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Ecotoxicological risk assessment and seasonal variation of some pharmaceuticals and personal care products in the sewage treatment plant and surface water bodies (lakes)

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Abstract This paper reports the seasonal variation and environmental quality control data for five fingerprint pharmaceuticals and personal care products (PPCPs) (acetaminophen ciprofloxacin, caffeine, irgasan and benzophenone) in the influent and the effluent of the sewage treatment plant (STP) and surface water bodies (six major lakes) in and around Nagpur, one of the "A class city" in the central India over a period of 1 year. The target compounds were analysed using developed offline solid-phase extraction (SPE) coupled with reversed phase high-performance liquid chromatography (RP-HPLC-PDA) method. All the five PPCPs were found in the influent, whereas four were found in the effluent of the STP. However, in the surface water bodies, three PPCPs were detected in all the seasons. Above PPCPs were present in the concentration range of 1–174 μg L^{-1} in the surface water bodies, 12–373 μg L^{-1} in the influent and 11–233 μg L^{-1} in the effluent of the STP. Amongst the five PPCPs, caffeine was found to be in higher concentration as compared to others. The seasonal trends indicate higher concentrations of PPCPs in summer season and lowest in the rainy season. Additionally, physico-chemical characterisations (inorganic and organic parameters) of the collected samples were performed to access the anthropogenic pollution. Ecotoxicological risk assessment was done to appraise the degree of toxicity of the targeted compounds. Hazard quotient (HQ) values were found to be < 1 indicating no adverse effect on the targeted organism.

Keywords Pharmaceuticals and personal care products · Sewage treatment plant · Surface water bodies (lakes) · Solid-phase extraction · HPLC-PDA · Anthropogenic pollution · Ecotoxicological risk assessment

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Introduction

The access to clean water is of ever extending consequence as the water bodies are threatened by human activities and can get further affected by anthropogenic climate change. A worldwide study reveals that over 65% of the rivers are polluted (Vorosmarty et al. 2010). This has led to the degradation and biodiversity loss in aquatic ecosystems, which cannot be underestimated. Emerging contaminants (ECs) such as pharmaceutical and personal care products (PPCPs) have been responsible for the major environmental pollution over last two decades and have gained much attention. These compounds make their way into the various water bodies either through excretion or discharge of untreated and treated sewage into surface water bodies. Sewage is a known source of PPCPs

which is an emerging issue of concern due to its adverse effect on ecosystem because of their bio-accumulation and their persistence in nature (Luo et al. 2014; Sui et al. 2014). Occurrence, bioactivity and known mode of action of PPCPs render them as toxic pollutants. These chemicals have similar physico-chemical behaviours and cause adverse biological effects on aquatic and terrestrial organisms. The present sewage treatment plants (STPs) are not efficient to completely remove PPCPs resulting in their persistence ranging from nanogramme to microgramme levels (Desta 2013; Jasim et al. 2006; Vidal-Dorsch et al. 2012; Rios et al. 2015; Heberer 2002). PPCPs are water soluble, and some of them may get degraded during sewage treatment, whereas others remain unchanged or get sorbed to solids in the activated/anaerobic sludge during secondary treatment (Kolpin et al. 2002). Eighty percent of STPs in India are not furnished with any tertiary treatment processes such as chlorination and/or activated carbon adsorption, resulting in the release of PPCPs in the surface water bodies such as rivers and lakes (Miege et al. 2009; Guerra et al. 2014; Gibbons et al. 2011; Hedgespeth et al. 2012; Hoque et al. 2014; Spongberg and Witter 2008; Bueno et al. 2012). Being present in the nanogram to microgram levels, their detection and quantification are quite demanding. However, the recent advancement in the analytical techniques has helped in their quantification (Jjemba 2006; Mottaleb et al. 2015; Wu et al. 2010; Xu et al. 2009). As the relevant data on PPCPs is currently scarce, neither threshold limits and regulations on PPCPs have been specified for the drinking water nor the discharge standards for treated wastewaters (Blair et al. 2013; Strickland et al. 2011; Sun et al. 2014, 2016; Chiu et al. 2009; Oulton et al. 2010; Kim et al. 2012; Daughton and Ternes 1999).

The five finger print PPCPs selected for this study are ciprofloxacin (antibiotic), acetaminophen (antipyretic and analgesic), caffeine (stimulant), benzophenone (UV filters) and irgasan (antifungal and antibacterial) in treated sewage and six lakes in the Nagpur city.

Ciprofloxacin (331.34 g mol^{-1}) (1-cyclopropyl-6-fluoro-4-oxo-7-piperazin-1-ylquinoline-3-carboxylic acid) is a broad-spectrum antimicrobial carboxyfluoroquinoline. It is the main metabolite of enrofloxacin, a commonly used veterinary fluoroquinolone (FQ). Of the administered dose of ciprofloxacin in humans, 45–62% are excreted unmetabolized via urine and 15–25% via faeces. Ciprofloxacin has high water solubility of 30,000 mg L^{-1} (at 20 °C). It is soluble in dilute (0.1N) hydrochloric acid and practically insoluble in ethanol. With p*K*a value 6.43 and 8.49, it has very low octanol–water partitioning coefficient (log Kow = 0.28) and does not undergo biodegradation or hydrolysis readily, due to the presence of highly stable quinolone ring. However, its high photodegradability with half-lives ranging from 5 min to about 1.5 h in different assessments can be attributed to the aromatic rings, heteroatoms and other functional chromophores, which are capable of absorbing solar radiation (Babic et al. 2013). On the other hand, sorption on soils, sediments or dissolved organic matter is also an important elimination path for FQs in the environment. Although FQs in sewage can be largely adsorbed onto the biosolids due to their high water–sludge partition coefficients, the residual (about 10%) in water as well as due to the desorption from the biosolids could cause further environment and health problem (Guo et al. 2013; Jones et al. 2002).

Acetaminophen (151.16 g mol^{-1}) (4′-hydroxyacetanilide, *N*-acetyl-*p*-aminophenol) is a widely used over-the-counter analgesic and antipyretic drug. Acetaminophen shows water solubility of 14,000 mg L^{-1} (at 25 °C) and is also readily soluble in methanol, ethanol, dimethylformamide, ethylene dichloride, acetone and ethyl acetate. However, its solubility in cold water is poor. Its p*K*a value is 9.38 and has very low octanol–water partitioning coefficient (log Kow = 0.46). The absorption of low therapeutic doses of acetaminophen is usually rapid and complete; the systemic bioavailability and the plasma half-life being about 75% at 1.5 and 2.5 h, respectively (Wu et al. 2012).

Caffeine (194.19 g mol^{-1}) (1,3,7-trimethylpurine-2, 6-dione), a legal stimulant, is one of the most widely used anthropogenic markers in the surface and ground water (Buerge et al. 2003). It presents high water solubility of 21,600 mg L^{-1} (at 25 °C). It is soluble in pyridine and freely soluble in pyrrole, slightly soluble in petroleum ether and freely soluble in tetrahydrofuran containing about 4% water. Its p*K*a value is 10.4, and it has very low octanol–water partitioning coefficient (log Kow = − 0.07) with low accumulation tendency. Caffeine gets metabolized in humans into mainly three main compounds named theophylline, theobromine and 1,7-dimethylxanthine (paraxanthine) and is readily biodegradable (Sui et al. 2010).

Benzophenone (182.22 g mol^{-1}) (diphenylmethanone) is commonly used as an ultraviolet (UV) filter in various

personal care products. It has low water solubility of 137 mg L^{-1} (at 25 °C) and is highly soluble in acetone, acetic acid and carbon disulphide and soluble in benzene and methanol. Its p*K*a value is 7.6 and has high octanol–water partitioning coefficient (log Kow = 3.18) (Zhang et al. 2011).

Irgasan (289.54 g mol^{-1}) (5-chloro-2-(2, 4-dichlorophenoxy) phenol) is a broad-spectrum antibacterial agent. It enters into water as it is used in medicated soaps, shampoos, toothpastes and deodorants. Its photochemical conversion to 2, 8-dichlorodibenzo-*p*-dioxin (weak oestrogen activity) is responsible for toxicity in fishes with more bioaccumulation (Thomas and Foster 2005). Irgasan has low water solubility (12 mg L^{-1} Reiss et al. 2002). However, it is much more soluble in ethanol (Aragon et al. 2008) and in fat, with a high octanol–water partitioning coefficient (log Kow = 4.2–4.8 at neutral pH). The log Kow depends on the pH of water because of the presence of the hydroxyl group. Because of its high hydrophobicity, it is expected to get adsorbed onto sludge and other particulate matter (Chu and Metcalfe 2007).

Nagpur [21° 8′ 55″ N and 79° 4′ 46″ E] is the second capital of the Maharashtra, India and is popularly known as orange city. This "A class" city is the 13th largest urban agglomeration in India and is located at the centre of the Indian peninsula. About 100 MLD of sewage generated in the city is treated in the STP using primary and the secondary processes (activated sludge system). The treated sewage is discharged to a nullah which ultimately joins river. The city is dotted with natural and artificial lakes. Ambazari, constructed at the upstream, is situated near the Southwest border of Nagpur and was earlier the primary source of water for the orange city. It is also the largest of all the lakes present in and around the city. Nag River originates from this lake. Other lakes included in this study are Gorewada, Futala, Sakkardara, Sonegaon and Gandhi sagar Lake (Fig. 1). Gorewada lake is located in North Western region of Nagpur city, Maharashtra. It is an artificial lake with a dam 2350 ft long. Since 2012, the lake is an important sources of water for Nagpur population. The water level of this lake is around 312.69 m.

Futala lake is located on the western side of the Nagpur city, spread over 60 acres. The catchment area of the lake is 6.475 km^2. The length of west weir is 8.0 m. Futala lake is having capacity to irrigate an area of 34.42 ha of cultivated agriculture land and Telenkhedi garden The lake is prominently used for irrigating nearby agricultural land and for commercial fisheries. Rest of the studied lakes are generally used for recreational purposes, bathing and other human activities. All the above rain fed lakes were evaluated for the occurrence of the five selected PPCPs to indicate pollution of these water bodies by anthropogenic inputs.

