Water Environment Federation
the water quality people™

Emerging pollutants in water environment: Occurrence, monitoring, fate, and risk assessment

Yankui Tang,[1] **Maozhong Yin,**[1] **Weiwei Yang,**[1,2] **Huilan Li,**[1] **Yaxuan Zhong,**[1] **Lihong Mo,**[1]
Yan Liang,[1] **Xiangmeng Ma,**[1] **Xiang Sun**[1]

[1]School of Resources, Environment and Materials, Guangxi University, Nanning, China

[2]College of Civil Engineering and Architecture, Guangxi University, Nanning, China

Received 31 May 2019; Accepted 12 June 2019

The Natural Science Foundation of China, Grant/Award Number: 15XKS018 and 51668006

Correspondence to: Yankui Tang, School of Resources, Environment and Materials, Guangxi University, Nanning, China.
Email: cindyyktang@gxu.edu.cn

DOI: 10.1002/wer.1163

Abstract

The occurrence of emerging pollutants (EPs) is continuously reported worldwide. Nevertheless, only few of these compounds are toxicologically evaluated due to their vast numbers. Reliable analytical methods and toxicity assessment methods are the basis of either the management or the elimination of EPs. In this paper, literature published in 2018 on EPs were reviewed with special regard to their occurrence, detection methods, fate in the environment, and ecological toxicity assessment. Particular focus was placed on practical considerations, novel processes, and new solution strategies. © 2019 Water Environment Federation

Practitioner points

- Literature published in 2018 on emerging pollutants were reviewed.
- This review article is with special regard to the occurrence, detection methods, fate and toxicity assessment of emerging pollutants.
- Particular focus was placed on practical considerations, novel processes and new solution strategies.

Key words

ecological risk; emerging pollutants; fate; occurrence

OVERVIEW

EMERGING pollutants (EPs), also known as contaminants of emerging concern (CECs), are the substances that are released in the environment for which no regulations are currently established. They are mainly organic compounds present as pharmaceuticals and personal care products, hormones, food additives, pesticides, plasticizers, wood preservatives, laundry detergents, disinfectants, surfactants, flame retardants, and other organic compounds in water generated mainly by human activities.

Since the time when EPs attracted wide attention, many attempts have been made to shed light on the concern of EPs release into environment and further promote policymakers to take related measures to prevent the ecological risks. In 2018, several review papers provided meaningful overview of the research progress in this field.

Sanganyado, Rajput, and Liu (2018) presented a review on the bioaccumulation of legacy pollutants and EPs in Indo-Pacific humpback dolphins (*Sousa chinensis*), which inhabit shallow coastal waters often impacted by anthropogenic activities. Philip, Aravind, and Aravindakumar (2018) explored the stepwise progress of Indian research on EPs. Qi et al. (2018) comprehensively reviewed the contamination of EPs in landfill leachate in China. Starling, Amorim, and Leão (2019) gathered the studies performed in Brazil with regard to the occurrence, control, and fate of EPs in environmental compartments and compared published data with obtained data in developed and developing countries. Gong, Li, Wu, Wang, and Sun (2018) provided an overview of the application of typical passive samplers for monitoring polar organic pollutants. Gogoi et al. (2018) reviewed various treatment techniques with their removal efficacy pertaining to EPs and pointed out that future research perspective should focus on the development of risk-based screening models and framework. In view of the fact that microplastics are also classified as EPs, the interaction between microplastics and pollutants was reviewed by Barboza, Dick Vethaak, Lavorante, Lundebye, and Guilhermino (2018) who summarized that marine microplastic debris may compromise human food safety and health. In view of the fact that conventional sewage treatment processes are not capable of treating EPs at very low concentrations. Taheran, Naghdi, Brar, Verma, and Surampalli (2018) presented a review suggested the secondary treatment be integrated with an advanced treatment scheme to polish the effluent and hence remove EPs.

In this paper, literature published in 2018 on EPs were reviewed with special regards to their occurrence, detection methods, fate in the environment, and ecological toxicity assessment. Particular focus was placed on practical considerations, novel strategies, and new solution processes.

