	[30]
2	OP	1.3×10^{-3}	[30]
3	NP	1.1×10^{-3}	[30]
4	NPE3	1.1×10^{-5}	[31]
5	NPE2	1.1×10^{-5}	[31]
6	OPE3	4×10^{-6}	[31]
7	OPE2	4×10^{-6}	[31]
8	E2	0.11	[31]
9	E3	0.1	[32]

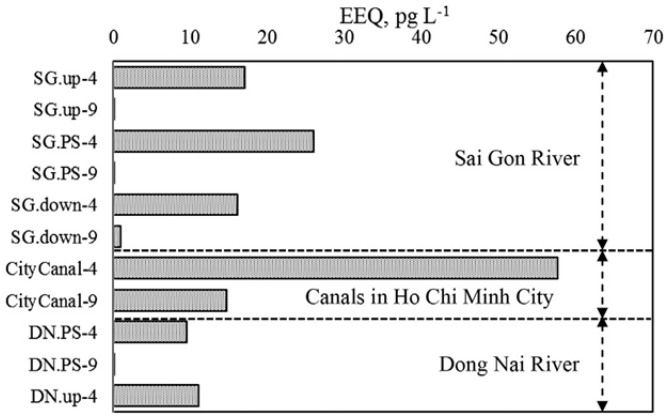


Fig. 4. Total estrogen equivalent of target e-EDCs.

Table 5
EEQ values in other studies.

Location	EEQ (ng L^{-1})	Reference
River in Japan	0.7e4.01	[33]
River in France	0.3e4.52	[34]
River in Holland	0.068e0.47	[35]
Vietnam (Sai Gon and Dong Nai river)	0.017e0.16	This study

Therefore, NPE3 was found at high concentration in agricultural area. This may be due to NPEs are components used in pesticide products [25]. Meanwhile, other e-EDCs (Atrazine (ATZ), OP, OPE3, OPE2, NPE2 and NP) were lower than the LOD. BPA, OPE3, NPE3, NP and E2 levels in effluent of landfill leachate were 27, 19, 173, 27 and 268 ng L^{-1}, respectively.

Wastewater from a paper mill at My Phuoc, Binh Duong Province was treated by using anaerobic process, aerobic process, flocculation and Fenton oxidation. The samples in effluent from a paper mill contained ATZ (13e65 ng L^{-1}), NPE3 (63e328 ng L^{-1}) and E2 (36e138 ng L^{-1}). NPE3, ATZ and E2 removal efficiencies of a wastewater treatment plant for paper mill were 81, 77 and 41%, respectively.

In effluent from a tannery factory, NPE3, NPE2, NP, E3 and BPA levels after biological treatment and coagulation-flocculation post-treatment were 194, 53, 12, 7 and 19 ng L^{-1}, respectively. Pothitou and Voutsa [26] monitored the occurrence of EDCs in effluent from tannery factories in Greece. The results show that BPA 1 mg L^{-1}, NPE2 52 mg L^{-1} and NP 433 mg L^{-1} are higher than those in this study.

E2, E3, BPA, ATZ, NPE2 and NPE3 were detected in effluent from Trang Bang industrial park using activated sludge followed by advanced oxidation processes and stabilization pond. NPE2, ATZ, BPA and NPE3 concentrations in this study were lower than those in other studies shown in Table 7. This reveals that application of biological and physico-chemical treatment processes in wastewater treatment plants could significantly reduce e-EDCs. Hence, pollution point sources have not significantly attributed to e-EDC in Sai Gon River, and presence of e-EDC mainly due to non-point sources such as surface runoff from agricultural activity and sewage from scattered residential areas without wastewater treatment plant.

3.3. Correlation among e-EDCs and physico-chemical parameters in Sai Gon and Dong Nai Rivers

To date, the current water quality monitoring stations can measure conventional physico-chemical and biological parameters

Table 6
Concentration of e-EDCs in effluent of pollution sources in 2013.

Location	E3	BPA	ATZ	OPE3	OPE2	NP	NPE3	NPE2	E2
SR	BDL-29.0	BDL-51	BDL	BDL	BDL	BDL	55e176	BDL	BDL-16
ML	BDL	27	BDL	19	BDL	27	173	BDL	268
PM	BDL-92	8e30	13e65	BDL	BDL	BDL	63e328	BDL	36e138
TN	7.2	19	BDL	BDL	BDL	12.0	194	53.1	BDL
RL	BDL	BDL-6	BDL	BDL	BDL-32	BDL-24	62e118	BDL	BDL-32
IP	10	2.4	7	BDL	BDL	BDL	72	8	18
LOD	1.3	0.9	1.5	1.6	2.7	1.9	5.9	3.4	3.5

SR: Surface run-off from agricultural area; ML: Municipal solid waste landfill; IP: Industrial Park wastewater treatment plants; PM: Paper mill; TN: Tannery factory; RL: Rubber latex processing industry.