As scanty database exist on the occurrence and the ultimate fate of PPCPs in the aquatic bodies in India, despite being one of the world leaders in pharmaceutical production and consumption, aquatic contamination by PPCPs may be a critical issue that needs to be assessed. In the light of these concerns, the aim of the present study was to identify the pollution loads of PPCPs discharged into the aquatic environment through municipal wastewater effluents in the region of Nagpur. Also, a record of seasonal conditions in the defined study area in terms of physical and chemical profile as well as qualitative and quantitative study of five fingerprint PPCPs over an annual cycle has been presented. A year-round study of a sewage treatment plant consisting of primary and secondary treatment was also performed.

Environmental risk assessment (ERA) is the process for evaluating how likely the environment may be impacted as a result of exposure to one or more environmental stressors such as chemicals, disease, invasive species and the change in climate (Dorne et al. 2007; Kienhuis et al. 2011; Gerbersdorf et al. 2015). These assessments are generally carried out to measure health risk on living organisms and ecosystem on exposure to the toxic contaminants (Van Leeuwen et al. 1996; Han et al. 2006; Agerstrand et al. 2015). ERA was also carried out for the selected PPCPs in terms of quantification of health risks to human and ecosystem if exposed to the above PPCPs.

Materials and methods

Study area and sampling

Influent and effluent stream samples were collected from an STP, designed to receive > 400 MLD sewage from urban households, industries, hospitals and other sources. However, at present, STP treats only 80 MLD of city sewage using two-stage treatment processes [primary and secondary (biological) treatment]. The primary treatment process includes grit removal, flow equalization and fat and grease removal, and secondary

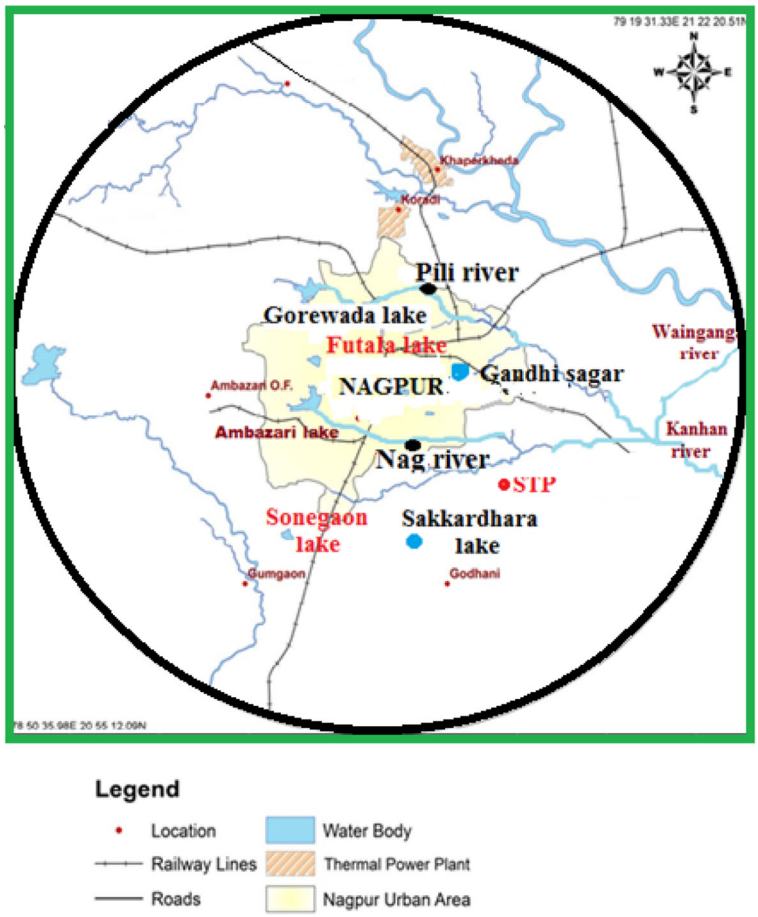

Fig. 1 Map of Nagpur city showing the sampling sites

treatment process consists of conventional activated sludge process.

Surface water samples were collected from six lakes (Ambazari lake, Gorewada lake, Futala lake, Sakkardara lake, Sonegaon lake and Gandhi sagar lake). Grab samples were collected in 5 L pre-cleaned, amber glass bottles after rinsing with the sample water twice before sample collection. All the samples were preserved by adjusting their pH to 3 using 1:1 hydrochloric acid to inhibit microbial growth and were stored at 4 °C prior to analysis.

Chemicals and standards

The reference standards of acetaminophen (≥ 98.0% purity), ciprofloxacin (98.0% purity), caffeine (99.0% purity), irgasan (≥ 97.0% purity) and benzophenone (99.0% purity) were purchased from Sigma-Aldrich. HPLC grade methanol (99.8%) and HPLC grade water (> 99.9% purity) were purchased from Rankem, India. Acetic acid (≥ 99.7% purity) was procured from Merck. Mill-Q type 1 water was obtained from Millipore, India. All the solvents were filtered (0.22 μm Millipore filter) and degassed in an ultra sonicator prior to use.

Instrumental conditions

Waters HPLC system (Model 2545), equipped with a quaternary gradient module pump (model 2535), Photo Diode Array detector (model 2998) and a water flex injector with a sample loop of 20 μL capacity was used. All the data were analysed with Empower 7 software. The column C18 [sunfire™ 5 μm, (4.6 × 250 mm)] was used for sample quantification and all the analysis were performed at ambient temperature. The pH of the solutions was measured with pH metre (LABINDIA pH metre, Pico+). Chemical extractions were performed by solid-phase extraction (SPE) using vacuum manifold from Supelco, Visiprep™.

Chemical extractions

Water samples were processed to extract the target analytes according to the method described in our earlier work (Archana et al. 2016). Briefly, the water samples were centrifuged at 4000 rpm for 20 min to remove solid particles and then filtered using glass fibre filters (0.45 μm). The pH of 1 L of each sample was maintained to 2 ± 0.5 with 1:1 HCl for acid extraction and another 1 L sample to 10 ± 0.5 with NH_4OH for the base extraction. As the selected PPCPs were acidic and basic in nature with different p*K*a values, the water samples were extracted by acid and base extraction separately to achieve better separation and resolution.

Agela Cleanert™ ODS SPE C18 cartridges (500 mg/5 mL) were conditioned separately for acid and base extractions. The SPE Cartridges were conditioned using 20 mL methanol followed by 6 mL Millipore water and 7 mL of acidified water (pH = 2 ± 0.5) for acid extraction, whereas for the base extraction, the SPE Cartridges were conditioned using 20 mL methanol followed by 6 mL Millipore water. Then, water samples were passed onto the respective cartridges using a vacuum manifold (Supelco) at a flow rate of 10 mL min^{-1}. The cartridges were then dried under vacuum for approximately 15 min. Subsequently, the analytes were eluted with sequential addition of 6 mL of methanol followed by 6 mL of 80:20 (*v*/*v*) methanol/1% acetic acid and 6 mL of 1:1 acetone/methanol mixture. Finally, the elutes were concentrated to near dryness under a gentle stream of nitrogen gas in a water bath at 50 ± 5 °C and reconstituted with 1 mL methanol and then filtered through 0.22 μm syringe filter before injecting into HPLC.

Chromatographic condition and analysis

HPLC analysis was performed by isocratic elution at the flow rate of 1 mL min^{-1}. The mobile-phase composition was methanol/1% acetic acid 80:20 (*v*/*v*) with the run time 15 min for the analysis. The wavelengths for maximum absorbance (λmax) for ciprofloxacin, acetaminophen, caffeine, benzophenone and irgasan were 278, 245, 273, 254 and 280 nm, respectively.

Quality assurance/quality control

The linearity of the instrument for all analytes gave the correlation coefficient ranging from 0.989 to 0.999 in the concentration range 2–50 μg L^{-1}. The LOD and LOQ values for the target analytes were obtained between 0.09–1.48 μg L^{-1} and 0.32–4.96 μg L^{-1}, respectively, as reported in our earlier work (Archana et al. 2016). The presence of target analytes in environmental matrix was confirmed by comparing the retention time and relative peak area observed from spiking studies. The water samples (surface water bodies and STP) were spiked with the standards of ciprofloxacin, acetaminophen, caffeine, benzophenone and irgasan for quantifying the recovery of the analytes. The mean recovery percentages of the target PPCPs, measured in triplicate, ranged from 89 ± 2.8 to 102 ± 6.5 in Millipore water, 74 ± 2.5 to 86 ± 4.8 in STP and 82 ± 1.8 to 91 ± 3.1 in surface water matrices. The precision (%RSD) ranged from 0.42 to 2.41%.

Physico-chemical characterization for surface water bodies

The physico-chemical characterization (inorganic and organic parameters) for the samples, under consideration, was performed according to standard methods for water and wastewater analyses APHA, AWWA and WPCF (American Public Health Association 1996).

Ecotoxicological risk potential in defined study area

Ecotoxicological risk assessment (ERA) describes the interaction of toxic substances with a variety of living organisms. ERA data is considered for a chemical to be deemed safe for its application (Fent et al. 2006; Jeong et al. 2009; Bu et al. 2013). The ERA of target analytes in aquatic systems was assessed in two ways. First, the standard toxicity data for different organisms from the literature was used to generate hazard quotients (HQs). Secondly, a critical environmental concentration was used to predict the risk exposure for a particular organism, when the toxicity data was not available (Lin et al. 2016; Roberts et al. 2016; Sires et al. 2007).

The HQ was calculated to evaluate the degree of risk for each target analyte, which can be mathematically formulated as follows

$$HQs = MECs/PNECs$$

HQ value of less than 1 when the assessment factor is applied indicates an insignificant risk. Predicted no-

effect concentrations (PNECs) represent the toxicity reference value (i.e. LC50, EC50, IC50 or No observed effect concentration (NOEC)).