Occurrence

Rivers

In 2018, there were many studies continuously reported EPs being detected in rivers around the world. In the Yangtze River Delta area (China), 44 analytes were ubiquitous at all 28 sampling sites and most of them were industrial chemicals including 1H-benzotriazole and organophosphate flame retardants (PFRs; Peng et al., 2018). In total, 22 out of the 235 EPs monitored were present at all 55 sampling sites in the Danube River and 125 were found in at least 50% (Ginebreda, Sabater-Liesa, Rico, Focks, & Barceló, 2018). Seven pharmaceuticals for human use, three steroid hormones, and one personal care product were determined in surface water, suspended particulate matter, and sediment of Piraí Creek and Jundiaí River, Brazil (de Sousa, Mozeto, Carneiro, & Fadini, 2018). Efavirenz, nevirapine, and carbamazepine were detected in all water samples taken from Hartbeespoort Dam catchment in South Africa (Rimayi, Odusanya, Weiss, Boer, & Chimuka, 2018). A comprehensive study revealed that sterols were quantified with high frequency in nearly 100% of investigated samples in the river sediments in Vojvodina Province, Serbia, and the rivers were moderately contaminated mainly by domestic wastewater (Škrbić, Kadokami, Antić, & Jovanović, 2018). EPs in urban waters in Ukraine were found exceeding EU standards and the highest loading from Ukrainian cities into EU rivers can be over 0.7 t/ac for diclofenac and 0.4 t/ac for nonylphenols (Vystavna et al., 2018).

Estuary areas

Estuary areas, which have always been developed as economic zones, are heavily urbanized and industrialized. Anthropogenically generated organic pollutants are easily adsorbed on the surface of particulate matter in water and these suspended solids carried by river streams are subjected to settling out in estuaries due to the decreased flow rate. In three estuaries of the Basque Country, Spain, anti-inflammatory drugs (diclofenac and acetaminophen), hypertensive drugs (irbesartan and valsartan), a stimulant (caffeine), an artificial sweetener (acesulfame) and a corrosion inhibitor (2-hydroxybenzothiazole) were the most ubiquitous compounds (Mijangos, Ziarrusta, Olivares, et al., 2018; Mijangos, Ziarrusta, Ros, et al., 2018). Multiclass EPs occurred in tropical coastal sediments of anthropogenically impacted Klang River estuary, Malaysia, where amoxicillin, bisphenol A, diazinon, progesterone, and estrone (E1), were detected in all sampling sites studied, and other compounds (primidone, diclofenac, testosterone, 17β-estradiol (E2), and 17α-ethynyl estradiol (EE2) were ubiquitously present in sediment samples, with percentage of detection range from 89.04% to 98.38% (Omar, Aris, Yusoff, & Mustafa, 2018). Among the studied EDCs (endocrine disrupting chemicals), nonylphenol was the most ubiquitous compound in marine sediments from the vicinities of submarine sewage outfalls (SSOs) along the São Paulo State Coast (Brazil) and the diversity of EDCs increased with an increase in populations serviced by SSOs (Santos, Buruaem, et al., 2018).

Source water and drinking water

Emerging pollutants have been proven to enter human daily life, notably the drinking water. A total of 65 emerging trace organic pollutants were detected in Shanghai's source water, China (Sun, Luo, et al., 2018; Sun, Chen, Lin, & An, 2018). A total of 33 pharmaceuticals and their metabolites were detected in the surface waters of the Yangtze River and the Han River, which serve as sources of drinking water for the adjacent communities. EPs were found in drinking water treatment plants in Northwestern Italy though at low concentration (Magi, Carro, Mirasole, & Benedetti, 2018).

Other environmental media

Rainwater. Notably, over 700 organic compounds belonging to the various classes of chemicals were detected in the rainwater sampled in Moscow, and among them, pyridines, organophosphates, and dichloronitromethane may be considered as EPs (Polyakova, Artaev, & Lebedev, 2018).

