Emerging Contaminants 2 (2016) 135–144

Contents lists available at ScienceDirect

Emerging Contaminants

journal homepage: http://www.keaipublishing.com/en/journals/emerging-contaminants/

Occurrence of pharmaceuticals and perfluorinated compounds and evaluation of the availability of reclaimed water in Kinmen

Webber Wei-Po Lai, Yen-Ching Lin, Hsin-Hsin Tung, Shang-Lien Lo, Angela Yu-Chen Lin*

Graduate Institute of Environmental Engineering, National Taiwan University, 71-Chou-shan Road, Taipei, 106, Taiwan

ARTICLE INFO

Article history:
Received 25 February 2016
Received in revised form
28 April 2016
Accepted 2 May 2016
Available online 18 May 2016

Keywords:
Emerging contaminant
Perfluorinated compound
Pharmaceutical
Water scarcity
Wastewater treatment plant

ABSTRACT

Emerging contaminants have commonly been observed in environmental waters but have not been included in water quality assessments at many locations around the world. To evaluate the availability of reclaimed water in Kinmen, Taiwan, this study provides the first survey of the distribution of thirty-three pharmaceuticals and five perfluorinated chemicals in lake waters and water from local wastewater treatment plants (WWTPs). The results showed that the target emerging contaminants in Kinmen lakes were at trace ng/L concentrations. In addition, most of the target compounds were present in the Jincheng and Taihu WWTP influents at ng/L concentrations levels, of which 5 compounds (erythromycin-H_2O (1340 ng/L), ibuprofen (1763 ng/L), atenolol (1634 ng/L), acetaminophen (2143 ng/L), and caffeine (3113 ng/L)) reached μg/L concentrations. The overall treatment efficiencies of the Jincheng and Taihu WWTPs with respect to these pharmaceuticals and perfluorinated chemicals were poor; half of the compounds were less than 50% removed. Five compounds (sulfamethoxazole, erythromycin-H_2O, clarithromycin, ciprofloxacin and ofloxacin) with risk quotient (RQ) values > 1 in the effluent should be further investigated to understand their effects on the aquatic environment. Additional and advanced treatment units are found necessary to provide high-quality recycled water and sustainable water resources.

1. Introduction

Kinmen, an outlying subtropical island of Taiwan (24 °30′N, 118 °25′E), is located on the west side of the Taiwan Strait. Kinmen covers a total area of 153.1 km^2 and has a total population of approximately 120,000 (http://www.kinmen.gov.tw/). The economic structure of Kinmen is dominated by agriculture, and the consumption of water for irrigation is approximately 9000 tons/day. Kaoliang Liquor is an economic mainstay of Kinmen and has resulted in agriculture and tourism development.

Water scarcity is a severe and urgent issue in Kinmen. Because urbanization has occurred rapidly in Kinmen in recent years, water consumption in Kinmen has increased. However, only a limited number of short and small rivers and streams exist in Kinmen, with rainfall mainly occurring from April to September. Furthermore, the annual evaporation (1684 mm/yr) is greater than the annual rainfall (1047 mm/yr) in Kinmen, which results in water shortages. Although several lakes and reservoirs are located in Kinmen, severe algal blooms and eutrophication have resulted in their poor water quality. Groundwater has played an important role in supplying a sufficient amount of water with up to 54% of water for domestic use, agricultural irrigation and industrial use (e.g., Kaoliang Liquor manufacturing process) obtained from groundwater sources. Accordingly, continuous and excessive groundwater pumping has led to decreased groundwater levels (a decrease of nearly 20 cm/yr) and groundwater salinization. To solve the urgent water scarcity problem, a project for the development of reclaimed water and alternative water sources in Kinmen has been implemented. Currently, treated water in Kinmen is recovered for non-potable reuse, such as agricultural irrigation and groundwater recharge, following conventional wastewater treatment processes. To improve the use and application of reclaimed water, emerging

* Corresponding author.
E-mail address: yuchenlin@ntu.edu.tw (A.Y.-C. Lin).
Peer review under responsibility of KeAi Communications Co., Ltd.

http://dx.doi.org/10.1016/j.emcon.2016.05.001

contaminants must remain part of the discussion because many emerging contaminants are not completely removed by conventional wastewater treatment processes and are, consequently, released into receiving aquatic environments and potentially threaten the ecosystem and human health [1–4].

Pharmaceuticals and personal care products (PPCPs), hormones and industrial compounds, such as perfluorinated compounds (PFCs), were the most commonly detected emerging contaminants. These compounds have been found at ng/L to μg/L concentrations around the world in many types of water matrices, including wastewater treatment plant (WWTP) influents and effluents, hospital wastewater, wastewater from pharmaceutical manufacturing companies, industrial wastewater and even surface water and groundwater. For example, nonsteroidal anti-inflammatory drugs (NSAIDs), antibiotics and other pharmaceuticals have commonly been detected in hospital wastewater and pharmaceutical manufacturing wastewater in Korea, Switzerland and the USA [5–7], with corresponding concentrations of up to μg/L. Regarding the removal efficiency of pharmaceuticals in WWTPs, Canadian researchers have indicated that many compounds are not effectively removed (e.g., diclofenac and gemfibrozil) and remain in effluents [8]. In addition, Spanish researchers have demonstrated that the removal efficiency of different pharmaceuticals varies greatly (6–93%) and differs among WWTPs [9]. In a nationwide reconnaissance conducted by the US Geological Survey [10], 95 pharmaceuticals, hormones, and other organic wastewater contaminants were investigated in 139 streams in the USA. The results of the reconnaissance indicated that many compounds may survive wastewater treatment processes and enter streams. A study from the UK [11] showed the frequent presence of low concentrations of pharmaceuticals in rivers (the most frequently detected compounds include erythromycin-H_2O, acetaminophen, trimethoprim, naproxen and ibuprofen). These pharmaceutical compounds have also been detected in groundwater [12]. In addition to pharmaceuticals, PFCs have generally been recognized as recalcitrant compounds, being detected in industrial wastewaters and their receiving water bodies in many countries (e.g., Japan, China, Thailand, Spain, Taiwan and Germany) [13–17]. In Taiwan, our previous work has demonstrated the occurrence of these emerging contaminants in many types of water matrices (e.g., WWTP wastewater, hospital wastewater, industrial wastewater, surface water and groundwater) [16–21]. Based on previous work, 38 of the most commonly occurring pharmaceuticals (including antibiotics, NSAIDs, lipid regulators, cholesterol lowering drugs, β-blockers, vasodilators, psychiatric drugs and psychostimulants) and PFCs were chosen as our target compounds and monitored for their occurrence on Kinmen Island.

The objectives of this study are to (i) simultaneously analyze 38 emerging contaminants using solid-phase extraction (SPE) combined with liquid chromatography–tandem mass spectrometry; (ii) investigate the occurrence of the target compounds in Taihu and Lunghu Lakes (the main drinking water sources for Kinmen residents); and (iii) investigate the occurrence and removal of the target compounds at the Jincheng and Taihu WWTPs (the largest and second largest WWTPs in Kinmen) and evaluate the use of the treated discharge water as reclaimed water regarding the target emerging contaminants. Because water scarcity is an urgent problem in Kinmen, this study could be used by the Kinmen government to assist in the establishment of guidelines (e.g., evaluation of the availability of reclaimed water in Kinmen and the development of related reclaimed water policies in the future). To our knowledge, this is the first study of the distribution of emerging contaminants in the water matrices of Kinmen Island. The experience at Kinmen Island can be used as an example for islands that are similar and in need of reclaimed waters around the world.

2. Materials and methods

2.1. Sample collection, pretreatment and analysis

The sampling sites, including two lakes (Taihu Lake and Lunghu Lake) and two WWTPs (Jincheng WWTP and Taihu WWTP), are shown in Fig. 1. Water samples were collected as grab samples. Although the grab sample method can result in large uncertainties (because it involves sampling water at one point in time), the samples were collected based on the hydraulic retention times of the two WWTPs to minimize these uncertainties. In addition, all of the samples were collected during the daytime. Triplicate samples were collected and stored in 1-L amber glass bottles in ice-packed containers. All sample bottles (except those used for PFC analysis) contained 4 mL 0.125 M EDTA-2Na/L before sample collection. The samples were vacuum-filtered through 0.45 and 0.22 μm disk filter paper (ADVANTEC, Toyo Roshi Kaisha, Ltd., Japan), acidified to pH 4 using hydrochloric acid and stored at 4 °C until solid-phase extraction (SPE).