The potential environmental risk posed by the contaminant includes acute and/or chronic toxicity data, based on the most sensitive organism or combination of organisms, to determine a PNEC of the pollutant. PNECs for aquatic organisms were derived by dividing either the EC50 by an assessment factor (AF) of 1000 or by dividing the NOEC values by an AF of 10. This value is then compared to predicted or measured environmental concentrations (PEC or MEC, respectively) to obtain HQs of the ECs of interest.

EC50 is defined as the half maximal effective concentration used to measure the drug's potency. The HQs for aquatic organisms were calculated for the target analytes in each sampling area.

Results and discussion

PPCPs are water soluble and enter the surrounding aquatic environment through sewerage systems following consumption and excretion by humans as well as from the effluent of the hospital, leachates from landfills, agricultural farms and abattoirs. Studies have shown that 90% of the administrated dose of most drugs remains unmetabolized and get excreted through urine (Sui et al. 2014; Leung et al. 2013). The fate and concentration of the PPCPs in the aqueous environment can vary, as it depends on several factors such as geographical location, effectiveness of wastewater treatment, proximity to wastewater plants and meteorological conditions (mainly rainfall and temperature) (Kasprzyk-Hordern et al. 2009). Seasonal variations in the physico-chemical characteristics of the surface water bodies under consideration for the summer, rainy and winter seasons are presented in Tables 1, 2 and 3, respectively.

Nagpur has a tropical climate. In winter, there is much less rainfall than in summer. The Köppen–Geiger climate classification is Aw. The temperature here averages 26.9 °C. About 1092 mm of precipitation falls annually. The driest month is November, with 7 mm of rainfall. Most precipitation falls in July, with an average of 317 mm. The hottest month of the year is May, with an average temperature of 40.3 °C. In December, the average temperature is 20.1 °C. It is the lowest average temperature of the whole year.

As expected, most of the parameters analysed under the physico-chemical characteristics are found to have higher values in the summer season (April to June) while lower values are observed during rainy season (July to September). This is attributed to high evaporation rate of water and low water levels in lakes during summer and subsequent dilution due to precipitation and run-off from catchments areas during rainy season. However, the seasonal variations for TOC values of Ambazari and Futala were found to be almost similar in all the three seasons. This may be because TOC content depended on the inflow of sewage into these lakes throughout the year. Gorewada is a natural lake used for water supply to Nagpur city with no source of pollution entering the lake. Similarly, Gandhi sagar, Sonegaon and Sakkardara lake are man-made lakes with rain water storage only.

The total dissolved solids (TDS) in all the lakes except Gorewada lake are in the range 448–887 mg L^{-1}.Also, the chemical oxygen demand (COD) values in water samples suggest pollution levels in the following order: Futala > Ambazari > Gandhi sagar > Sonegaon > Sakkardara and Gorewada lakes. The high pollution levels in the Futala lake is supported by its water quality index (WQI), which has been reported as 55.81–75.83, 88.72–169.37 and 75.01–124.13 in August, September and October 2013, respectively (Puri et al. 2015).WQI of < 50 indicates excellent water quality (Puri et al. 2011).

Occurrence of target PPCPs in STP

Influence of physico-chemical characteristics on the occurrence of PPCPs in STP

Once PPCPs reach the environment, its concentration level is governed by biotic and abiotic factors. The abiotic factors include sorption, photodegradation and hydrolysis. Individual PPCPs generally have distinct physico-chemical properties and therefore may have different mechanisms for its removal in STP. The removal of PPCPs in the activated sludge process (STP) is mainly attributed to two mechanisms, i.e. sorption onto the particulate phase and biodegradation. It is well known that during the process of wastewater treatment, PPCPs and its metabolites can partition between the solid/particulate phase and the aqueous phase depending on their hydrophobicity. Generally, hydrophilic and water-soluble PPCPs are not likely to be detected in

Table 1 Physico-chemical characteristics of surface water bodies (lakes) during summer season

Parameters	Ambazari lake	Futala lake	Gandhi sagar	Gorewada lake	Sonegaon lake	Sakkardara lake
Total solids	611 ± 2	806 ± 2	980 ± 1	319 ± 1	773 ± 0.58	883 ± 1
Total suspended solids	87 ± 2	86 ± 2	93 ± 2	59 ± 2	95 ± 0.7	83 ± 0.2
Total dissolved solids	524 ± 2	720 ± 2	887 ± 3	260 ± 3	678 ± 1	800 ± 1
Chemical oxygen demand	90 ± 3	152 ± 1	80 ± 2	8 ± 0.4	50 ± 1	83 ± 0.04
Total hardness as $CaCO_3$	190 ± 2	230 ± 2	320 ± 1	120 ± 1	160 ± 3	600 ± 3
Alkalinity as $CaCO_3$	146 ± 2	165 ± 2	283 ± 2	143 ± 1	130 ± 1	261 ± .0.1
Sulphate	64 ± 1	102 ± 2	75 ± 2	68 ± 1	63 ± 1	83 ± 2
Chloride	56 ± 1	92 ± 3	93 ± 2	47 ± 2	87 ± 0.3	69 ± 2
pH	8 ± 0.08	8 ± 0.05	8 ± 0.03	8 ± 0.1	7.6 ± 0.05	7 ± 1
Total organic carbon	68 ± 0.6	271 ± 2	23 ± 1	16 ± 2	40 ± 1	14 ± 2
Total carbon	95 ± 1	327 ± 3	99 ± 2	34 ± 2	53 ± 0.5	78 ± 2
Inorganic carbon	27 ± 0.6	55 ± 0.7	76 ± 1	18 ± 1	13 ± 0.5	64 ± 0.09

All parameters except pH are expressed in milligrams per litre and are average of three consecutive readings. Error represents in terms of standard deviation

sludge as these compounds show less tendency to sorb onto the solid/particulate phase. Generally, the affinity towards the particulate phase for most of the PPCPs is poor, due to their polar nature (Sipma et al. 2010).

The hydrophobicity of a neutral compound can be expressed as its octanol–water partition coefficient (Kow) but, in case of ionisable compounds, acid–base equilibrium must be considered. The coefficient of sludge water partition (Kd) can be estimated from the values based on the Kow and the fraction of organic carbon in sludge. A high Kow/log Kd value indicates that PPCPs have greater tendency to get sorbed onto the suspended particles and end up in the sewage sludge (Girardi et al. 2011). PPCPs with low Kow if resistant to microbial degradation are likely to be present in effluent of STP.

This study was performed with the aim to examine the levels of PPCPs in the treated effluent to source apportion the levels found in fresh water bodies. In the studied STP, the average removal efficiency in the effluent was ranging from 40 to 70% for the five finger print PPCPs under consideration. The removal rate for

Table 2 Physico-chemical characteristics of surface water bodies (lakes) during rainy season

Parameters	Ambazari lake	Futala lake	Gandhi sagar	Gorewada lake	Sonegaon lake	Sakkardara lake
Total solids	526 ± 1	605 ± 2	865 ± 1	226 ± 1	596 ± 1	710 ± 1
Total suspended solids	78 ± 1	80 ± 1	90 ± 1	50 ± 1	86 ± 1	72 ± 1
Total dissolved solids	448 ± 1	525 ± 2	775 ± 2	176 ± 1	510 ± 1	638 ± 2
Chemical oxygen demand	77 ± 4	130 ± 2	73 ± 1	6 ± 0.5	80 ± 1	102 ± 0.4
Total hardness as $CaCO_3$	172 ± 3	215 ± 2	305 ± 2	108 ± 1	145 ± 2	575 ± 4
Alkalinity as $CaCO_3$	134 ± 2	152 ± 4	262 ± 2	130 ± 2	119 ± 1	243 ± 1
Sulphate	52 ± 4	94 ± 2	62 ± 2	55 ± 2	54 ± 2	71 ± 2
Chloride	49 ± 2	86 ± 2	82 ± 2	39 ± 1	72 ± 1	55 ± 2
pH	7.9 ± 0.05	8.1 ± 0.05	8.1 ± 0.05	8 ± 0.05	7.4 ± 0.05	7.1 ± 0.05
Total organic carbon	68 ± 0.6	262 ± 1	64 ± 2	13 ± 1	30 ± 2	52 ± 1
Total carbon	86 ± 2	315 ± 2	79 ± 1	30 ± 1	45 ± 1	62 ± 1
Inorganic carbon	18 ± 1	53 ± 2	15 ± 1	17 ± 2	15 ± 1	10 ± 1

All parameters except pH are expressed in milligrams per litre and are average of three consecutive readings. Error represents in terms of standard deviation

Table 3 Physico-chemical characteristics of surface water bodies (lakes) during winter season

Parameters	Ambazari lake	Futala lake	Gandhi sagar	Gorewada lake	Sonegaon lake	Sakkardara lake
Total solids	591 ± 2	698 ± 2	898 ± 1	292 ± 1	611 ± 2	732 ± 1
Total suspended solids	82 ± 1	81 ± 1	93 ± 1	55 ± 2	89 ± 2	79 ± 1
Total dissolved solids	509 ± 2	617 ± 3	805 ± 1	237 ± 2	522 ± 2	653 ± 1
Chemical oxygen demand	83 ± 3	145 ± 1	75 ± 1	7 ± 0.3	84 ± 1	106 ± 1
Total hardness as $CaCO_3$	178 ± 3	224 ± 4	315 ± 2	112 ± 1	150 ± 2	589 ± 4
Alkalinity as $CaCO_3$	139 ± 3	158 ± 3	270 ± 2	135 ± 2	124 ± 2	252 ± 1
Sulphate	58 ± 3	98 ± 3	68 ± 2	61 ± 1	58 ± 1	78 ± 1
Chloride	53 ± 2	90 ± 2	88 ± 1	42 ± 2	79 ± 2	62 ± 1
pH	8.2 ± 0.07	8 ± 0.1	8 ± 0.05	8 ± 0.1	7.5 ± 0.05	7.3 ± 0.05
Total organic carbon	70 ± 0.6	268 ± 1.63	66 ± 1	15 ± 1	33 ± 1	57 ± 1
Total carbon	90 ± 2	320 ± 1	85 ± 1	32 ± 1	49 ± 1	68 ± 1
Inorganic carbon	20 ± 1	52 ± 2	19 ± 2	17 ± 1	16 ± 1	11 ± 1

All parameters except pH are expressed in milligrams per litre and are average of three consecutive readings. Error represents in terms of standard deviation

ciprofloxacin was 44–55% which may be due to its high log Kd (sorption constant to activated sludge) value of 4.3.