Groundwaters. The occurrence of EPs was widely detected in the groundwaters and wastewaters in Poland, and it was found that EPs in surface water mainly came from drainage of sewage treatment plants, which only partly remove EPs, while the EPs in groundwater mainly came from the infiltration of landfill leachate (Kapelewska et al., 2018). Artificial sweeteners were widely detected at high levels in groundwater and surface water of Dongjiang River basin in south China (Yang et al., 2018).

Screening and Detection Methods

Frequent discovery of EPs has aroused serious concern about their potential environmental risks. However, because EPs exist at trace levels in the environment, difficulties in water sample enrichment, interference of environmental matrix effect, and complex analysis process are still obstacles to further study of EPs.

In 2018, many studies were still attempting to develop sensitive methodologies and techniques for suspect screening, sampling, preconcentration, and detection of EPs.

Screening

Suspect screening is an effective approach for identifying unknown compounds based on specific compound information derived from different sources including research literatures and online databases. Asghar, Zhu, Sun, Peng, and Shuai (2018) developed a systematic method via solid phase extraction (SPE) followed by liquid chromatography–high-resolution mass spectrometry (LC-HRMS) for suspect screening and target quantification of the human pharmaceutical residues in surface water. Hermes, Jewell, Wick, and Ternes (2018) developed a direct injection and multiresidue analytical method separated in two chromatographic runs by utilizing scheduled analysis to simultaneously quantify 154 compounds, 84 precursors, and 70 transformation products or metabolites.

Sampling and preconcentration

Passive sampling coupled with liquid chromatography–tandem mass spectrometry has been profitably employed to detect EPs in waters at very low concentration levels. Although polar organic chemical integrative samplers (POCIS) used in passive sampling can be purchased commercially to use, but the storage lifetime of a sampler should be taken into account. Magi et al. (2018) reported that the sampling rates obtained for commercial POCIS samplers, which had been stored for over nine years, were excessively low, showing a possible alteration of the sorption capacity of the samplers.

Gabbana, Oliveira, Paveglio, and Trindade (2018) developed a new cell configuration for in situ extraction and preconcentration (based on liquid–liquid microextraction) and further electroanalysis for EPs determination in water at trace-level.

Abujaber et al. (2018) proposed magnetic cellulose nanoparticles (MCNPs) coated with 1-butyl-3- methylimidazolium hexafluorophosphate [C4MIM][PF6] ionic liquid (IL) through electrostatic interactions for the first time as sorbents in a magnetic solid phase extraction (MSPE) method for the determination of EPs (ibuprofen, paracetamol, naproxen, and diclofenac) in natural waters. The extraction recoveries ranged from 85% to 116%, indicating that the method is simple, rapid, and environmentally friendly.

Mijangos, Ziarrusta, Olivares, et al. (2018), Mijangos, Ziarrusta, Ros, et al. (2018) developed a new procedure using polyethersulfone (PES) microextraction followed by liquid chromatography–tandem mass spectrometry (LC–MS/MS) analysis for the simultaneous determination of 41 multiclass priority and EPs in seawater, WWTP effluents, and estuary samples. In contrast to the SPE protocol, the PES method allowed a cost-efficient extraction of complex aqueous samples with lower matrix effect from 120 ml of water sample.

Rocío-Bautista et al. (2018) synthesized the CIM-80 material (aluminum(III)-mesaconate) in high yield through a novel green procedure involving water and urea as co-reactants. The CIM-80 material was tested in a microextraction methodology for the monitoring of up to 22 water pollutants while presenting little environmental impact and the average extraction efficiency can reach values up to 70% for two EPs (triclosan and carbamazepine).

Improvement and optimization of SPE

Solid phase extraction, followed by liquid chromatography or gas chromatography coupled mass spectrometry, is still considered as a relatively fast, accurate, and reliable method for the analysis of a large number of EPs. The optimization of solid phase extraction method and the improvement of adsorbent are the focus of current studies. Miniaturization of SPE systems, maintaining the quality in the extraction and preconcentration while reducing the use of organic solvents are especially current tendency. Development of new extraction systems that can be fitted to in situ continual monitoring buoys is also needed. A first model of a low-pressure micro-SPE (m-SPE) was developed for in situ EPs monitoring, which reduces the volumes of sample and solvents required in the laboratory in comparison with conventional SPE. This low-pressure m-SPE technique is expected to be applied in robotic or automated systems in marine gliders and marine oceanographic buoys (Abaroa-Pérez, Sánchez-Almeida, Hernández-Brito, & Vega-Moreno, 2018).