The samples were analyzed using SPE combined with liquid chromatography–tandem mass spectroscopy (LC–MS/MS). To obtain the most linear range and the best analytical signals with LC–MS/MS, the target compounds were classified into the following four categories: Group 1: sulfonamide antibiotics (sulfadiazine, sulfamethoxazole, sulfathiazole, sulfamethazine, sulfamonomethoxine and sulfadimethoxine), macrolide antibiotics (erythromycin-H_2O, clarithromycin, roxithromycin and tylosin), imidazole antibiotics (dimetridazole and metronidazole), quinolone antibiotics (nalidixic acid, flumequine, pipemidic acid, norfloxacin, ciprofloxacin and ofloxacin), non-steroidal anti-inflammatory drugs (acetaminophen), other antibiotics (trimethoprim), vasodilator (pentoxifylline), psychiatric drugs (carbamazepine) and psychostimulants (caffeine); Group 2: non-steroidal anti-inflammatory drugs (ibuprofen, naproxen and ketoprofen), lipid regulators and cholesterol-lowering drugs (clofibric acid, gemfibrozil and bezafibrate); Group 3: β-blockers (propranolol, atenolol, metoprolol and sotalol); and Group 4: perfluoroalkyl sulfonic acids (PFOS) and perfluorinated carboxylic acids (PFHxA, PFOA, PFDA and PFHpA). Based on the physicochemical properties and extraction efficiencies of the four groups, Oasis MCX cartridges (Waters, Milford, MA, USA) were utilized for negative-mode analytes, and Oasis HLB cartridges (Waters, Milford, MA, USA) were utilized for positive- and negative-mode analytes. The different target compound classes were extracted using the following three SPE methods.

2.1.1. Method 1 (for groups 1 and 2)

The HLB cartridges were preconditioned using 6 mL of methanol and 6 mL of DI water (pH = 4.0). Aliquots from 400 mL water samples (the pH was adjusted to 4.0 with hydrochloric acid) were spiked with 40 μL of an internal standard (1 mg/L of $^{13}C_6$-sulfamethazine, metronidazole-$^{13}C_2$, $^{15}N_2$, ciprofloxacin-d_8, erythromycin-$^{13}C,d_3$ and roxithromycin-d_7) and loaded into the cartridges at a flow rate of 3–6 mL/min. After sample passage, the cartridges were rinsed with 6 mL of DI water (pH = 4.0) and drained, and after drainage, the analytes were eluted with 3 mL of methanol and 3 mL of a 50% methanol-diethylether (v:v = 50:50) mixture. The eluents were collected, evaporated under a stream nitrogen and reconstituted to a volume of 0.4 mL with 25% aqueous methanol. The final solutions were passed through a 0.45-μm PVDF filter membrane prior to LC–MS/MS analysis.

2.1.2. Method 2 (for group 3)

The MCX cartridges were preconditioned with 6 mL of methanol and 6 mL of DI water (pH = 4.0). Aliquots from 200 mL water samples (the pH was adjusted to 4.0 using hydrochloric acid) were

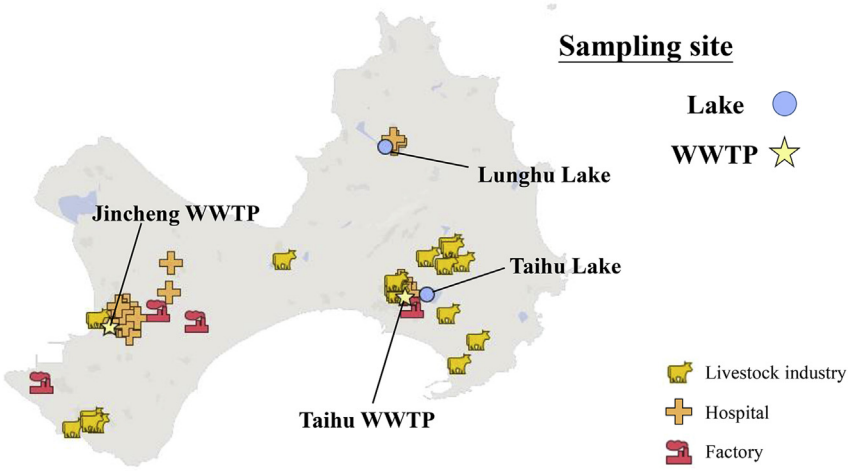

Fig. 1. Map of the sampling sites (WWTPs: Jincheng WWTP and Taihu WWTP; lakes: Taihu Lake and Lunghu Lake) and the potential contamination sources.

spiked with 40 μL of an internal standard (1 mg/L atenolol-d_7) and loaded into the cartridges at a flow rate of 3–6 mL/min. Following sample passage, the cartridges were rinsed with 6 mL of DI water (pH = 4.0) and drained. After draining, the analytes were eluted with 6 mL of a mixture of 5% ammonium hydroxide in methanol (v:v = 5:95). The eluents were collected, evaporated until dry under a stream of nitrogen and reconstituted to 0.4 mL with 25% aqueous methanol. The final solutions were passed through a 0.45-μm PVDF filter membrane prior to LC–MS/MS analysis.

2.1.3. Method 3 (for group 4)

The HLB cartridges were preconditioned with 6 mL of methanol and 6 mL of DI water. Aliquots from 400 mL water samples were spiked with 40 μL of an internal standard (10 μg/L $^{13}C_8$-PFOA) and loaded into the cartridges at a flow rate of 3–6 mL/min. After sample passage, the cartridges were rinsed with 6 mL of DI water and drained. After draining, the analytes were eluted with 6 mL methanol. The eluents were collected, evaporated under a stream of nitrogen and reconstituted to a volume of 0.4 mL with 50% aqueous methanol. The final solutions were passed through a 0.45-μm PVDF filter membrane prior to LC–MS/MS analysis.

Samples were concentrated 500 times by SPE on an Oasis MCX cartridge for positive-mode analytes and 1000 times on an Oasis HLB cartridge for negative- and positive-mode analytes. All extractions were completed within 24 h of sample collection.

Chromatographic separations were performed in gradient mode. Groups 1, 2 and 3 used 0.1% formic acid in DI water (mobile phase A) and 0.1% formic acid in methanol (mobile phase B); and Group 4 used 1 mM ammonium acetate in DI water (mobile phase A) and 1 mM ammonium acetate in methanol (mobile phase B). Twenty-seven target compounds (positive mode) and eleven target compounds (negative mode) were separated by LC–MS/MS using run times of 15 min and 7 min, respectively (Table S1).

Quantification was performed using the internal standard method and the multiple reaction monitoring (MRM) mode of a Sciex API 4000 liquid chromatography mass spectrometry system (Applied Biosystems, Foster City, CA) with positive and negative electrospray ionization (ESI). Table S2 shows the internal standards of the investigated compounds and their LC–MS/MS parameters. The target compounds of Groups 1 and 3 were ionized in ESI positive mode, forming $[M+H]^+$ ions. The target compounds of Groups 2 and 4 were ionized in ESI negative mode, forming $[M-H]^-$ ions. The MS/MS fragmentation conditions were investigated, and the collision energies were optimized for each individual compound to obtain the optimal response (Table S3). The best resolutions for the optimal separations in this study were obtained using a ZORBAX Eclipse XDB-C_{18} column (150 × 4.6 mm, 5 μm). The linearity of the calibration curves was estimated by linear-mode least-squares regression analysis ($y = a + bx$). The method detection limits (MDLs) were determined from the minimum concentration of analyte in the linear range with a signal-to-noise ratio of ≥10:1.