It was observed that the removal efficiency of acetaminophen was in the range of 40–50%, which may be due to its rapid biodegradation in the biological treatment processes used in the STP under consideration. The extremely high value of Kd for acetaminophen is due to its rapid biodegradation that dominated the sorption process and therefore led to very low measured concentrations in the aqueous phase (Radjenovic et al. 2007). This could be the reason that acetaminophen was detected in the influent as well as the effluent of STP only in the summer season. Therefore, its occurrence and seasonal variation in the lakes under consideration was not observed.

Generally, the STPs show poor removal efficiency (less than 25%) for the hydrophilic compounds during the primary treatment stage (Yang et al. 2011). Being a hydrophilic compound, caffeine shows lesser tendency to get adsorb onto sludge which may be due to its low Kow value. Inspite of this, the removal efficiency of 62–70% was observed for caffeine which may be attributed to its rapid biodegradation. Consistently high removal efficiencies for caffeine have also been reported by other researchers (Buerge et al. 2003; Kosma et al. 2010).

Benzophenone and irgasan are characterized by high log Kow values exceeding 3, which indicate their tendency to get sorbed onto the sludge/particulate phase. This may be the reason for their lower concentrations as compared to the other target PPCPs. The removal efficiency for benzophenone was 43–58% and for irgasan was 55–62%.

Seasonal variation of target PPCPs in STP

The concentration of target PPCPs exhibited discordant seasonal variations, which may be due to their distinct utilization. All the investigated analytes except acetaminophen were found in both effluent and influent of STP in all seasons. Significantly higher concentrations (except for ciprofloxacin) were found in the influent samples in summer compared to the samples collected in the rainy and winter season. The concentrations of the all analytes in influent and effluent of STP over an annual cycle are presented in Table 4.

Antibiotic ciprofloxacin was found to be in higher concentration of 140 μg L^{-1} in winters and lowest concentration in rainy seasons. Ciprofloxacin is more frequently detected in winter due to its higher consumption during winter season (Sui et al. 2010). Additionally, perhaps the inhibition of abiotic/biotic degradation in winter season may be another cause for its detection in higher concentration (Sun et al. 2014). Lucia Birosova et al. reported the presence of ciprofloxacin in two WWTPs in Slovakia with the concentration of 1.4 and 2.1 μg L^{-1} in the month of February and 0.48 and 2.7 μg L^{-1} in the month of August. In municipal WWTPs, ciprofloxacin was predominantly present in their influent especially in winters (Birosova et al. 2014).

Table 4 Seasonal variation studies in influent and effluent from STP

Target analytes	Sewage treatment plant (STP)					
	Summer season (μg L^{-1})		Rainy season (μg L^{-1})		Winter season (μg L^{-1})	
	Influent	Effluent	Influent	Effluent	Influent	Effluent
Ciprofloxacin	61 ± 6	31 ± 3	12 ± 1	5 ± 1	140 ± 4	58 ± 4
Acetaminophen	30 ± 3	11 ± 4	< LOQ	< LOQ	< LOQ	< LOQ
Caffeine	373 ± 10	232 ± 5	132 ± 4	86 ± 4	213 ± 5	148 ± 5
Benzophenone	156 ± 5	88 ± 6	46 ± 3	23 ± 2	138 ± 3	61 ± 3
Irgasan	226 ± 7	129 ± 5	41 ± 2	24 ± 2	129 ± 3	77 ± 3

The concentration of acetaminophen was found to be 30.19 μg L^{-1} during summer and negligible during rainy and winter seasons. The reason for the lower concentration of acetaminophen can be attributed to its hydrolysis into metabolites due to its short half-life of 1–4 h (Prescott 1980). Earlier, authors have reported average concentration for acetaminophen to be 23.2 μg L^{-1} in the samples from STPs in Madrid (Rosal et al. 2010) and 7.5 μg L^{-1} in the influent and effluent samples collected from 10 WWTPs in Korea (Behera et al. 2011).

Caffeine was found to be present in higher concentration of 373 μg L^{-1} in summer followed by the winter and the rainy seasons. Caffeine is sold in numerous over-the-counter and prescription medications. Additionally, it is present in a wide assortment of consumer items such as coffee, tea and other beverages. Out of 16 target compounds that were detected in the primary effluent of advanced wastewater reclamation plant in Gwinnett, USA, caffeine was found to be in higher concentration of 54.0 μg L^{-1} whereas the average concentrations for ciprofloxacin, irgasan and acetaminophen were found to be 0.62, 0.47 and 8.0 μg L^{-1} respectively (Yang et al. 2011).

Benzophenone, widely used as UV filter in various cosmetics, was detected in all the seasons in the concentration range 23–156 μg L^{-1}. The concentration range of benzophenone was found to be 0.086–0.124 μg L^{-1}, 0.438–0.626 μg L^{-1}, 0.226–0.315 μg L^{-1} in the month of February, July and September respectively, in the samples collected from WWTP Tianjin, North China (Li et al. 2007). The average concentration for benzophenone was reported to be 0.393 μg L^{-1} in the influent and 0.086 μg L^{-1} in the effluent samples collected from STPs, Alcala de Henares, Madrid (Rosal et al. 2010).

Irgasan, an antimicrobial agent, was found in highest concentration in the summer season (225.5 μg L^{-1}) in the influent of STP followed by winter and rainy season.

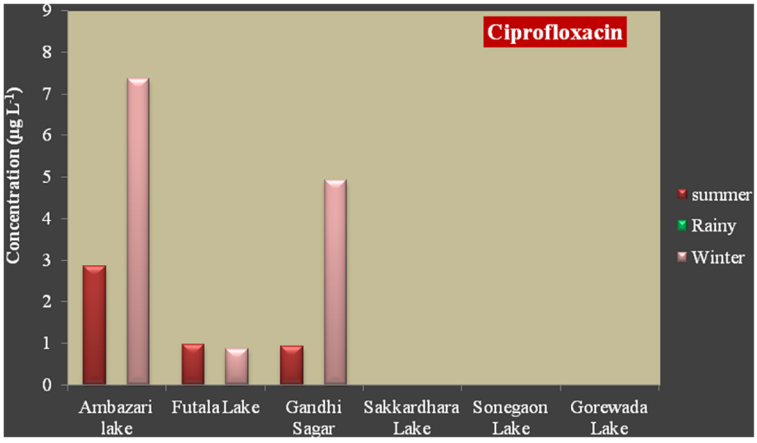

Fig. 2 Seasonal variation for ciprofloxacin in the studied Lake

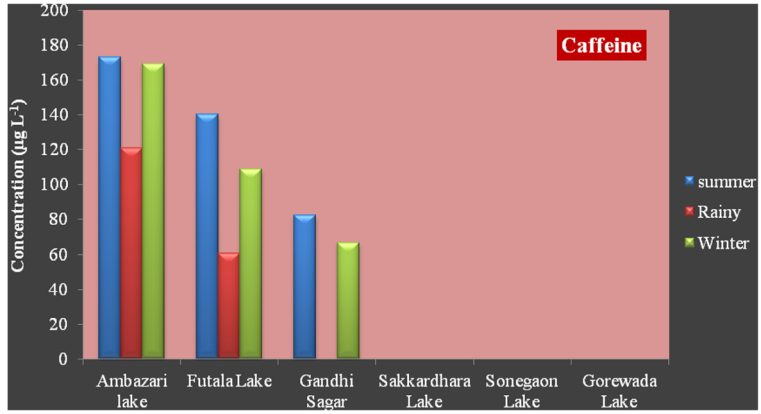

Fig. 3 Seasonal variation for caffeine in the studied Lake

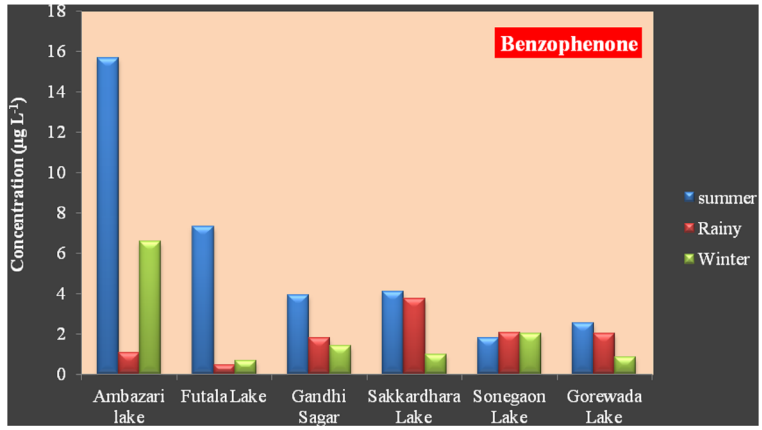

Fig. 4 Seasonal variation for benzophenone in the studied Lake

This compound is used in variety of consumer products including soaps, toothpastes and cleaning agents. The concentration of all the targeted analytes in influent and effluent of STP over an annual cycle is presented in Table 4.

Occurrence of target PPCPs in surface water bodies (lakes)

All the investigated PPCPs except acetaminophen were detected in Ambazari, Futala and Gandhi sagar lakes.