Osorio, Schriks, Vughs, Voogt, and Kolkman (2018) developed a novel sample preparation procedure relying on SPE by preparing a cartridge (an 6 ml empty glass column) filled with 350 mg of a mixture of Strata X-AW, Strata X-CW, and Isolute ENV+ in a ratio of 1/1/1.5 (X-AW/X-CW/ENV+) at the bottom and 200 mg Oasis HLB on top and found this optimized mixed-bed method displayed more efficient for the recovery of the wide scope of studied chemicals.

Jadhav, Nisticò, Magnacca, and Scalarone (2018) reported the synthesis, characterization, and testing of hybrid SPE cartridges based on poly (N-isopropylacrylamide)-grafted silica nanoparticles and their work constitutes an important step toward the development of hybrid thermoresponsive SPE beds casted into portable devices.

Česen et al. (2018) compared Oasis HLB and Oasis Prime cartridges for SPE and found that recovery of 8 EPs in surface water and 13 EPs in wastewater was higher (≥40%) with Prime than HLB cartridges. The advantage of Prime cartridge is that it omits conditioning step and subsequently reduces sample preparation time and solvent consumption, although both cartridges contain the same sorbent (N-vinylpyrrolidone and divinylbenzene copolymer). This advantage makes extraction with Prime much "greener."

Emerging methods

Atmospheric pressure chemical ionization (APCI) and atmospheric pressure photoionization (APPI) analyses have been introduced to use more selective ionization to reduce interferences from matrix, increase selectivity, and subsequently enhance the ratio of signal to noise for target compounds in matrix-rich aqueous samples (Mirabelli & Zenobi, 2018; Yuan, Benskin, Chen, & Bergman, 2018). A reliable analytical method to measure progestogens in surface water and wastewater was developed using SPE followed with LC-APCI/APPI-HRPS (liquid chromatography–tandem atmospheric pressure chemical ionization/atmospheric pressure photoionization with/atmospheric pressure photoionization with a hybrid quadrupole/orbital trap system operated in high resolution product scan mode) and in which, whole water samples can be used in the SPE system and sample filtration as well as extraction can be conducted in one step (Golovko, Šauer, Fedorova, Kroupová, & Grabic, 2018).

The significant environmental persistence and bioaccumulation potential of some EPs have spawned an ongoing effort to introduce replacement compounds which pose less toxicological risk. However, many of these emerging chemical species lack validated quantitative methods and appropriate analytical standards for accurate monitoring and identification. To fill this knowledge gap, McCord, Newton, and Strynar (2018) attempted to validate a general method for the quantitative determination of perfluoroether carboxylic acids (PFECAs) by LC–MS/MS on spike-recovery samples in surface, drinking, and wastewater for a variety of perfluorinated ether standards and found that the relative error measurements for spike-recovery samples in each matrix and the coefficient of variation (CV) for each compound are within acceptable range, proving the reliability of the method.

At present, how to enhance identification rates of EPs for policymakers or taking control measures in time is one of the major concerned issues for researchers. Gago-Ferrero, Krettek, Fischer, Wiberg, and Ahrens (2018) used advanced liquid chromatography (LC)–HRMS-based suspect screening strategies to search for the selected compounds in 24 hr composite samples from the effluent of three major WWTPs in Sweden and demonstrated that regulatory databases combined with the latest advances in high-resolution mass spectrometry (HRMS) can be efficiently used to prioritize and identify new, potentially hazardous pollutants being discharged into the aquatic environment.

QuEChERS (an acronym for Quick, Easy, Cheap, Effective, Rugged, and Safe) is a commonly used technique employed in most multiresidue pesticide test laboratories. Miossec, Lanceleur, and Monperrus (2018) found that QuEChERS method can be adapted and validated by gas chromatography–mass spectrometry (GC-MS) to simultaneously determine priority and EPs in sediments. The sample preparation was adapted by modifying the nature of the extraction solvent and optimizing clean-up and evaporation steps. The method shows good linearity and repeatability.