Table 7
Concentrations of e-EDCs in the effluent of industrial parks.

Location	Concentration (ng L^{-1})						Reference
	NPE2	NPE3	BPA	E3	ATZ	E2	
USA	NA	8770e78800	NA	NA	NA	NA	[36]
Greece	87	NA	33	BDL	NA	NA	[26]
Spain	NA	NA	70 [37]	NA	124[m] [38]	NA	[38] [37]
China	NA	NA	NA	BDL-11	NA	BDL-8.4	[39]
Vietnam	8	72	2.4	10	7	18	This study

*m: Mean value.
BDL: below detection limit; NA: Not Available.

(DO, pH, COD, BOD, EC, turbidity, TN, TP, ammonia, etc.), while monitoring trace organic pollutants such as e-EDCs have not been available in Vietnam due to high analytic costs. Based on correlation among e-EDCs and physico-chemical parameters, e-EDCs contamination may be predicted from monitoring data for physico-chemical parameters. This may assist the water authorities in preliminarily finding areas/sites that may have high potential risk of EDCs contamination.

Table 8 shows that NPE2 has highly positive correlation ($r > 0.5$ and $P < 0.005$) with DOC, TN, ammonia, phosphate and negative correlation with DO. This indicates that surface water contaminated with organic matters and nitrogen compounds can positively relate to NPEs contamination. Conductivity has a significant correlation with estradiol. In addition, EEQ has also positive correlation with DOC and EC and negative correlation with DO.

The results show NPE2 was remarkable correlation with DOC ($r ¼ 0.661$, $P ¼ 0.001$) that was consistent with report of Gong et al. [27] in the surface water samples of Zhujiang and Dongjiang Rivers, Pearl River Delta of South China. The correlation NPE2 with DOC may be related to association of EDCs with colloidal DOC or it was discharged from the same source [27].

4. Conclusions

This study demonstrated that (i) NPE3 and NPE2 were found in most of the samples, especially, they were high at the sites nearby the water intake of water treatment plant in Sai Gon River (235 ng L^{-1} NPE3 and 109 ng L^{-1} NPE2); (ii) total EEQ of 57 pg L^{-1} was the highest level in urban canals in HCMC in the dry season; (iii) EEQ and NPE2 have highly significant correlation ($R^2 > 0.7$) with physico-chemical parameters (DOC, TN, EC and DO); and (iv) Compared with other studies, NPE2, NPE3, BPA and ATZ concentrations of effluents from the point sources and non-point sources in this study were not high.

Table 8
Correlation among concentrations e-EDCs and physico-chemical parameters in Sai Gon and Dong Nai Rivers in September 2013 and April 2013.

		DOC	DO	pH	Turbidity	EC	TN	N-ammonia	TP	ATZ	E2	NPE3	NPE2	EEQ
ATZ	P	0.407	-0.282	0.454	0.155	0.073	0.366	-0.084	0.247	1	0.738	0.762[b]	0.323	0.411
	S	0.168	0.351	0.119	0.631	0.812	0.219	0.785	0.415		0.094	0.002	0.282	0.164
	N	13	13	13	12	13	13	13	13	13	6	13	13	13
E2	P	0.489	0.024	-0.360	-0.330	0.809[b]	-0.090	0.032	-0.012	0.738	1	0.395	0.335	0.918[b]
	S	0.152	0.947	0.306	0.425	0.005	0.817	0.930	0.973	0.094		0.259	0.344	0.000
	N	10	10	10	8	10	9	10	10	6	10	10	10	10
NPE3	P	0.114	-0.279	0.414[a]	-0.227	0.280	0.104	-0.138	-0.126	0.762[b]	0.395	1	0.379	0.439[a]
	S	0.606	0.198	0.049	0.336	0.195	0.664	0.531	0.566	0.002	0.259		0.082	0.036
	N	23	23	23	20	23	20	23	23	13	10	23	22	23
NPE2	P	0.661[b]	-0.424[a]	0.131	-0.057	0.078	0.719[b]	0.652[b]	0.553[b]	0.323	0.335	0.379	1	0.541[b]
	S	0.001	0.049	0.560	0.816	0.730	0.001	0.001	0.008	0.282	0.344	0.082		0.009
	N	22	22	22	19	22	19	22	22	13	10	22	22	22
EEQ	P	0.601[b]	-0.425[a]	0.284	-0.007	0.691[b]	0.452[a]	0.450[a]	0.365	0.411	0.918[b]	0.439[a]	0.541[b]	1
	S	0.002	0.043	0.189	0.977	0.000	0.045	0.031	0.087	0.164	0.000	0.036	0.009	
	N	23	23	23	20	23	20	23	23	13	10	23	22	23

- P: Pearson Correlation; - S: Significant (2-tailed); - N: Sample number.
[a] Correlation is significant at the 0.05 level (2-tailed).
[b] Correlation is significant at the 0.01 level (2-tailed).