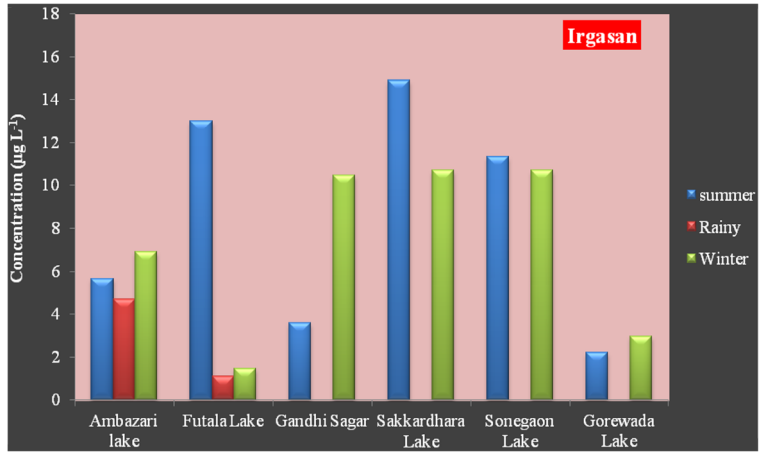

Fig. 5 Seasonal variation for irgasan in the studied Lake

Table 5 PNEC (ng L^{-1}) and HQs of ciprofloxacin in the defined study area

Organism	Acute/chronic	PNECs (ng L^{-1})	HQs of STP influent	HQs of STP effluent	HQs of Ambazari	HQs of Futala	HQs of Gandhi sagar
Cyanobacterium *Microcystis aeruginosa*[a]	EC50	17,000	3.616471	1.835294	0.432353	0.057059	0.29
Chlorella vulgaris[b]	EC50	313,000	0.196422	0.099681	0.023482	0.003099	0.015751
Sludge bacteria[a]	EC50	610,000	0.100787	0.051148	0.012049	0.00159	0.008082
Pseudomonas putida[a]	EC50	80,000	0.7685	0.39	0.091875	0.012125	0.061625
Selenastrum capricomutum[c]	EC50	2,970,000	0.0207	0.010505	0.002475	0.000327	0.00166
Pseudokirchneriella subcapitata[d]	IC50	3,070,000	0.020026	0.010163	0.002394	0.000316	0.001606
Dalphnia magna[e]	EC50	24,000,000	0.002562	0.0013	0.000306	4.04×10^{-5}	0.000205
Ceriodaphina dubia[e]	EC50	87,000,000	0.000707	0.000359	8.45×10^{-5}	1.11×10^{-5}	5.67×10^{-5}
Cylindrotheca closterium[b]	EC50	55,430,000	0.001109	0.000563	0.000133	1.75×10^{-5}	8.89×10^{-5}
Navicula ramosissima[b]	EC50	72,120,000	0.000852	0.000433	0.000102	1.34×10^{-5}	6.84×10^{-5}

[a] Naslund et al. (2008)

[b] Hagenbuch and Pinckney (2012)

[c] Liu et al. (2011)

[d] Johansson et al. (2014)

[e] Dalla Bona et al. (2015)

However, in the rainy season, ciprofloxacin was not detected. The present study shows concentration of ciprofloxacin in Ambazari lake to be six times higher than the concentration in the Yamuna River (1.4 μg L^{-1}) as reported by Mutiyar and Mittal (2014). The concentration range for ciprofloxacin was reported as 10–2500 μg L^{-1} in Sakavagu-Nakkavagu Rivers, India and 2500–6500 μg L^{-1} in a lake situated in Patancheru, India (Fick et al. 2009). The measured concentration range for ciprofloxacin was reported to be 1.32–16 ng L^{-1} and < 1.8–37.50 ng L^{-1} in river Po and Arno, respectively (Zuccato et al. 2010).

Caffeine was found to be in concentration range 60–174 μg L^{-1} in Ambazari, Futala and Gandhi sagar lakes. Caffeine can serve an indicator for urban sewage pollution in these lakes (Daneshvar et al. 2012; Diwan et al. 2013). The measured concentration range for caffeine was 6–18 ng L^{-1} in the samples collected from Cocagne watershed southeast New Brunswick, Canada, whereas the highest concentrations of 0.089 and 1.3 μg L^{-1} were

Table 6 PNEC (ng L^{-1}) and HQs of acetaminophen in the defined study area

Organism	Acute/chronic	PNECs (ng L^{-1})	HQs of STP influent	HQs of STP effluent
V. fischeri[a]	EC50	92,200,000	0.000327	0.000122
P. subcapitata[a]	EC50	317,400,000	9.51×10^{-5}	3.55×10^{-5}
C. raciborskii[a]	EC50	192,900,000	0.000157	5.84×10^{-5}
D. iongispina[a]	EC50	65,900,000	0.000458	0.000171
D. magna[b]	EC50	50,000,000	0.000604	0.000225
L. minor[a]	EC50	429,900,000	7.02×10^{-5}	2.62×10^{-5}
Brachionus calyciflorus[a]	LC50	5,306,000,000	5.69×10^{-6}	2.12×10^{-6}
Dalphina magna[a]	EC50	136,000,000	0.000222	8.29×10^{-5}
Tetrahymena pyriformis[a]	EC50	112,000,000	0.00027	0.000101
Streptocephalus proboscideug[a]	EC50	29,000,000	0.001041	0.000389

[a] Nunes et al. (2014)

[b] Stuer-Lauridsen et al. (2000)

Table 7 PNEC (ng L^{-1}) and HQs of caffeine in the defined study area

Organism	Acute/chronic	PNECs (ng L^{-1})	HQs of STP influent	HQs of STP effluent	HQs of Ambazari	HQs of Futala	HQs of Gandhi sagar
Leuciscus idus[a]	LC50	87,000,000	0.001514	0.000984	0.001387	0.00125	0.000763
Daphnia magna[b]	EC50	182,000,000	0.000724	0.00047	0.000663	0.000597	0.000365
P. promelas[b]	EC50	70,000,000	0.001882	0.001223	0.001724	0.001553	0.000948
X. laevis[b]	EC50	130,000,000	0.001013	0.000659	0.000928	0.000836	0.000511
C. dilutus[b]	EC50	1,520,000,000	8.67×10^{-5}	5.63×10^{-5}	7.94×10^{-5}	7.15×10^{-5}	4.37×10^{-5}

[a] Marques et al. (2013)

[b] Moore et al. (2008)

reported in the samples of two coastal watersheds, Halifax and Pictou, located in Nova Scotia, Canada, respectively (Comeau et al. 2008).

Amongst the target PPCPs, benzophenone and irgasan were detected in Gorewada, Sakkardara and Sonegaon lakes in low levels as these water bodies do not receive any wastewater from the city. The present study shows higher concentration for benzophenone in the lakes as compared to the values (0.002–0.068 μg L^{-1}) reported in the heavily and moderately polluted rivers in Japan (Kameda et al. 2011). The concentration of benzophenone was found to be in the non-detected range in the samples collected from rivers (25 sites) and lakes (6 sites) in Korea (Jeon et al. 2006).

However, the concentration range reported for irgasan was < LOQ–0.03, 0.007–0.03 and 0.09–0.478 μg L^{-1} in Liuxi River, Zhujiang River and Shijing River, respectively, in China (Zhao et al. 2010). Subedi et al. reported the concentration range for irgasan to be ND–0.005 μg L^{-1} in Skaneateles Lake in New York (Subedi and Kannan 2015). The presence of benzophenone and irgasan in the studied surface water bodies can be attributed to washing and recreational activities. The discharges of sewage, immersion of idols during festival season (August to October), dispose of detritus and other recreational activities

Table 8 PNEC (ng L^{-1}) and HQs of benzophenone in the defined study area

Organism	Acute/chronic	PNECs (ng L^{-1})	HQs of STP Influent	HQs of STP Effluent	HQs of Ambazari	HQs of Futala	HQs of Gandhi sagar
Daphnia magna[a]	LC50	1,670,000	0.068064	0.034331	0.009389	0.004383	0.002353
Desmodesmus subspicatus[a]	IC50	960,000	0.118403	0.059722	0.016333	0.007625	0.004094
Scenedesmus vacuolatus[a]	EC50	360,000	0.315742	0.159258	0.043556	0.020333	0.010917
Caenorhabditis elegans[b]	LC50	56,800,000	0.002001	0.001009	0.000276	0.000129	6.92×10^{-5}

Organism	Acute/chronic	PNECs (ng L^{-1})	HQs of Gorewada	HQs of Sonegaon	HQs of Sakkardara
Daphnia magna[a]	LC50	1,670,000	0.001527	0.001222	0.002449
Pesmodesmus subspicatus[a]	IC50	960,000	0.002656	0.002125	0.00426
Scenedesmus vacuolatus[a]	EC50	360,000	0.007083	0.005667	0.011361
Caenorhabditis elegans[b]	LC50	56,800,000	4.49×10^{-5}	3.59×10^{-5}	7.0×10^{-5}

[a] Kim and Choi (2014)

[b] Ura et al. (2002)

Table 9 PNEC (ng L^{-1}) and HQs of irgasan in the defined study area

Organism	Acute/chronic	PNECs (ng L^{-1})	HQs of Ambazari	HQs of Futala	HQs of Gandhi sagar	HQs of Gorewada	HQs of Sonegaon	HQs of Sakkardara
Scenedesmus subspicatus[a]	EC50	700,000	0.008071	0.0186	0.005114	0.003129	0.016214	0.021314
Pseudokirchneriella subcapitata[b]	EC50	4,700,000	0.001202	0.00277	0.000762	0.000466	0.002415	0.003174
Daphnia magna[a]	EC50	390,000	0.014487	0.033385	0.009179	0.005615	0.029103	0.038256
Pimephales promelas[a]	EC50	260,000	0.021731	0.050077	0.013769	0.008423	0.043654	0.057385
Lepomis macrochirus[a]	EC50	370,000	0.01527	0.035189	0.009676	0.005919	0.030676	0.040324
Artemia salina[c]	LC50	171,100	0.033022	0.076096	0.020923	0.0128	0.066335	0.0872
Tetrobymena thermophila[c]	LC50	1,063,000	0.005315	0.012248	0.003368	0.00206	0.010677	0.014036
Chironomus tetanus[b]	EC50	280,000	0.020179	0.0465	0.012786	0.007821	0.040536	0.053286
Hyalella azteca[b]	EC50	250,000	0.0226	0.05208	0.01432	0.00876	0.0454	0.05968