Buckypaper (BP) is a strong and lightweight substance manufactured from compressed carbon nanotubes. Tomai et al. (2018) reported, for the first time, the use of oxidized BP as a sorbent membrane of a stir-disc SPE module. The original device consisted of a BP disc ($d = 34$ mm) enveloped in a polypropylene mesh pouch. It was designed to extract organic micropollutants from water samples in dynamic mode and HPLC-MS/MS was then used to analyze the extracts. They found that hydrophilic compounds with $\log P < 1$ showed poor affinity for the oxidized BP, compounds having $\log P > 1$ exhibited recoveries ranging between 50% and 100% depending on their pKa, while compounds with pKa between 6 and 7.5 gave low yields irrespective of their logP.

For those steroidal estrogens, which were included in the “watch-list” of the Water Framework Directive (WFD), their extremely low concentrations in water require much sensitive chemical detection methods. Efforts aiming to identify reliable effect-based methods (EBMs) for screening of endocrine disrupting compounds (EDCs), to harmonize monitoring and data interpretation methods have been made by researchers. Könemann et al. (2018) analyzed estrone, 17β-estradiol and 17α-ethinyl estradiol using chemical analyses and EBMs and the results show that 17β-estradiol equivalents are highly correlated among EBMs, indicating that in vitro EBMs integrate effects of mixtures of chemical compounds with the same mode of action and the researchers highly recommended implementation of EBMs in the water framework directive. A complementary chemical analysis and in vitro bioassay approach was successfully applied to evaluate endocrine activity in drinking water, surface water and treated wastewater sampled from Germany, Australia, France, South Africa, the Netherlands and Spain (Leusch et al., 2018).

Houtman, Broek, and Brouwer (2018) applied in vitro reporter gene bioassays and a UPLC-tQ-MS target analysis method for measuring 25 steroid hormones used in high volumes in pharmacy and demonstrated that it was possible to link observed activities to compounds measured in the same samples by using an integrated approach of bioassays (a panel of CALUX bioassays) and chemical analysis. All five types of activities tested were observed in the WWTP samples.

Monitoring networks (MNs) of a river largely relies on discrete spatial and temporal observations carried out at certain sites located throughout the catchment. The distribution of sampling sites, the dynamics of the variable considered and the river hydrological conditions might constrain the function of MNs. In Ginebreda’s study, all three aspects mentioned above were captured and quantified by applying a spatial autocorrelation modeling approach and the results show that spatial autocorrelation modeling approach can be introduced to aid water managers to improve the design of river MNs (Ginebreda et al., 2018).

TRANSPORT, TRANSFORMATION AND BIOACCUMULATION

For a long time, studies have focused on the occurrence and detection of EPs in environmental media. However, EPs can migrate to water bodies through various direct and indirect routes from point to nonpoint sources and can be bioaccumulated through food webs, causing health risks to wildlife and humans. Therefore, their fates and bioaccumulation have been the focus of many studies.

Nagy-Kovács et al. (2018) studied the effects of banks filtration on EPs and found that the removal for different pollutants was significant differences by the banks filtration in Danube River and the concentration range in bank filtrate was much lower compared to river water, revealing the equilibration effect of bank filtration for water quality.

Trček, Žigon, Zidar, and Auersperger (2018) provided the first evidence for relevant benzotriazoles (BTs) degradation products (BTTPs) in urban aquifers that may impact the groundwater quality. They found that sediments with a lower hydraulic conductivity give rise to perched aquifer conditions that lead to the temporal storage of leaking effluents and they presumed that methylation and tautomerization play important roles in the transformation of BTs. The leakage of wastewater pipelines is most probably the source of BTs and more stable BTTPs enter the saturated zone of the aquifer, bringing a contamination risk for groundwater that is or may be used as a source for drinking water.