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References

[1] Campbell CG, Borglin SE, Green FB, Grayson A, Wozei E, Stringfellow WT. Biologically directed environmental monitoring, fate, and transport of estrogenic endocrine disrupting compounds in water: a review. Chemosphere 2006;65:1265e80.

[2] Petrovic M, Eljarrat E, de Alda ML, Barceló D. Endocrine disrupting compounds and other emerging contaminants in the environment: a survey on new monitoring strategies and occurrence data. Anal Bioanal Chem 2004;378: 549e62.

[3] Stoxplus. 2013 Annual Sector Report on Vietnam Water Supply. Ha Noi, Vietnam: StoxPlus Corporation; 2014.

[4] DST. Project Report on Impact of Climate Change on Discharge Water Quality and Saline Water Intrusion of Sai Gon River and Suggestion of Feasible Adaptive Measures. Ho Chi Minh City, Vietnam: Department of Science and Technology; 2013 (in Vietnamese).

[5] MONRE. National Surface Water Quality Standards QCVN 08: 2008/BTNMT. Ha Noi, Vietnam: Ministry of Natural Resources and Environment; 2008 (in Vietnamese).

[6] Le TAH. The YES Assay as a Tool to Analyse Endocrine Disruptors in Different Matrices in Vietnam [Ph.D. Dissertation]. Bonn (Germany): Rheinische Friedrich-Wilhelms Univ.; 2012.

[7] Caldwell DJ, Mastrocco F, Hutchinson TH, Længe R, Heijerick D, Janssen C, et al. Derivation of an aquatic predicted no-effect concentration for the synthetic hormone, 17a-ethinyl estradiol. Environ Sci Technol 2008;42:7046e54.

[8] Parrott JL, Blunt BR. Life-cycle exposure of fathead minnows (Pimephales promelas) to an ethinylestradiol concentration below 1 ng/L reduces egg fertilization success and demasculinizes males. Environ Toxicol 2005;20: 131e41.

[9] APHA. Standard Methods for the Examination of Water and Waste Water. 20th ed. Washington, DC: American Public Health Association; 1998.

[10] Dinh QT, Alliot F, Moreau-Guigon E, Eurin J, Chevreuil M, Labadie P. Measurement of trace levels of antibiotics in river water using on-line enrichment and triple-quadrupole LCeMS/MS. Talanta 2011;85:1238e45.

[11] Gómez MJ, Petrović M, Fernández-Alba AR, Barceló D. Determination of pharmaceuticals of various therapeutic classes by solid-phase extraction and liquid chromatographyetandem mass spectrometry analysis in hospital effluent wastewaters. J Chromatogr A 2006;1114:224e33.

[12] DST. Study on Integrated Solutions for Protection of Sai Gon River Water Quality Served for Safe Water Supply in Ho Chi Minh City. Ho Chi Minh City, Vietnam: Department of Science and Technology; 2008 (in Vietnamese).

[13] SAWACO. Annual Report of Water Quality Monitoring at Tan Hiep Water Treatment Plant. Ho Chi Minh City, Vietnam: Saigon Water Corporation; 2011 (in Vietnamese).

[14] MOH. National Technical Standards on Drinking Water Quality QCVN 01: 2009/BYT. Ha Noi, Vietnam: Ministry of Health; 2009 (in Vietnamese).

[15] Alexander HC, Dill DC, Smith LW, Guiney PD, Dorn P, Bisphenol A. Acute aquatic toxicity. Environ Toxicol Chem 1988;7:19e26.

[16] Ferguson PL, Iden CR, Brownawell BJ. Distribution and fate of neutral alkylphenol ethoxylate metabolites in a sewage-impacted urban estuary. Environ Sci Technol 2001;35:2428e35.

[17] Ying GG, Williams B, Kookana R. Environmental fate of alkylphenols and alkylphenol ethoxylates e a review. Environ Int 2002;28:215e26.

[18] OEHHA. Toxicological Profile for Nonylphenol. Sacramento, CA: Office of Environmental Health Hazard Assessment; 2009.

[19] USEPA. Nonylphenol (NP) and Nonylphenol Ethoxylates (NPEs) Action Plan. Washington, DC: United States Environmental Protection Agency; 2010.