3. Results and discussion

In this study, we sampled two lakes (Taihu Lake and Lunghu Lake) and two WWTPs (Jincheng WWTP and Taihu WWTP). Because Taihu Lake and Lunghu Lake are the main sources of drinking water in Kinmen, we sampled the water from these two lakes to understand the distribution of the target emerging contaminants. Table 1 shows the characteristics (water sources, usage, storage capacity and watershed area) of these two lakes. Regarding the two WWTPs, the treated water in the Jincheng and Taihu WWTPs is generally used for non-potable reuse purposes, such as groundwater recharge and agricultural and landscape irrigation. The presence of emerging contaminants is one critical aspect that must be considered when evaluating the potential uses of recycled water. Detailed information regarding the treatment processes, type of treated water, hydraulic retention time, daily flow and receiving water bodies is provided in Table 2. For the Jincheng WWTP, the two sampling times were in June 2013 and June 2014. At the first sampling time, the influent and the effluent of the Jincheng WWTP were sampled, and the overall removal efficiencies were calculated. At the second sampling time, we investigated the overall removal efficiencies and the efficiencies of the primary and secondary treatment processes.

3.1. Occurrence of pharmaceuticals and PFCs in the lakes (Taihu Lake and Lunghu Lake) in Kinmen

Prior to sample analysis, method validation was performed. Recovery experiments were performed using DI water spiked with the target analytes (Group 1, Group 2 and Group 3: 50 ng/L; Group 4: 25 ng/L) to estimate the percent recovery. The recoveries, method detection limits (MDLs) and linearity (regression coefficient) of the investigated emerging contaminants are shown in Table S4. The accuracy and precision were determined from triplicate sample analyses and standard solutions of the target compounds. The standard calibration curves of the target compounds

Table 1
Characteristics of the investigated lakes.

Lake	Water sources	Usage	Storage capacity (m^3)	Watershed area (ha)
Taihu Lake	Rainwater, surface runoff	Drinking water	1,625,000	741
Lunghu Lake			452,000	220

Table 2
Characteristics of the investigated wastewater treatment plants.

WWTP	Services	Type of treated water	Primary treatment process	Secondary treatment process	Disinfection method	Hydraulic retention time (hr)	Daily flow (CMD)	Receiving water bodies
Jincheng WWTP	Jincheng Township, Jinning Township	Domestic Industrial	Screening + Grit chamber	Oxidation ditch + Sedimentation	Chlorination	20	4500	Taiwan Strait
Taihu WWTP	Jinhu Township, Jinsha Township	Livestock Hospital effluent				32	1500	

with internal standards were made using ten data points, and the standards had concentrations of 0.5–500 μg/L. The standard calibration curves of the target compounds without internal standards were created using seven data points from 5 to 1000 μg/L. The recoveries were 67–118%, with relative standard deviation (RSD) values ranging from 1 to 17% for the different target compounds in DI water, except for gemfibrozil (133.7%). The MDLs ranged from 0.05 to 5 ng/L, with linearity >0.9953.

Table 3 shows the occurrence of 38 emerging contaminants in Taihu Lake and Lunghu Lake. The results indicated that the concentrations of the target emerging contaminants in the two lakes were at the trace ng/L level. For Taihu Lake, the concentrations of every detected compound except caffeine (101.2 ng/L) were less than 50 ng/L. The observed concentrations of the emerging contaminants in Lunghu Lake were also at the trace level, with the concentrations of the detected compounds falling between 0.4 and 16.8 ng/L. Due to difficulties in monitoring and controlling pollution sources (e.g., pollution of domestic wastewater or livestock industries wastewater) in Kinmen lakes, these results can be used to indicate the contamination levels of the drinking water sources because these two lakes are the main sources of tap water for the residents of Kinmen. Long-term and continuous monitoring of the distribution of the target emerging contaminants in Kinmen lakes is recommended.

3.2. Occurrence and removal of pharmaceuticals and PFCs in the WWTPs (Jincheng WWTP and Taihu WWTP) in Kinmen

Table 4 shows the occurrence and removal of 38 emerging contaminants in the Jincheng WWTP. These two WWTPs are located near hospitals, livestock industries and factories, which are considered to be potential contamination sources of emerging contaminants [20,22,23]. In the following paragraphs, we discuss the results obtained from the Jincheng WWTP in detail because the Jincheng WWTP is the largest WWTP in Kinmen and can represent the other WWTPs in Kinmen. Among the 38 target compounds, 34 compounds from various classes were detected in the Jincheng WWTP influent. Most of the compounds existed at ng/L concentrations, whereas 4 pharmaceuticals were observed at significant concentrations (μg/L levels), including ibuprofen (1260 ng/L), atenolol (1634 ng/L), acetaminophen (1950 ng/L), and caffeine (2975 ng/L). Other studies have also noted that these four compounds exist at higher concentrations in WWTP influents in various countries [24]. In addition, all these pharmaceuticals belong to human medicines, suggesting that the primary source of pollution was human activities (e.g., from hospital wastewaters or domestic wastewaters). Additional detailed investigations are needed to confirm the exact sources of pollution. Compared with the emerging contaminant distributions in Taihu Lake and Lunghu Lake, the concentrations of the contaminants in the two WWTPs were significantly higher, potentially because the sources of water for the two lakes (Taihu Lake and Lunghu Lake) and the two WWTPs (Jincheng WWTP and Taihu WWTP) were different. The lake water was mainly replenished by rainwater and surface runoff, whereas wastewater was produced from human activities. Furthermore, concerning the weather conditions, sunlight irradiation on Kinmen Island is intense (average annual solar radiation: 757 W/m^2), with a long irradiation time (almost 8 h/day during summer). Therefore, these emerging contaminants may be photodegraded via sunlight photolysis [25–27], which would reduce their concentrations in the lake water. However, future elucidation and investigations are required.

The removal efficiencies of each compound in the Jincheng WWTP are also shown in Table 4. In summary, the removal efficiency of the Jincheng WWTP with regard to the target emerging contaminants was poor. The primary and secondary treatment units at the Jincheng WWTP were unable to effectively remove the target emerging contaminants. Up to 21 and 28 compounds were less than 50% removal in the primary and secondary treatment units, respectively. Although 4 compounds (sulfamonomethoxine, acetaminophen, ibuprofen and caffeine) were effectively removed (>80% removal) during both sampling periods, 9 compounds (clarithromycin, nalidixic acid, flumequine, dimetridazole, propranolol, metoprolol, gemfibrozil, carbamazepine and trimethoprim) exhibited no any removal. In addition, 15 compounds and 19 compounds were less than 50% removal according to the first and second sampling, respectively.

The performance of the Jincheng WWTP regarding the target emerging contaminants was similar to the performances of other WWTPs that also performed secondary treatment processes. Previously, it has been shown that acetaminophen, ibuprofen and caffeine are effectively removed in secondary treatment processes in Taiwan, Austria and Japan [28–31]. Specifically, it was found in this study that secondary treatment resulted in >85% removal of these compounds. Lindqvist et al. [32] investigated ketoprofen removal in seven sewage treatment plants in Finland and observed an average removal efficiency of 78%, which was slightly higher than the removal efficiency observed in this study. Carbamazepine and trimethoprim were persistent throughout the Jincheng WWTP, which corresponded with other studies that also

Table 3
Occurrence of 38 emerging contaminants in the Taihu Lake and Lunghu Lake.