Organism	Acute/chronic	PNECs(ng L^{-1})	HQs of STP influent	HQs of STP effluent
Scenedesmus subspicatus[a]	EC50	700,000	0.058214	0.034743
Pseudokirchneriella subcapitata[b]	EC50	4,700,000	0.00867	0.005174
Daphnia magna[a]	EC50	390,000	0.104487	0.062359
Pimephales promelas[a]	EC50	260,000	0.156731	0.093538
Lepomis macrochirus[a]	EC50	370,000	0.110135	0.06573
Artemia salina[c]	LC50	171,100	0.238165	0.142139
Tetrobymena thermophila[c]	LC50	1,063,000	0.038335	0.022879
Chironomus tetanus[b]	EC50	280,000	0.145536	0.086857
Hyalella azteca[b]	EC50	250,000	0.163	0.09728

[a] Bedoux et al. (2012)

[b] Dussault et al. (2008)

[c] Han et al. (2016)

can contribute to pollution. Overall, the concentrations of target analytes were found to be highest in summer followed by winter and rainy season. The concentrations of the target analytes in surface water bodies (lakes) over a period of 1 year are depicted in Figs. 2, 3, 4 and 5.

Ecotoxicological and pollution implications

HQ is a useful measure to specify potential ecotoxicological risk of the target analytes. However, it is very difficult to evaluate whether the adverse effects will also be caused to the non target organisms in the ecosystem (Escher et al. 2011). In this context, risks towards some of the aquatic organisms were evaluated in defined study area. PNEC values were estimated for some target organisms from data available in the literature on acute/chronic toxicity. In fact, the shortfall of chronic toxicity data is a major hindrance to the effective risk assessment of PPCPs, as they are most likely to induce chronic rather than acute toxic effects (Gros et al. 2010).

Literature studies reveal that many PPCPs are used worldwide in large quantities and have been recently referred as ECs. Therefore, the chronic toxicity data for most of the PPCPs is not available till date. This was the reason that the acute toxicity data were considered to calculate the PNEC for each PPCP for the present study.

Researchers have generally used acute toxicity data (EC50, LC50, IC50 values) to predict PNEC in order to characterize potential ecotoxicological risk. This has helped to estimate whether the levels detected would induce any adverse effect to aquatic organisms or not.

Risks towards some of the targeted aquatic organisms were evaluated in both the influent and effluent of STP along with the lakes under consideration. On an average, the HQ values measured in the study area were within the range when an application factor of 1000 was applied, as depicted in the Tables 5, 6, 7, 8 and 9. It can be seen that the HQ values were below 1, and therefore, no risks are associated due to the presence of targeted PPCPs in surface waters bodies (lakes).

Similarly, the HQ values for all the studied PPCPs (except ciprofloxacin) for targeted organisms were found to be below 1 in the studied STP. However, higher HQ values in the influent and the effluent of the studied STP for ciprofloxacin indicate that the aquatic organism Cyanobacterium *Microcystis aeruginosa* is suspected to be at high risk.

ERA studies reveal that the measured concentration levels of the targeted PPCPs do not pose any risk towards the aquatic organisms. However, adverse health effects can be faced by the aquatic organisms if,the HQ values reach close to one. This may happen if the aquatic organisms are continuously exposed to the targeted PPCPs.

Conclusion

The present study establishes an annual baseline of the persistence, seasonal quantification and health risk assessment for PPCPs in raw and treated sewage as well as surface water bodies (lakes) in Nagpur, India. The targeted PPCPs were detected in sewage and surface water bodies in the concentrations range of 11–373 μg L^{-1} and 1–174 μg L^{-1}, respectively. The higher removal efficiencies of the targeted PPCPs were observed in STP for compounds having higher Kow, 55–62% for irgasan and 43–58% for benzophenone. Inadequate removal of PPCPs from STP requires reassessment of current prototype and its operations along with more databases of these pollutants all over the regions and seasons. For better prediction of the persistence of PPCPs in the sewage effluent, a thorough understanding of their removal during STP treatment process is required in order to minimize pollution load. This is important as there is an increased demand for the reuse of treated sewage for agriculture and/or habitat restoration. The physico-chemical characteristics indicate the pollution levels of the lakes of Nagpur city in the following order: Futala > Ambazari > Gandhi sagar > Sonegaon > Sakkardara and Gorewada. Caffeine was found in the lakes which are polluted by untreated sewage discharge or inhabited intensely with anthropogenic activities. Benzophenone and irgasan were detected in all the lakes; however, ciprofloxacin and caffeine were found only in Ambazari, Futala and Gandhi sagar lakes.

ERA calculations for the targeted organisms reveal that HQ values for the PPCPs, except ciprofloxacin in the raw and treated sewage, were found to be at no risk levels. Similarly none of the targeted PPCPs pose any risk towards the aquatic organisms in surface water bodies at the present MEC levels. However, continuous release of this group of compounds into the water bodies as well as their bioaccumulation may cause potential long term exposure to the aquatic organisms.

References

Agerstrand, M., Berg, C., Bjorlenius, B., Breitholtz, M., Brunstrom, B., Fick, J., et al. (2015). Improving environmental risk assessment of human pharmaceuticals. *Environmental Science & Technology, 49*(9), 5336–5345.

American Public Health Association. (1996). In L. S. Clesceri (Ed.), *Standard methods for the examination of water and wastewater, supplement*. Washington, DC: American Public Health Association.

Aragon, D. M., Ruidiaz, M. A., Vargas, E. F., Bregni, C., Chiappetta, D. A., Sosnik, A., & Martiinez, F. (2008). Solubility of the antimicrobial agent triclosan in organic solvents of different hydrogen bonding capabilities at several temperatures. *Journal of Chemical & Engineering Data, 53*(11), 2576–2580.

Archana, G., Dhodapkar, R., & Kumar, A. (2016). Offline solid-phase extraction for preconcentration of pharmaceuticals and personal care products in environmental water and their simultaneous determination using the reversed phase high-performance liquid chromatography method. *Environmental Monitoring and Assessment, 188*(9), 512.

Babic, S., Perisa, M., & Skoric, I. (2013). Photolytic degradation of norfloxacin, enrofloxacin and ciprofloxacin in various aqueous media. *Chemosphere, 91*(11), 1635–1642.

Bedoux, G., Roig, B., Thomas, O., Dupont, V., & Le Bot, B. (2012). Occurrence and toxicity of antimicrobial triclosan and by-products in the environment. *Environmental Science and Pollution Research, 19*(4), 1044–1065.

Behera, S. K., Kim, H. W., Oh, J. E., & Park, H. S. (2011). Occurrence and removal of antibiotics, hormones and several

other pharmaceuticals in wastewater treatment plants of the largest industrial city of Korea. *Science of the Total Environment, 409*(20), 4351–4360.

Birosova, L., Mackulak, T., Bodik, I., Ryba, J., Skubak, J., & Grabic, R. (2014). Pilot study of seasonal occurrence and distribution of antibiotics and drug resistant bacteria in wastewater treatment plants in Slovakia. *Science of the Total Environment, 490*, 440–444.

Blair, B. D., Crago, J. P., Hedman, C. J., & Klaper, R. D. (2013). Pharmaceuticals and personal care products found in the Great Lakes above concentrations of environmental concern. *Chemosphere, 93*(9), 2116–2123.

Bu, Q., Wang, B., Huang, J., Deng, S., & Yu, G. (2013). Pharmaceuticals and personal care products in the aquatic environment in China: a review. *Journal of Hazardous Materials, 262*, 189–211.

Bueno, M. M., Gomez, M. J., Herrera, S., Hernando, M. D., Aguera, A., & Fernandez-Alba, A. R. (2012). Occurrence and persistence of organic emerging contaminants and priority pollutants in five sewage treatment plants of Spain: two years pilot survey monitoring. *Environmental Pollution, 164*, 267–273.

Buerge, I. J., Poiger, T., Muller, M. D., & Buser, H. R. (2003). Caffeine, an anthropogenic marker for wastewater contamination of surface waters. *Environmental Science & Technology, 37*(4), 691–700.

Chiu, C. A., Westerhoff, P., Herckes, P., & Masles, M. (2009). Monitoring of Trace-Level Pharmaceuticals and Personal Care Products in Salt River Project Waters. http://faculty.engineering.asu.edu/pwesterhoff/wp-content/uploads/2012/10/PPCP_EDC-FINAL-report-2010.pdf.

Chu, S., & Metcalfe, C. D. (2007). Analysis of paroxetine, fluoxetine and norfluoxetine in fish tissues using pressurized liquid extraction, mixed mode solid phase extraction cleanup and liquid chromatography–tandem mass spectrometry. *Journal of Chromatography A, 1163*(1), 112–118.

Comeau, F., Surette, C., Brun, G. L., & Losier, R. (2008). The occurrence of acidic drugs and caffeine in sewage effluents and receiving waters from three coastal watersheds in Atlantic Canada. *Science of the Total Environment, 396*(2), 132–146.

Dalla Bona, M., Zounkova, R., Merlanti, R., Blaha, L., & De Liguoro, M. (2015). Effects of enrofloxacin, ciprofloxacin, and trimethoprim on two generations of Daphnia magna. *Ecotoxicology and Environmental Safety, 113*, 152–158.

Daneshvar, A., Aboulfadl, K., Viglino, L., Broseus, R., Sauve, S., Madoux-Humery, A. S., & Prevost, M. (2012). Evaluating pharmaceuticals and caffeine as indicators of fecal contamination in drinking water sources of the Greater Montreal region. *Chemosphere, 88*(1), 131–139.