[20] BIWASE. Thu Dau Mot Wastewater Treatment Enterprise. Thu Dau Mot City, Vietnam: Binh Duong Water Supply Sewerage Environment Limited Company; 2012 (in Vietnamese).

[21] Ding WH, Tzing SH, Lo JH. Occurrence and concentrations of aromatic surfactants and their degradation products in river waters of Taiwan. Chemosphere 1999;38:2597e606.

[22] Rice CP, Schmitz-Afonso I, Loyo-Rosales JE, Link E, Thoma R, Fay L, et al. Alkylphenol and alkylphenol-ethoxylates in carp, water, and sediment from the Cuyahoga River, Ohio. Environ Sci Technol 2003;37:3747e54.

[23] IGES. Sustainable Groundwater Management in Asian Cities. Kanagawa, Japan: Institute for Global Environmental Strategies; 2007.

[24] Alidina M, Shewchuk J, Drewes JE. Effect of temperature on removal of trace organic chemicals in managed aquifer recharge systems. Chemosphere 2015;122:23e31.

[25] Cox C. Nonyl phenol and related chemicals. J Pestic Reform 1996;16:15e20.

[26] Pothitou P, Voutsa D. Endocrine disrupting compounds in municipal and industrial wastewater treatment plants in Northern Greece. Chemosphere 2008;73:1716e23.

[27] Gong J, Ran Y, Chen D, Yang Y, Ma X. Occurrence and environmental risk of endocrine-disrupting chemicals in surface waters of the Pearl River, South China. Environ Monit Assess 2009;156:199e210.

[28] Bennie D, Sullivan C, Lee HB, Peart T, Maguire R. Occurrence of alkylphenols and alkylphenol mono- and diethoxylates in natural waters of the Laurentian Great Lakes basin and the upper St. Lawrence River. Sci Total Environ 1997;193:263e75.

[29] Ahel M, Schaffner C, Giger W. Behaviour of alkylphenol polyethoxylate surfactants in the aquatic environment e III. Occurrence and elimination of their persistent metabolites during infiltration of river water to groundwater. Water Res 1996;30:37e46.

[30] Rutishauser BV, Pesonen M, Escher BI, Ackermann GE, Aerni HR, Suter MJF, et al. Comparative analysis of estrogenic activity in sewage treatment plant effluents involving three in vitro assays and chemical analysis of steroids. Environ Toxicol Chem 2004;23:857e64.

[31] de Voogt P, van Hattum B. Critical factors in exposure modeling of endocrine active substances. Pure Appl Chem 2003;75:1933e48.

[32] Soto AM, Sonnenschein C, Chung KL, Fernandez MF, Olea N, Serrano FO. The E-SCREEN assay as a tool to identify estrogens: an update on estrogenic environmental pollutants. Environ Health Persp 1995;103:113e22.

[33] Hashimoto S, Horiuchi A, Yoshimoto T, Nakao M, Omura H, Kato Y, et al. Horizontal and vertical distribution of estrogenic activities in sediments and waters from Tokyo Bay, Japan. Arch Environ Con Tox 2005;48:209e16.

[34] Cargouet M, Perdiz D, Mouatassim-Souali A, Tamisier-Karolak S, Levi Y. Assessment of river contamination by estrogenic compounds in Paris area (France). Sci Total Environ 2004;324:55e66.

[35] Murk AJ, Legler J, van Lipzig MM, Meerman JH, Belfroid AC, Spenkelink A, et al. Detection of estrogenic potency in wastewater and surface water with three in vitro bioassays. Environ Toxicol Chem 2002;21:16e23.

[36] Naylor CG, Mieure JP, Adams WJ, Weeks JA, Castaldi FJ, Ogle LD, et al. Alkylphenol ethoxylates in the environment. J Am Oil Chem Soc 1992;69:695e703.

[37] Céspedes R, Lacorte S, Ginebreda A, Barceló D. Chemical monitoring and occurrence of alkylphenols, alkylphenol ethoxylates, alcohol ethoxylates, phthalates and benzothiazoles in sewage treatment plants and receiving waters along the Ter River basin (Catalonia, NE Spain). Anal Bioanal Chem 2006;385:992e1000.

[38] Köck-Schulmeyer M, Villagrasa M, de Alda ML, Céspedes-Sánchez R, Ventura F, Barceló D. Occurrence and behavior of pesticides in wastewater treatment plants and their environmental impact. Sci Total Environ 2013;458: 466e76.

[39] Zhou Y, Zha J, Wang Z. Occurrence and fate of steroid estrogens in the largest wastewater treatment plant in Beijing, China. Environ Monit Assess 2012;184:6799e813.