Target compounds	MDLs (ng/L)	Sampling time		
		2013/3/6	2013/6/25	2014/6/12
		Taihu Lake		Lunghu Lake
Sulfonamide antibiotics				
Sulfadiazine	0.1	ND	ND	ND
Sulfamethoxazole	0.1	ND	1.3 ± 0.8	ND
Sulfathiazole	0.5	ND	ND	ND
Sulfamethazine	0.1	1.5 ± 0.0	2.1 ± 0.2	ND
Sulfamonomethoxine	0.5	ND	ND	ND
Sulfadimethoxine	0.5	ND	ND	ND
Macrolides antibiotics				
Erythromycin-H_2O	0.1	0.9 ± 0.1	3.3 ± 2.8	3.4 ± 1.8
Clarithromycin	0.5	ND	1.1 ± 0.0	0.4 ± 0.6
Roxithromycin	0.5	ND	ND	ND
Tylosin	1.0	ND	ND	ND
Quinolone antibiotics				
Nalidixic acid	1.0	ND	ND	ND
Flumequine	0.5	ND	3.0 ± 0.6	ND
Pipemidic acid	1.0	ND	ND	ND
Norfloxacin	1.0	ND	ND	ND
Ciprofloxacin	0.5	ND	5.8 ± 4.4	ND
Ofloxacin	0.5	ND	5.1 ± 0.9	1.0 ± 1.8
Imidazole antibiotics				
Dimetridazole	0.5	3.4 ± 0.0	5.8 ± 0.2	3.8 ± 0.5
Metronidazole	0.5	ND	ND	ND
β-blockers				
Propranolol	0.6	ND	ND	ND
Atenolol	1.2	ND	ND	ND
Metoprolol	0.6	ND	ND	ND
Sotalol	0.5	ND	ND	ND
NSAIDs				
Acetaminophen	0.1	ND	ND	ND
Ibuprofen	5	ND	41.7 ± 1.0	11.2 ± 0.5
Naproxen	5	ND	0.3 ± 0.2	ND
Ketoprofen	5	ND	0.8 ± 0.2	ND
Lipid regulator and cholesterol lowering drug				
Clofibic acid	0.1	0.4 ± 0.0	ND	ND
Gemfibrozoil	0.1	ND	ND	0.6 ± 0.7
Bezafibrate	0.1	ND	ND	ND
Psychostimulants				
Caffeine	0.1	101.2 ± 2.8	76.8 ± 3.1	ND
Psychiatric drugs				
Carbamazepine	0.1	0.4 ± 0.0	0.1 ± 0.1	ND
Vasodilators				
Pentoxifylline	0.25	ND	ND	ND
Other antibiotics				
Trimethoprim	0.1	ND	ND	ND
PFASs				
PFOS	0.25	1.3 ± 0.1	ND	5.9 ± 0.3
PFCAs				
PFHxA	0.1	32.2 ± 3.2	17.3 ± 3.6	3.2 ± 2.1
PFOA	0.05	11.8 ± 0.7	4.5 ± 0.2	16.8 ± 0.4
PFDA	0.05	0.7 ± 0.2	0.9 ± 0.0	0.7 ± 0.1
PFHpA	0.05	3.5 ± 0.2	3.0 ± 0.4	1.5 ± 0.2

featured biological treatment processes reported in Italy, Spain and Austria. Particularly, carbamazepine was considered as a suitable marker for anthropogenic influences in the aquatic environment because of its stable characteristics [33–35]. Secondary treatment processes have a wide range of removal efficiencies with regard to sulfonamide and macrolide antibiotics in Taiwan, the USA (Wisconsin), Japan and Spain [19,36–38]. This study also showed large disparities (0–100%) in the removal of sulfonamides and macrolides. Imidazole antibiotics (dimetridazole and metronidazole), lipid regulator and cholesterol-lowering drugs (clofibric acid, gemfibrozil and bezafibrate) and vasodilators (pentoxifylline) were found to have broad removal ranges (0–81%) in Taiwan [19]. However, these compounds exhibited no removal in the Jincheng WWTP in this study. In terms of quinolone antibiotics, Jie et al. [39] studied 11 quinolone antibiotics in a WWTP in China and showed that their removal efficiencies were between 40 and 75%. In this work, a broad range was observed (0–82%) in the Jincheng WWTP. Sorption onto sludge and soil is generally considered a dominant removal mechanism for quinolones [39,40]. All the investigated PFCs were partially removed (0–72%), except for the PFOS (100%) in the first sampling. Other various studies reported in Germany, Italy and the USA (North Carolina) [41–43] have indicated the persistent characteristics of PFCs in municipal wastewaters and surface waters. Overall, 34 types of emerging contaminant residues existed in the effluent, of which 11 compounds (sulfamethoxazole, erythromycin-H_2O, clarithromycin, tylosin and atenolol) present at concentrations greater than 100 ng/L. Many of the compounds, including erythromycin-H_2O, clarithromycin, nalidixic acid, flumequine, dimetridazole, propranolol, metoprolol, gemfibrozil, bezafibrate, carbamazepine, pentoxifylline, trimethoprim and PFHxA, exhibited increased concentrations in the effluent compared with the influent. Similar patterns have been found in other studies [19,44,45] for erythromycin-H_2O, trimethoprim and propranolol. Some likely explanations for this observation may include (i) signal suppression because of the high organic matter concentration in the raw wastewater influent [46,47], (ii) deconjugation of conjugated metabolites during the treatment processes [48,49], and (iii) underestimation of the actual quantity due to the filtering out of particulate matter containing adsorbed target compounds during the sample filtration pretreatment [50]. Further investigations are needed to verify this phenomenon.

In addition to the Jincheng WWTP, we also collected water samples from the Taihu WWTP (the second largest WWTP in Kinmen). Table 5 shows the monitoring results of target compounds in the Taihu WWTP. In general, the occurrence and removal efficiency in the Taihu WWTP were similar to those in the Jincheng WWTP. Thirty-two compounds were monitored in the Taihu WWTP influent and 4 compounds had concentrations at the μg/L concentration level, including erythromycin-H_2O (1340 ng/L), ibuprofen (1763 ng/L), acetaminophen (2143 ng/L) and caffeine (3113 ng/L). The other two compounds, ibuprofen (810 ng/L) and gemfibrozil (774 ng/L), also had concentrations nearly at the μg/L concentration level. With respect to removal efficiency, 14 compounds exhibited less than 50% removal, of which 10 compounds were no any removal. Among all types of target compounds, PFCs were poorly removed in the Jincheng and Taihu WWTPs.

Because limited information is available regarding the health risks of these emerging contaminants, the risk quotient (RQ), a ratio of the measured environmental concentration (MEC) to the predicted no-effect concentration (PNEC), is commonly used in preliminary risk assessments for the aquatic environment according to the European Medicine Agency guidelines [9,21,51,52]. Table 6 summarizes the PNEC, MECs and RQ values of the PPCPs detected in the effluent of the Jincheng and Taihu WWTP effluent. The maximum MECs were used to calculate the RQs as a worst-case scenario. The reported PNEC values were calculated by dividing the lowest no observed effect concentration (NOEC) with an assessment factor. While NOEC data were not available, lowest observable effect concentrations (LOEC) and critical environmental concentrations (CEC) were used to represent the PNEC. In Table 6, the PNEC values with one asterisk symbol were calculated from EC_{50} [53], and the PNEC values with two asterisk symbols are the effective concentrations of aquatic ecotoxicity [54]. In this study, the RQ values of 5 compounds (sulfamethoxazole, erythromycin-H_2O, clarithromycin, ciprofloxacin and ofloxacin) exceeded one, which indicated their high environmental impact risks. The other 9 compounds (norfloxacin, acetaminophen, ibuprofen, naproxen, ketoprofen, gemfibrozil, propranolol, carbamazepine,

Table 4
Occurrence and removal of 38 emerging contaminants in the Jincheng WWTP.