Daughton, C. G., & Ternes, T. A. (1999). Pharmaceuticals and personal care products in the environment: agents of subtle change? *Environmental Health Perspectives, 107*, 907.

Desta, M. B. (2013). Batch sorption experiments: Langmuir and Freundlich isotherm studies for the adsorption of textile metal ions onto teff straw (Eragrostis tef) agricultural waste. *Journal of thermodynamics, 1*, 1–6.

Diwan, V., Lundborg, C. S., & Tamhankar, A. J. (2013). Seasonal and temporal variation in release of antibiotics in hospital wastewater: estimation using continuous and grab sampling. *PloS One, 8*(7), e68715.

Dorne, J. L. C. M., Skinner, L., Frampton, G. K., Spurgeon, D. J., & Ragas, A. M. J. (2007). Human and environmental risk assessment of pharmaceuticals: differences, similarities, lessons from toxicology. *Analytical and Bioanalytical Chemistry, 387*(4), 1259–1268.

Dussault, E. B., Balakrishnan, V. K., Sverko, E. D., Solomon, K. R., & Sibley, P. K. (2008). Toxicity of human pharmaceuticals and personal care products to benthic invertebrates. *Environmental Toxicology and Chemistry, 27*(2), 425–432.

Escher, B. I., Baumgartner, R., Koller, M., Treyer, K., Lienert, J., & McArdell, C. S. (2011). Environmental toxicology and risk assessment of pharmaceuticals from hospital wastewater. *Water Research, 45*(1), 75–92.

Fent, K., Weston, A. A., & Caminada, D. (2006). Ecotoxicology of human pharmaceuticals. *Aquatic Toxicology, 76*(2), 122–159.

Fick, J., Soderstrom, H., Lindberg, R. H., Phan, C., Tysklind, M., & Larsson, D. G. (2009). Contamination of surface, ground, and drinking water from pharmaceutical production. *Environmental Toxicology and Chemistry, 28*(12), 2522–2527.

Gerbersdorf, S. U., Cimatoribus, C., Class, H., Engesser, K. H., Helbich, S., Hollert, H., & Seiler, T. B. (2015). Anthropogenic trace compounds (ATCs) in aquatic habitats—research needs on sources, fate, detection and toxicity to ensure timely elimination strategies and risk management. *Environment International, 79*, 85–105.

Gibbons, S. E., Wang, C., & Ma, Y. (2011). Determination of pharmaceutical and personal care products in wastewater by capillary electrophoresis with UV detection. *Talanta, 84*(4), 1163–1168.

Girardi, C., Greve, J., Lamshöft, M., Fetzer, I., Miltner, A., Schaffer, A., & Kastner, M. (2011). Biodegradation of ciprofloxacin in water and soil and its effects on the microbial communities. *Journal of Hazardous Materials, 198*, 22–30.

Gros, M., Petrovic, M., Ginebreda, A., & Barcelo, D. (2010). Removal of pharmaceuticals during wastewater treatment and environmental risk assessment using hazard indexes. *Environment International, 36*(1), 15–26.

Guerra, P., Kim, M., Shah, A., Alaee, M., & Smyth, S. A. (2014). Occurrence and fate of antibiotic, analgesic/anti-inflammatory, and antifungal compounds in five wastewater treatment processes. *Science of the Total Environment, 473*, 235–243.

Guo, H. G., Gao, N. Y., Chu, W. H., Li, L., Zhang, Y. J., Gu, J. S., & Gu, Y. L. (2013). Photochemical degradation of ciprofloxacin in UV and UV/H2O2 process: kinetics, parameters, and products. *Environmental Science and Pollution Research, 20*(5), 3202–3213.

Hagenbuch, I. M., & Pinckney, J. L. (2012). Toxic effect of the combined antibiotics ciprofloxacin, lincomycin, and tylosin on two species of marine diatoms. *Water Research, 46*(16), 5028–5036.

Han, G. H., Hur, H. G., & Kim, S. D. (2006). Ecotoxicological risk of pharmaceuticals from wastewater treatment plants in Korea: occurrence and toxicity to Daphnia magna. *Environmental Toxicology and Chemistry, 25*(1), 265–271.

Han, J., Won, E. J., Hwang, U. K., Kim, I. C., Yim, J. H., & Lee, J. S. (2016). Triclosan (TCS) and triclocarban (TCC) cause lifespan reduction and reproductive impairment through oxidative stress-mediated expression of the defensome in the monogonont rotifer (Brachionus koreanus). *Comparative*

Biochemistry and Physiology Part C: Toxicology & Pharmacology, 185, 131–137.

Heberer, T. (2002). Occurrence, fate, and removal of pharmaceutical residues in the aquatic environment: a review of recent research data. *Toxicology Letters, 131*(1), 5–17.

Hedgespeth, M. L., Sapozhnikova, Y., Pennington, P., Clum, A., Fairey, A., & Wirth, E. (2012). Pharmaceuticals and personal care products (PPCPs) in treated wastewater discharges into Charleston Harbor, South Carolina. *Science of the Total Environment, 437*, 1–9.

Hoque, M. E., Cloutier, F., Arcieri, C., McInnes, M., Sultana, T., Murray, C., & Metcalfe, C. D. (2014). Removal of selected pharmaceuticals, personal care products and artificial sweetener in an aerated sewage lagoon. *Science of the Total Environment, 487*, 801–812.

Jasim, S. Y., Irabelli, A., Yang, P., Ahmed, S., & Schweitzer, L. (2006). Presence of pharmaceuticals and pesticides in Detroit River water and the effect of ozone on removal. *Ozone: Science and Engineering, 28*(6), 415–423.

Jeon, H. K., Chung, Y., & Ryu, J. C. (2006). Simultaneous determination of benzophenone-type UV filters in water and soil by gas chromatography–mass spectrometry. *Journal of Chromatography A, 1131*(1), 192–202.

Jeong, S. H., Song, Y. K., & Cho, J. H. (2009). Risk assessment of ciprofloxacin, flavomycin, olaquindox and colistinsulfate based on microbiological impact on human gut biota. *Regulatory Toxicology and Pharmacology, 53*(3), 209–216.

Jjemba, P. K. (2006). Excretion and ecotoxicity of pharmaceutical and personal care products in the environment. *Ecotoxicology and Environmental Safety, 63*(1), 113–130.

Johansson, C. H., Janmar, L., & Backhaus, T. (2014). Toxicity of ciprofloxacin and sulfamethoxazole to marine periphytic algae and bacteria. *Aquatic Toxicology, 156*, 248–258.

Jones, O. A. H., Voulvoulis, N., & Lester, J. N. (2002). Aquatic environmental assessment of the top 25 English prescription pharmaceuticals. *Water Research, 36*(20), 5013–5022.

Kameda, Y., Kimura, K., & Miyazaki, M. (2011). Occurrence and profiles of organic sun-blocking agents in surface waters and sediments in Japanese rivers and lakes. *Environmental Pollution, 159*(6), 1570–1576.

Kasprzyk-Hordern, B., Dinsdale, R. M., & Guwy, A. J. (2009). The removal of pharmaceuticals, personal care products, endocrine disruptors and illicit drugs during wastewater treatment and its impact on the quality of receiving waters. *Water Research, 43*(2), 363–380.

Kienhuis, A. S., Bessems, J. G., Pennings, J. L., Driessen, M., Luijten, M., et al. (2011). Application of toxicogenomics in hepatic systems toxicology for risk assessment: acetaminophen as a case study. *Toxicology and Applied Pharmacology, 250*(2), 96–107.

Kim, S., & Choi, K. (2014). Occurrences, toxicities, and ecological risks of benzophenone-3, a common component of organic sunscreen products: a mini-review. *Environment International, 70*, 143–157.

Kim, J. W., Yoon, S. M., Lee, S. J., Narumiya, M., Nakada, N., Han, I. S., et al. (2012). Occurrence and fate of PPCPs wastewater treatment plants in Korea. In 2nd International Conference on Environment and Industrial Innovation, Singapore vol. 35, pp. 57–61.

Kolpin, D. W., Furlong, E. T., Meyer, M. T., Thurman, E. M., Zaugg, S. D., Barber, L. B., & Buxton, H. T. (2002). Pharmaceuticals, hormones, and other organic wastewater contaminants in US streams, 1999-2000: a national reconnaissance. *Environmental Science & Technology, 36*(6), 1202–1211.

Kosma, C. I., Lambropoulou, D. A., & Albanis, T. A. (2010). Occurrence and removal of PPCPs in municipal and hospital wastewaters in Greece. *Journal of Hazardous Materials, 179*(1), 804–817.

Leung, H. W., Jin, L., Wei, S., Tsui, M. M. P., Zhou, B., et al. (2013). Pharmaceuticals in tap water: human health risk assessment and proposed monitoring framework in China. *Environmental Health Perspectives, 121*(7), 839.

Li, W., Ma, Y., Guo, C., Hu, W., Liu, K., Wang, Y., & Zhu, T. (2007). Occurrence and behavior of four of the most used sunscreen UV filters in a wastewater reclamation plant. *Water Research, 41*(15), 3506–3512.

Lin, T., Yu, S., & Chen, W. (2016). Occurrence, removal and risk assessment of pharmaceutical and personal care products (PPCPs) in an advanced drinking water treatment plant (ADWTP) around Taihu Lake in China. *Chemosphere, 152*, 1–9.

Liu, B. Y., Nie, X. P., Liu, W. Q., Snoeijs, P., Guan, C., & Tsui, M. T. (2011). Toxic effects of erythromycin, ciprofloxacin and sulfamethoxazole on photosynthetic apparatus in Selenastrum capricornutum. *Ecotoxicology and Environmental Safety, 74*(4), 1027–1035.

Luo, Y., Guo, W., Ngo, H. H., et al. (2014). A review on the occurrence of micropollutants in the aquatic environment and their fate and removal during wastewater treatment. *Science of the Total Environment, 473-474*, 619–641.