Sampling time		June 2013			June 2014					
Target compounds	MDLs (ng/L)	Occurrence (ng/L)		Removal (%)	Occurrence (ng/L)			Removal (%)		
		Influent	Effluent	Overall	Influent	Before secondary treatment	Effluent	Primary treatment	Secondary treatment	Overall
Sulfonamide antibiotics										
Sulfadiazine	0.1	4.6 ± 0.2	1.0 ± 0.2	78%	ND	ND	ND	–	–	–
Sulfamethoxazole	0.1	208.2 ± 34.6	109.2 ± 10.6	48%	414 ± 28.0	423 ± 33.5	237 ± 15.7	NR	44%	43%
Sulfathiazole	0.5	16.3 ± 0.4	ND	100%	ND	ND	ND	–	–	–
Sulfamethazine	0.1	2.9 ± 0.3	1.5 ± 0.1	48%	ND	ND	ND	–	–	–
Sulfamonomethoxine	0.5	19.2 ± 2.9	3.7 ± 0.8	81%	8.8 ± 2.0	7.1 ± 1.2	1.2 ± 1.3	19%	83%	86%
Sulfadimethoxine	0.5	ND	ND	–	5.3 ± 1.6	1.0 ± 1.4	ND	81%	100%	100%
Macrolides antibiotics										
Erythromycin-H_2O	0.1	259.5 ± 31.8	298.5 ± 2.1	NR	455 ± 61.3	488 ± 48.6	411 ± 2.5	NR	16%	10%
Clarithromycin	0.5	107.0 ± 9.9	221.0 ± 39.6	NR	282 ± 11.5	274 ± 31.9	311 ± 13.9	3%	NR	NR
Roxithromycin	0.5	ND	ND	–	27.8 ± 6.2	1.5 ± 1.8	4.9 ± 0.5	95%	NR	82%
Tylosin	1.0	608.0 ± 77.8	139.5 ± 7.8	77%	293 ± 123	136 ± 6.5	151 ± 10.2	54%	NR	48%
Quinolone antibiotics										
Nalidixic acid	0.25	ND	12.7 ± 0.4	NR	ND	ND	1.0 ± 0.3	–	NR	NR
Flumequine	0.5	4.6 ± 0.6	9.8 ± 1.3	NR	19.5 ± 1.7	15.1 ± 1.1	32.7 ± 3.5	23%	NR	NR
Pipemidic acid	0.5	ND	ND	–	41.5 ± 11.0	22.7 ± 0.3	24.4 ± 1.1	45%	NR	41%
Norfloxacin	0.5	72.6 ± 4.8	21.5 ± 1.1	70%	422 ± 51	89 ± 13	77.9 ± 8.0	79%	13%	82%
Ciprofloxacin	0.5	34.6 ± 5.7	23.1 ± 4.2	33%	262 ± 56.3	76.7 ± 7.7	75.0 ± 6.0	71%	2%	71%
Ofloxacin	0.5	176.7 ± 18.4	78.9 ± 4.3	55%	713 ± 68.9	298 ± 25.0	434 ± 41.9	58%	NR	39%
Imidazole antibiotics										
Dimetridazole	0.25	3.8 ± 1.3	14.8 ± 0.6	NR	2.9 ± 1.5	4.1 ± 0.7	66.4 ± 9.8	NR	NR	NR
Metronidazole	0.25	ND	ND	–	38.2 ± 3.0	36.6 ± 19.7	37.7 ± 1.9	4%	NR	1%
β-blockers										
Propranolol	0.1	5.3 ± 0.2	6.2 ± 0.5	NR	4.0 ± 0.3	3.7 ± 0.1	4.6 ± 1.0	8%	NR	NR
Atenolol	0.1	1271.0 ± 1.4	230.0 ± 2.8	82%	1634 ± 118	1107 ± 53.0	653 ± 23.4	32%	41%	60%
Metoprolol	0.1	29.5 ± 3.3	40.3 ± 3.0	NR	5.3 ± 2.0	15.2 ± 3.0	20.0 ± 1.5	NR	NR	NR
Sotalol	0.5	ND	ND	–	ND	ND	ND	–	–	–
NSAIDs										
Acetaminophen	0.1	1950.0 ± 14.1	2.6 ± 0.3	100%	1887 ± 25.2	676 ± 38.1	104.3 ± 4.9	64%	100%	94%
Ibuprofen	5	1022.5 ± 38.9	60.5 ± 4.8	94%	1260 ± 30.0	619 ± 24.0	189 ± 10.3	51%	69%	85%
Naproxen	5	145.0 ± 1.4	34.1 ± 2.7	76%	685 ± 16.8	225 ± 17.5	257 ± 24.1	67%	NR	62%
Ketoprofen	5	7.2 ± 1.1	2.7 ± 0.3	63%	41.0 ± 3.2	26.6 ± 3.7	20 ± 0.8	35%	27%	52%
Lipid regulator and cholesterol lowering drug										
Clofibic acid	0.1	ND	ND	–	ND	ND	ND	–	–	–
Gemfibrozoil	0.1	23.0 ± 2.7	46.6 ± 1.8	NR	10.8 ± 0.1	72.8 ± 5.8	106 ± 2.2	NR	NR	NR
Bezafibrate	0.1	ND	ND	–	ND	ND	3.5 ± 0.5	–	NR	NR
Psychostimulants										
Caffeine	0.1	2975.0 ± 205.1	22.2 ± 2.1	99%	2393 ± 115	1156 ± 23.1	176 ± 8.7	52%	85%	93%
Psychiatric drugs										
Carbamazepine	0.1	30.8 ± 0.8	52.1 ± 1.7	NR	21.3 ± 2.2	24.2 ± 2.0	50.7 ± 3.9	NR	NR	NR
Vasodilators										
Pentoxifylline	0.25	ND	ND	–	2.6 ± 0.3	4.3 ± 0.1	6.8 ± 0.4	NR	NR	NR
Other antibiotics										
Trimethoprim	0.1	4.2 ± 0.5	13.8 ± 1.2	NR	19.1 ± 1.9	16.0 ± 1.1	35.0 ± 1.5	16%	NR	NR
Perfluoroalkyl sulfonic acids										
PFOS	0.25	2.1 ± 0.0	ND	100%	9.5 ± 1.7	10.7 ± 0.4	5.6 ± 0.1	NR	48%	41%
Perfluorinated carboxylic acids										
PFHxA	0.1	16.2 ± 0.6	23.7 ± 1.6	NR	24.2 ± 1.0	16.3 ± 2.6	15.6 ± 3.1	33%	4%	43%
PFOA	0.05	6.0 ± 0.1	1.7 ± 0.2	72%	13.1 ± 2.4	13.3 ± 3.1	9.3 ± 0.5	NR	30%	29%
PFDA	0.05	1.1 ± 0.0	0.4 ± 0.1	64%	2.2 ± 0.5	2.5 ± 0.0	1.3 ± 0.1	NR	48%	41%
PFHpA	0.05	1.0 ± 0.2	0.8 ± 0.1	20%	0.3 ± 0.2	0.1 ± 0.1	0.1 ± 0.1	67%	NR	67%

and PFOS) with RQ values exceeding 0.1 also have medium environmental risk. However, further investigations to understand the ecological impacts and human health risks of these compounds are needed. Because these data were acquired during 2013–2015, periodical monitoring is recommended to ensure the stability of the reclaimed water quality. The provided data can also be use by the Kinmen government to establish guidelines, evaluate the availability of reclaimed water and develop related policies. In summary, to supply high-quality recycled water and sustainable water resources, the effectiveness of the WWTPs must be improved or tertiary/advanced treatment must be added.

4. Conclusions

To evaluate the availability of reclaimed water in Kinmen, this study investigated the distributions of 38 emerging contaminants in Kinmen water matrices, including lake waters (Taihu and Lunghu lake) and WWTP wastewaters (Jincheng and Taihu WWTP), by using SPE combined with high-performance liquid chromatography–tandem mass spectrometry. The results showed that the

Table 5
Occurrence and removal of 38 emerging contaminants in the Taihu WWTP.

Sampling time		July 2015		
Target compounds	MDLs (ng/L)	Occurrence (ng/L)		Removal (%)
		Influent	Effluent	Overall
Sulfonamide antibiotics				
Sulfadiazine	0.1	9.2 ± 2.0	3.6 ± 1.2	61
Sulfamethoxazole	0.1	244 ± 37.1	81.6 ± 12.9	66
Sulfathiazole	0.5	ND	ND	–
Sulfamethazine	0.1	24.7 ± 3.9	6.6 ± 0.9	73
Sulfamonomethoxine	0.5	6.4 ± 2.5	1.4 ± 0.7	78
Sulfadimethoxine	0.5	ND	ND	–
Macrolides antibiotics				
Erythromycin-H_2O	0.1	1340 ± 56.9	156 ± 33.6	88
Clarithromycin	0.5	175 ± 37.1	14.3 ± 0.5	92
Roxithromycin	0.5	3.1 ± 1.3	1.2 ± 0.1	60
Tylosin	1.0	ND	ND	–
Quinolone antibiotics				
Nalidixic acid	0.25	79.9 ± 6.4	ND	100
Flumequine	0.5	1.3 ± 0.4	31.6 ± 5.3	NR
Pipemidic acid	0.5	ND	ND	–
Norfloxacin	0.5	72.7 ± 15.8	54.1 ± 16.0	26
Ciprofloxacin	0.5	168.9 ± 24.0	19.1 ± 3.7	89
Ofloxacin	0.5	345 ± 38.2	195 ± 17.2	43
Imidazole antibiotics				
Dimetridazole	0.25	2.8 ± 0.7	54.2 ± 3.8	NR
Metronidazole	0.25	12.1 ± 1.5	49.0 ± 1.4	NR
β-blockers				
Propranolol	0.1	ND	0.3 ± 0.2	NR
Atenolol	0.1	196.6 ± 11.1	1.1 ± 0.7	99
Metoprolol	0.1	62.9 ± 6.0	90.7 ± 22.7	NR
Sotalol	0.5	72.9 ± 8.2	17.6 ± 4.8	76
NSAIDs				
Acetaminophen	0.1	2143 ± 11.5	ND	100
Ibuprofen	5	1763 ± 277	154 ± 15	91
Naproxen	5	412 ± 12.0	ND	100
Ketoprofen	5	ND	ND	–
Lipid regulator and cholesterol lowering drug				
Clofibic acid	0.1	1.6 ± 0.2	ND	100
Gemfibrozoil	0.1	46.7 ± 5.8	15.8	66
Bezafibrate	0.1	22.6 ± 4.3	ND	100
Psychostimulants				
Caffeine	0.1	3113 ± 190	ND	100
Psychiatric drugs				
Carbamazepine	0.1	83.4 ± 5.6	87.6 ± 2.5	NR
Vasodilators				
Pentoxifylline	0.25	264 ± 41.9	62.2 ± 5.0	76
Other antibiotics				
Trimethoprim	0.1	1.9 ± 1.0	1.8 ± 0.1	2
Perfluoroalkyl sulfonic acids				
PFOS	0.25	20.8 ± 4.1	10.6 ± 1.0	49
Perfluorinated carboxylic acids				
PFHxA	0.1	21.5 ± 1.6	61.4 ± 2.7	NR
PFOA	0.05	23.0 ± 1.4	24.7 ± 1.0	NR
PFDA	0.05	2.6 ± 0.7	3.4 ± 0.4	NR
PFHpA	0.05	2.3 ± 0.7	3.2 ± 0.4	NR

concentrations of the target emerging contaminants in the two lakes had reached trace ng/L concentrations. However, many compounds were detected in the Jincheng and Taihu WWTP. Most of the target compounds were present in the influents at ng/L concentrations, of which 5 compounds (erythromycin-H_2O (1340 ng/L), ibuprofen (1763 ng/L), atenolol (1634 ng/L), acetaminophen (2143 ng/L), and caffeine (3113 ng/L)) reached μg/L concentrations. Further investigations are needed to elucidate the exact pollution sources. Regarding the removal efficiencies, the results indicated that the overall treatment efficiencies of these emerging contaminants treated by the two WWTPs were poor, as also indicated in similar studies. For the Jincheng WWTP, although 4 compounds (sulfamonomethoxine, acetaminophen, ibuprofen and caffeine) were >80% removed, 19 compounds were less than 50% removed, and 9 compounds were no any removal at all. Five compounds (sulfamethoxazole, erythromycin-H_2O, clarithromycin, ciprofloxacin and ofloxacin) with RQ values > 1 in the WWTP effluent are recommended for further investigation to understand their effects on the aquatic environment. Regular monitoring of the occurrence and removal of emerging contaminants is necessary. To mitigate water scarcity and achieve the goal of water recycling in Kinmen, the addition of tertiary/advanced treatment process to the outlets of the Jincheng and Taihu WWTPs would enhance the efficiency of pollutant removal and further improve the effluent water quality, ensuring the safety of the reclaimed water for future use.

Table 6
Maximum MECs and risk quotients (RQ) for the PPCPs and PFCs detected in this study (The RQ values which exceed 0.1 are indicated in bold).

Compounds	Minimum PNEC (ng/L)	Jincheng WWTP effluent		Taihu WWTP effluent	
		Maximum MEC (ng/L)	Worst case-scenario (RQ = MEC/PNEC)	Maximum MEC (ng/L)	Worst case-scenario (RQ = MEC/PNEC)
Sulfonamide antibiotics					
Sulfamethoxazole	27[a,l]	237	**8.8**	81.6	**3.0**
Sulfamethazine	>100,000[b]	1.5	0.000015	6.6	0.000066
Sulfadimethoxine	3500[c,l]	ND	–	ND	–
Macrolide antibiotics					
Erythromycin-H_2O	20[d,l]	411	**21**	156	**7.8**
Clarithromycin	40[e]	311	**7.8**	14.3	**0.36**
Roxithromycin	150[e]	4.9	0.03	1.2	0.008
Tylosin	34,000[m]	151	0.004	ND	–
Quinolone antibiotics					
Ciprofloxacin	20[e]	75	**3.8**	19.1	**0.96**
Norfloxacin	150[e]	77.9	**0.5**	54.1	**0.36**
Ofloxacin	16[a]	434	**27**	195	**12.2**
Imidazoles antibiotics					
Metronidazole	1250[e]	37.7	0.03	49.0	0.04
NSAIDs					
Acetaminophen	1000[c,l]	104.3	**0.10**	ND	-
Ibuprofen	1650[f,l]	189	**0.11**	154	0.09
Naproxen	2620[f,l]	257	**0.10**	ND	-
Ketoprofen	160[g]	20	**0.13**	ND	-
Lipid-regulator/cholesterol-lowering drug					
Clofibric acid	4200[h]	ND	–	ND	–
Gemfibrozil	900[c,l]	106	**0.12**	15.8	0.02
Bezafibrate	5300[c,l]	3.5	0.001	ND	–
β-blockers					
Propranolol	10[a]	6.2	**0.62**	0.3	0.03
Atenolol	30,000[d,l]	653	0.02	1.1	0.00004
Metoprolol	800[c,l]	40.3	0.05	90.7	0.11
Psychostimulants					
Caffeine	5200[g]	176	0.03	ND	–
Psychiatric drugs					
Carbamazepine	250[g]	52.1	**0.21**	87.6	**0.35**
Other antibiotics					
Trimethoprim	1000	35	0.04	1.8	0.0018
Perfluoroalkyl sulfonic acids					
PFOS	50[i,j]	5.6	**0.11**	10.6	**0.21**
Perfluorinated carboxylic acids					
PFOA	60,000[k]	9.3	0.0002	24.7	0.0004

[a] Ref. [57].
[b] Ref. [60].
[c] Ref. [59].
[d] Ref. [61].
[e] Ref. [55].
[f] Ref. [58].
[g] Ref. [62].
[h] Ref. [56].
[i] Ref. [63].
[j] Ref. [64].
[k] Ref. [65].
[l] The value is calculated from EC_{50} (Ref. [53]).
[m] Effect concentration of aquatic ecotoxicity (Ref. [54]).

Acknowledgments

Financial support was provided by the Ministry of Science and Technology (MOST) (MOST-103-119-M-002-004) Taiwan, ROC.

Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.emcon.2016.05.001.