Marques, R. R., Sampaio, M. J., Carrapico, P. M., Silva, C. G., Morales-Torres, S., et al. (2013). Photocatalytic degradation of caffeine: developing solutions for emerging pollutants. *Catalysis Today, 209*, 108–115.

Miege, C., Choubert, J. M., Ribeiro, L., Eusebe, M., & Coquery, M. (2009). Fate of pharmaceuticals and personal care products in wastewater treatment plants–conception of a database and first results. *Environmental Pollution, 157*(5), 1721–1726.

Moore, M. T., Greenway, S. L., Farris, J. L., & Guerra, B. (2008). Assessing caffeine as an emerging environmental concern using conventional approaches. *Archives of Environmental Contamination and Toxicology, 54*(1), 31–35.

Mottaleb, M. A., Bellamy, M. K., Mottaleb, M. A., & Islam, M. R. (2015). Use of LC-MS and GC-MS methods to measure emerging contaminants pharmaceutical and personal care products (PPCPs) in fish. *Journal of Chromatography & Separation Techniques, 6*(3), 1.

Mutiyar, P. K., & Mittal, A. K. (2014). Risk assessment of antibiotic residues in different water matrices in India: key issues and challenges. *Environmental Science and Pollution Research, 21*(12), 7723–7736.

Naslund, J., Hedman, J. E., & Agestrand, C. (2008). Effects of the antibiotic ciprofloxacin on the bacterial community structure and degradation of pyrene in marine sediment. *Aquatic Toxicology, 90*(3), 223–227.

Nunes, B., Antunes, S. C., Santos, J., Martins, L., & Castro, B. B. (2014). Toxic potential of paracetamol to freshwater organisms: a headache to environmental regulators? *Ecotoxicology and Environmental Safety, 107*, 178–185.

Oulton, R. L., Kohn, T., & Cwiertny, D. M. (2010). Pharmaceuticals and personal care products in effluent matrices: a survey of transformation and removal during wastewater treatment and implications for wastewater management. *Journal of Environmental Monitoring, 12*(11), 1956–1978.

Prescott, L. F. (1980). Kinetics and metabolism of paracetamol and phenacetin. *British Journal of Clinical Pharmacology, 10*(S2), 291S–298S.

Puri, P. J., Yenkie, M. K. N., Sangal, S. P., Gandhare, N. V., Sarote, G. B., & Dhanorkar, D. B. (2011). Surface water (lakes) quality assessment in Nagpur city (India) based on water quality index (WQI). *Rasayan Journal of Chemistry, 4*(1), 43–48.

Puri, P. J., Yenkie, M. K. N., Rana, D. B., Meshram, S. U., & Awale, L. S. (2015). Surface water (Futala Lake) quality and its pollution load in terms of water quality index (WQI). *Advances in Applied Science Research, 6*(1), 15–26.

Radjenovic, J., Petrovic, M., & Barcelo, D. (2007). Analysis of pharmaceuticals in wastewater and removal using a membrane bioreactor. *Analytical and Bioanalytical Chemistry, 387*(4), 1365–1377.

Reiss, R., Mackay, N., Habig, C., & Griffin, J. (2002). An ecological risk assessment for triclosan in lotic systems following discharge from wastewater treatment plants in the United States. *Environmental Toxicology and Chemistry, 21*(11), 2483–2492.

Rios, J. M., Lana, N. B., Berton, P., Ciocco, N. F., & Altamirano, J. C. (2015). Use of wild trout for PBDE assessment in freshwater environments: review and summary of critical factors. *Emerging Contaminants, 1*(1), 54–63.

Roberts, J., Kumar, A., Du, J., Hepplewhite, C., Ellis, D. J., Christy, A. G., & Beavis, S. G. (2016). Pharmaceuticals and personal care products (PPCPs) in Australia's largest inland sewage treatment plant, and its contribution to a major Australian river during high and low flow. *Science of the Total Environment, 541*, 1625–1637.

Rosal, R., Rodriguez, A., Perdigon-Melon, J. A., Petre, A., Garcia-Calvo, E., Gomez, M. J., & Fernandez-Alba, A. R. (2010). Occurrence of emerging pollutants in urban wastewater and their removal through biological treatment followed by ozonation. *Water Research, 44*(2), 578–588.

Sipma, J., Osuna, B., Collado, N., Monclús, H., Ferrero, G., Comas, J., & Rodriguez-Roda, I. (2010). Comparison of removal of pharmaceuticals in MBR and activated sludge systems. *Desalination, 250*(2), 653–659.

Sires, I., Oturan, N., Oturan, M. A., Rodriguez, R. M., Garrido, J. A., & Brillas, E. (2007). Electro-Fenton degradation of antimicrobials triclosan and triclocarban. *Electrochimica Acta, 52*(17), 5493–5503.

Spongberg, A. L., & Witter, J. D. (2008). Pharmaceutical compounds in the wastewater process stream in Northwest Ohio. *Science of the Total Environment, 397*(1), 148–157.

Strickland Jr, C. H., Rush, P., & Commissioner, P. D. (2011). 2010 Occurrence of Pharmaceutical and Personal Care Products (PPCPs) in Source Water of the New York City Water Supply. http://www.nyc.gov/html/dep/pdf/quality/nyc_dep_2010_ppcpreport.pdf.

Stuer-Lauridsen, F., Birkved, M., Hansen, L. P., Lutzhoft, H. C. H., & Halling-Sorensen, B. (2000). Environmental risk assessment of human pharmaceuticals in Denmark after normal therapeutic use. *Chemosphere, 40*(7), 783–793.

Subedi, B., & Kannan, K. (2015). Occurrence and fate of select psychoactive pharmaceuticals and antihypertensives in two wastewater treatment plants in New York State, USA. *Science of the Total Environment, 514*, 273–280.

Sui, Q., Huang, J., Deng, S., Yu, G., & Fan, Q. (2010). Occurrence and removal of pharmaceuticals, caffeine and DEET in wastewater treatment plants of Beijing, China. *Water Research, 44*(2), 417–426.

Sui, Q., Huang, J., Lu, S., et al. (2014). Removal of pharmaceutical and personal care products by sequential ultraviolet and ozonation process in a full-scale wastewater treatment plant. *Frontiers of Environmental Science & Engineering, 8*(1), 62–68.

Sun, Q., Lv, M., Hu, A., Yang, X., & Yu, C. P. (2014). Seasonal variation in the occurrence and removal of pharmaceuticals and personal care products in a wastewater treatment plant in Xiamen, China. *Journal of Hazardous Materials, 277*, 69–75.

Sun, Q., Li, M., Ma, C., Chen, X., Xie, X., & Yu, C. P. (2016). Seasonal and spatial variations of PPCP occurrence, removal and mass loading in three wastewater treatment plants located in different urbanization areas in Xiamen, China. *Environmental Pollution, 208*, 371–381.

Thomas, P. M., & Foster, G. D. (2005). Tracking acidic pharmaceuticals, caffeine, and triclosan through the wastewater treatment process. *Environmental Toxicology and Chemistry, 24*(1), 25–30.

Ura, K., Kai, T., Sakata, S., Iguchi, T., & Arizono, K. (2002). Aquatic acute toxicity testing using the nematode Caenorhabditis elegans. *Journal of Health Science, 48*(6), 583–586.

Van Leeuwen, C. J., Bro-Rasmussen, F., Feijtel, T. C., Arndt, R., Bussian, B. M., Calamari, D., et al. (1996). Risk assessment and management of new and existing chemicals. *Environmental Toxicology and Pharmacology, 2*(4), 243–299.

Vidal-Dorsch, D. E., Bay, S. M., Maruya, K., Snyder, S. A., Trenholm, R. A., & Vanderford, B. J. (2012). Contaminants of emerging concern in municipal wastewater effluents and marine receiving water. *Environmental Toxicology and Chemistry, 31*(12), 2674–2682.

Vorosmarty, C. J., McIntyre, P. B., Gessner, M. O., Dudgeon, D., Prusevich, A., Green, P., Glidden, S., Bunn, S. E., Sullivan, C. A., Liermann, C. R., & Davies, P. M. (2010). Global threats to human water security and river biodiversity. *Nature, 467*(7315), 555–561.

Wu, C., Spongberg, A. L., Witter, J. D., Fang, M., & Czajkowski, K. P. (2010). Uptake of pharmaceutical and personal care products by soybean plants from soils applied with biosolids and irrigated with contaminated water. *Environmental Science & Technology, 44*(16), 6157–6161.

Wu, S., Zhang, L., & Chen, J. (2012). Paracetamol in the environment and its degradation by microorganisms. *Applied Microbiology and Biotechnology, 96*(4), 875–884.

Xu, J., Wu, L., & Chang, A. C. (2009). Degradation and adsorption of selected pharmaceuticals and personal care products (PPCPs) in agricultural soils. *Chemosphere, 77*(10), 1299–1305.

Yang, X., Flowers, R. C., Weinberg, H. S., & Singer, P. C. (2011). Occurrence and removal of pharmaceuticals and personal

care products (PPCPs) in an advanced wastewater reclamation plant. *Water Research, 45*(16), 5218–5228.

Zhang, Z., Ren, N., Li, Y. F., Kunisue, T., Gao, D., & Kannan, K. (2011). Determination of benzotriazole and benzophenone UV filters in sediment and sewage sludge. *Environmental Science & Technology, 45*(9), 3909–3916.

Zhao, J. L., Ying, G. G., Liu, Y. S., Chen, F., Yang, J. F., & Wang, L. (2010). Occurrence and risks of triclosan and triclocarban in the Pearl River system, South China: from source to the receiving environment. *Journal of Hazardous Materials, 179*(1), 215–222.

Zuccato, E., Castiglioni, S., Bagnati, R., Melis, M., & Fanelli, R. (2010). Source, occurrence and fate of antibiotics in the Italian aquatic environment. *Journal of Hazardous Materials, 179*(1), 1042–1048.