References

[1] A.A. Robinson, J.B. Belden, M.J. Lydy, Toxicity of fluoroquinolone antibiotics to aquatic organisms, Environ. Toxicol. Chem. 24 (2005) 423–430.
[2] Q. Sui, X. Cao, S. Lu, W. Zhao, Z. Qiu, G. Yu, Occurrence, sources and fate of pharmaceuticals and personal care products in the groundwater: a review, Emerg. Contam. 1 (2015) 14–24.
[3] K. Fent, A.A. Weston, D. Caminada, Ecotoxicology of human pharmaceuticals, Aquat. Toxicol. 76 (2006) 122–159.
[4] M. Ricart, H. Guasch, M. Alberch, D. Barcelo, C. Bonnineau, A. Geiszinger, M. Farre, J. Ferrer, F. Ricciardi, A.M. Romani, S. Morin, L. Proia, L. Sala, D. Sureda, S. Sabater, Triclosan persistence through wastewater treatment plants and its potential toxic effects on river biofilms, Aquat. Toxicol. 100 (2010) 346–353.
[5] W.J. Sim, J.W. Lee, E.S. Lee, S.K. Shin, S.R. Hwang, J.E. Oh, Occurrence and distribution of pharmaceuticals in wastewater from households, livestock farms, hospitals and pharmaceutical manufactures, Chemosphere 82 (2011) 179–186.
[6] K.D. Brown, J. Kulis, B. Thomson, T.H. Chapman, D.B. Mawhinney, Occurrence of antibiotics in hospital, residential, and dairy, effluent, municipal wastewater, and the Rio Grande in New Mexico, Sci. Total Environ. 366 (2006) 772–783.
[7] T. Heberer, Occurrence, fate, and removal of pharmaceutical residues in the aquatic environment: a review of recent research data, Toxicol. Lett. 131 (2002) 5–17.
[8] L. Lishman, S.A. Smyth, K. Sarafin, S. Kleywegt, J. Toito, T. Peart, B. Lee,

M. Servos, M. Beland, P. Seto, Occurrence and reductions of pharmaceuticals and personal care products and estrogens by municipal wastewater treatment plants in Ontario, Canada, Sci. Total Environ. 367 (2006) 544–558.
[9] J.L. Santos, I. Aparicio, E. Alonso, Occurrence and risk assessment of pharmaceutically active compounds in wastewater treatment plants. a case study: Seville city (Spain), Environ. Int. 33 (2007) 596–601.
[10] D.W. Kolpin, E.T. Furlong, M.T. Meyer, E.M. Thurman, S.D. Zaugg, L.B. Barber, H.T. Buxton, Pharmaceuticals, hormones, and other organic wastewater contaminants in US streams, 1999-2000: a national reconnaissance, Environ. Sci. Technol. 36 (2002) 1202–1211.
[11] B. Kasprzyk-Hordern, R.M. Dinsdale, A.J. Guwy, The occurrence of pharmaceuticals, personal care products, endocrine disruptors and illicit drugs in surface water in South Wales, UK, Water Res. 42 (2008) 3498–3518.
[12] D.J. Lapworth, N. Baran, M.E. Stuart, R.S. Ward, Emerging organic contaminants in groundwater: a review of sources, fate and occurrence, Environ. Pollut. 163 (2012) 287–303.
[13] L.P. Yang, L.Y. Zhu, Z.T. Liu, Occurrence and partition of perfluorinated compounds in water and sediment from Liao River and Taihu Lake, China, Chemosphere 83 (2011) 806–814.
[14] B.R. Shivakoti, S. Tanaka, S. Fujii, C. Kunacheva, S.K. Boontanon, C. Musirat, S.T.M.L.D. Seneviratne, H. Tanaka, Occurrences and behavior of perfluorinated compounds (PFCs) in several wastewater treatment plants (WWTPs) in Japan and Thailand, J. Environ. Monit. 12 (2010) 1255–1264.
[15] C. Gomez-Canela, J.A.C. Barth, S. Lacorte, Occurrence and fate of perfluorinated compounds in sewage sludge from Spain and Germany, Environ. Sci. Pollut. R. 19 (2012) 4109–4119.
[16] A.Y.C. Lin, S.C. Panchangam, P.S. Ciou, High levels of perfluorochemicals in Taiwan's wastewater treatment plants and downstream rivers pose great risk to local aquatic ecosystems, Chemosphere 80 (2010) 1167–1174.
[17] A.Y.C. Lin, S.C. Panchangam, C.C. Lo, The impact of semiconductor, electronics and optoelectronic industries on downstream perfluorinated chemical contamination in Taiwanese rivers, Environ. Pollut. 157 (2009) 1365–1372.
[18] A.Y.C. Lin, Y.T. Tsai, Occurrence of pharmaceuticals in Taiwan's surface waters: impact of waste streams from hospitals and pharmaceutical production facilities, Sci. Total Environ. 407 (2009) 3793–3802.
[19] A.Y.C. Lin, T.H. Yu, S.K. Lateef, Removal of pharmaceuticals in secondary wastewater treatment processes in Taiwan, J. Hazard Mater. 167 (2009) 1163–1169.
[20] A.Y.C. Lin, T.H. Yu, C.F. Lin, Pharmaceutical contamination in residential, industrial, and agricultural waste streams: risk to aqueous environments in Taiwan, Chemosphere 74 (2008) 131–141.
[21] Y.C. Lin, W.W.P. Lai, H.H. Tung, A.Y.C. Lin, Occurrence of pharmaceuticals, hormones, and perfluorinated compounds in groundwater in Taiwan, Environ. Monit. Assess. 187 (2015).
[22] W.J. Sim, H.Y. Kim, S.D. Choi, J.H. Kwon, J.E. Oh, Evaluation of pharmaceuticals and personal care products with emphasis on anthelmintics in human sanitary waste, sewage, hospital wastewater, livestock wastewater and receiving water, J. Hazard Mater 248 (2013) 219–227.
[23] V. Osorio, A. Larranaga, J. Acena, S. Perez, D. Barcelo, Concentration and risk of pharmaceuticals in freshwater systems are related to the population density and the livestock units in Iberian Rivers, Sci. Total Environ. 540 (2016) 267–277.
[24] Y.L. Luo, W.S. Guo, H.H. Ngo, L.D. Nghiem, F.I. Hai, J. Zhang, S. Liang, X.C.C. Wang, A review on the occurrence of micropollutants in the aquatic environment and their fate and removal during wastewater treatment, Sci. Total Environ. 473 (2014) 619–641.
[25] A.Y.C. Lin, X.H. Wang, W.N. Lee, Phototransformation determines the fate of 5-Fluorouracil and cyclophosphamide in natural surface waters, Environ. Sci. Technol. 47 (2013) 4104–4112.
[26] K.H. Wammer, A.R. Korte, R.A. Lundeen, J.E. Sundberg, K. McNeill, W.A. Arnold, Direct photochemistry of three fluoroquinolone antibacterials: norfloxacin, ofloxacin, and enrofloxacin, Water Res. 47 (2013) 439–448.
[27] M.W. Lam, C.J. Young, S.A. Mabury, Aqueous photochemical reaction kinetics and transformations of fluoxetine, Environ. Sci. Technol. 39 (2005) 513–522.
[28] T.H. Yu, A.Y.C. Lin, S.K. Lateef, C.F. Lin, P.Y. Yang, Removal of antibiotics and non-steroidal anti-inflammatory drugs by extended sludge age biological process, Chemosphere 77 (2009) 175–181.
[29] A.Y.C. Lin, C.F. Lin, Y.T. Tsai, H.H.H. Lin, J. Chen, X.H. Wang, T.H. Yu, Fate of selected pharmaceuticals and personal care products after secondary wastewater treatment processes in Taiwan, Water Sci. Technol. 62 (2010) 2450–2458.
[30] M. Clara, B. Strenn, O. Gans, E. Martinez, N. Kreuzinger, H. Kroiss, Removal of selected pharmaceuticals, fragrances and endocrine disrupting compounds in a membrane bioreactor and conventional wastewater treatment plants, Water Res. 39 (2005) 4797–4807.
[31] N. Nakada, T. Tanishima, H. Shinohara, K. Kiri, H. Takada, Pharmaceutical chemicals and endocrine disrupters in municipal wastewater in Tokyo and their removal during activated sludge treatment, Water Res. 40 (2006) 3297–3303.
[32] N. Lindqvist, T. Tuhkanen, L. Kronberg, Occurrence of acidic pharmaceuticals in raw and treated sewages and in receiving waters, Water Res. 39 (2005) 2219–2228.
[33] S. Castiglioni, R. Bagnati, R. Fanelli, F. Pomati, D. Calamari, E. Zuccato, Removal of pharmaceuticals in sewage treatment plants in Italy, Environ. Sci. Technol. 40 (2006) 357–363.
[34] M. Carballa, F. Omil, T. Ternes, J.M. Lema, Fate of pharmaceutical and personal care products (PPCPs) during anaerobic digestion of sewage sludge, Water Res. 41 (2007) 2139–2150.
[35] M. Clara, B. Strenn, N. Kreuzinger, Carbamazepine as a possible anthropogenic marker in the aquatic environment: investigations on the behaviour of Carbamazepine in wastewater treatment and during groundwater infiltration, Water Res. 38 (2004) 947–954.
[36] K.G. Karthikeyan, M.T. Meyer, Occurrence of antibiotics in wastewater treatment facilities in Wisconsin, USA, Sci. Total Environ. 361 (2006) 196–207.
[37] G.C. Ghosh, T. Okuda, N. Yamashita, H. Tanaka, Occurrence and elimination of antibiotics at four sewage treatment plants in Japan and their effects on bacterial ammonia oxidation, Water Sci. Technol. 59 (2009) 779–786.
[38] J. Radjenovic, M. Petrovic, D. Barcelo, Fate and distribution of pharmaceuticals in wastewater and sewage sludge of the conventional activated sludge (CAS) and advanced membrane bioreactor (MBR) treatment, Water Res. 43 (2009) 831–841.
[39] A. Jia, Y. Wan, Y. Xiao, J.Y. Hu, Occurrence and fate of quinolone and fluoroquinolone antibiotics in a municipal sewage treatment plant, Water Res. 46 (2012) 387–394.
[40] E.M. Golet, I. Xifra, H. Siegrist, A.C. Alder, W. Giger, Environmental exposure assessment of fluoroquinolone antibacterial agents from sewage to soil, Environ. Sci. Technol. 37 (2003) 3243–3249.
[41] A.M. Becker, S. Gerstmann, H. Frank, Perfluorooctane surfactants in waste waters, the major source of river pollution, Chemosphere 72 (2008) 115–121.
[42] R. Loos, G. Locoro, T. Huber, J. Wollgast, E.H. Christoph, A. De Jager, B.M. Gawlik, G. Hanke, G. Umlauf, J.M. Zaldivar, Analysis of perfluorooctanoate (PFOA) and other perfluorinated compounds (PFCs) in the River Po watershed in N-Italy, Chemosphere 71 (2008) 306–313.
[43] S. Nakayama, M.J. Strynar, L. Helfant, P. Egeghy, X.B. Ye, A.B. Lindstrom, Perfluorinated compounds in the cape fear drainage basin in North Carolina, Environ. Sci. Technol. 41 (2007) 5271–5276.
[44] P.H. Roberts, K.V. Thomas, The occurrence of selected pharmaceuticals in wastewater effluent and surface waters of the lower Tyne catchment, Sci. Total Environ. 356 (2006) 143–153.
[45] A. Gulkowska, H.W. Leung, M.K. So, S. Taniyasu, N. Yamashita, L.W.Y. Yeunq, B.J. Richardson, A.P. Lei, J.P. Giesy, P.K.S. Lam, Removal of antibiotics from wastewater by sewage treatment facilities in Hong Kong and Shenzhen, China, Water Res. 42 (2008) 395–403.
[46] T.A. Ternes, Analytical methods for the determination of pharmaceuticals in aqueous environmental samples, Trac-Trend Anal. Chem. 20 (2001) 419–434.
[47] J.P. Antignac, K. de Wasch, F. Monteau, H. De Brabander, F. Andre, B. Le Bizec, The ion suppression phenomenon in liquid chromatography-mass spectrometry and its consequences in the field of residue, Anal. Chim. Acta 529 (2005) 129–136.
[48] T.A. Ternes, Occurrence of drugs in German sewage treatment plants and rivers, Water Res. 32 (1998) 3245–3260.
[49] T. Heberer, Tracking persistent pharmaceutical residues from municipal sewage to drinking water, J. Hydrol. 266 (2002) 175–189.
[50] R.H. Lindberg, P. Wennberg, M.I. Johansson, M. Tysklind, B.A.V. Andersson, Screening of human antibiotic substances and determination of weekly mass flows in five sewage treatment plants in Sweden, Environ. Sci. Technol. 39 (2005) 3421–3429.
[51] M.D. Hernando, M. Mezcua, A.R. Fernandez-Alba, D. Barcelo, Environmental risk assessment of pharmaceutical residues in wastewater effluents, surface waters and sediments, Talanta 69 (2006) 334–342.
[52] A. Tauxe-Wuersch, L.F. De Alencastro, D. Grandjean, J. Tarradellas, Occurrence of several acidic drugs in sewage treatment plants in Switzerland and risk assessment, Water Res. 39 (2005) 1761–1772.
[53] P. Verlicchi, M. Al Aukidy, E. Zambello, Occurrence of pharmaceutical compounds in urban wastewater: removal, mass load and environmental risk after a secondary treatment-A review, Sci. Total Environ. 429 (2012) 123–155.
[54] A.B.A. Boxall, D.W. Kolpin, B. Halling-Sorensen, J. Tolls, Are veterinary medicines causing environmental risks? Environ. Sci. Technol. 37 (2003) 286a–294a.
[55] K. Kummerer, A. Henninger, Promoting resistance by the emission of antibiotics from hospitals and households into effluent, Clin. Microbiol. Infect. 9 (2003) 1203–1214.
[56] B. Ferrari, N. Paxeus, R. Lo Giudice, A. Pollio, J. Garric, Ecotoxicological impact of pharmaceuticals found in treated wastewaters: study of carbamazepine, clofibric acid, and diclofenac, Ecotox Environ. Safe 55 (2003) 359–370.
[57] B. Ferrari, R. Mons, B. Vollat, B. Fraysse, N. Paxeus, R. Lo Giudice, A. Pollio, J. Garric, Environmental risk assessment of six human pharmaceuticals: are the current environmental risk assessment procedures sufficient for the protection of the aquatic environment? Environ. Toxicol. Chem. 23 (2004) 1344–1354.
[58] B. Quinn, F. Gagne, C. Blaise, An investigation into the acute and chronic toxicity of eleven pharmaceuticals (and their solvents) found in wastewater effluent on the cnidarian, Hydra attenuata, Sci. Total Environ. 389 (2008) 306–314.
[59] H. Sanderson, D.J. Johnson, C.J. Wilson, R.A. Brain, K.R. Solomon, Probabilistic hazard assessment of environmentally occurring pharmaceuticals toxicity to fish, daphnids and algae by ECOSAR screening, Toxicol. Lett. 144 (2003) 383–395.
[60] K. Kümmerer, Pharmaceuticals in the environment: sources, fate, effects and risks, Springer, 2004.

[61] C. Boillot, Évaluation des risques écotoxicologiques liés aux rejets d'ef fl uents hospitaliers dans les milieux aquatiques. Contribution à l'amélioration de la phase Bcaratérisation des effets, PhD Thesis, Institut National des Sciences Appliquées de Lyon, France, N° d'ordre 2008 ISAL 0021 (2008).

[62] K. Komori, Y. Suzuki, M. Minamiyama, A. Harada, Occurrence of selected pharmaceuticals in river water in Japan and assessment of their environmental risk, Environ. Monit. Assess. 185 (6) (2013) 4529–4536.

[63] J.L. Newsted, P.D. Jones, K. Coady, J.P. Giesy, Avian toxicity reference values for perfluorooctane sulfonate, Environ. Sci. Technol. 39 (23) (2005) 9357–9362.

[64] P. Rostkowski, N. Yamashita, I.M.K. So, S. Taniyasu, P.K.S. Lam, J. Falandysz, J.P. Giesy, Perfluorinated compounds in streams of the Shihwa industrial zone and Lake Shihwa, South Korea. Environ. Toxicol. Chem. 25 (9) (2006) 2374–2380.

[65] Y. Wang, J. Mu, J. Wang, Aquatic predicted no-effect concentration (PNEC) derivation for perfluorooctane sulfonic acid (PFOA), in: Bioinformatics and Biomedical Engineering, (iCBBE) 2011 5th International Conference on, 2011, pp. 1–4.