Dsikowitzky et al. (2018) revealed based on a mass flux approach assessment that the Ciliwung River (the largest city bound river of Jakarta) annually transports around 5–17 tons of the quantified pollutants (including EPs) into the Java Sea.

Plastic polymers act as passive samplers in air system and concentrate hydrophobic organic contaminants by sorption or specific interactions, which can be transported to other systems such as the marine environment. Recently, more and more attention has been paid to littoral plastics debris, which can actually be regarded as passive samplers. EPs are taken up through adsorbing or interacting with microplastics and then brought from littoral into the ocean, thus affecting the habitat of marine plankton (León et al., 2018). Studies have shown that even marine benthic biodiversity is affected by pollutants carried by microplastics (D'Alessandro et al., 2018).

Destruction marine ecosystems biodiversity can lead to a decline in marine productivity, while pollution of the ocean poses a risk to the safety of harvested seafood, which are nowadays a global concern.

Emerging pollutants in wildlife were continuously reported in 2018. For example, multiple classes of pharmaceutical, pesticides, and phosphorus-based flame retardants occurred at low μg/kg levels in marine bivalves collected adjacent to point source municipal wastewater and landfill leachate effluent discharges in Hong Kong (Burket, Sapozhnikova, Zheng, Chung, & Brooks, 2018). Sea urchins are a highly prized worldwide delicacy. However, (Rocha et al., 2018) reported for the first time the contamination levels of a large set of 99 emerging and persistent organic contaminants in roe/gonads of sea urchin *Paracentrotus lividus*, though the contents of pollutants indicate that sea urchins collected in South West Atlantic coast are safe for human consumption. Sposito et al. (2018) analyzed changes in the expression of zebrafish target genes exposed to the mixtures of most frequently detected EPs (caffeine, imidacloprid, 2-hydroxy atrazine, tebuthiuron, atrazine, and bisphenol A) at three different levels and found all the mixtures induced the expression of cyp19a1b (a marker for (xeno-) estrogen exposure). Though the studied rivers show no indication of any harmful effects on the zebrafish due to low PE levels, the researchers pointed out that the frequent and intensive agricultural activities in the vicinity can aggravate contamination, lead to unsuspected peaks of EP pollution, and subsequent negatively affect habitat of living organisms. Sun, Luo, et al. (2018), Sun, Chen, et al. (2018) measured the legacy and emerging organohalogenated contaminants (OHCs) in edible wild aquatic organisms sampled from the Pearl River and Dongjiang River in a representative industrial and urban region in China. They observed high concentrations of target contaminants. Although agrochemical inputs remained an important source of OHCs so far in industrialized and urbanized watershed in China and no health risk was related to the daily intake of the existing individual contaminant, but Sun et al. suggested vigilance be needed for recent inputs of pollutants originated from e-waste recycling activities.

Emerging pollutants are also frequently detected in cultured aquatic products. Pesticides were found present in the fish samples from Northeast China. Among them, atrazine and linuron were far above those of other pesticides in fish samples from Liaoning province and Inner Mongolia, respectively. The findings provide a warning that the potential risk of consuming aquatic products should be paid more attention (Fu, Lu, Tan, Wang, & Chen, 2018).

The emergence of various EPs in organisms means that they may bring about ecological risks and subsequently affect human health through the food webs. There are few reports on the transformation mechanisms and EP metabolites in organisms. More discoveries are expected in these areas in the future.

Risk Assessment

Although EPs frequently occur in various environmental media in the world, the knowledge of their behaviors and hazard/ecological risks is extremely insufficient. Acknowledging the complexity and diverse classes of EPs, it is necessary to develop reliable methods for risk assessment of these contaminants.

Risk quotient and hazard quotient methods

Both risk quotient (RQ) and hazard quotient (HQ) are frequently used to describe the risk category of a chemical substance. RQ is the ratio of a point estimate of exposure and a point estimate of effects, which is primarily used by US EPA to assess the ecological risk of pesticides. HQ is the quotient of a measured or estimated environmental concentration (MEC) and an effect concentration (EC).

An environmental risk assessment was conducted based on a deterministic approach by using the RQ method, and the results suggested a high-risk potential in some of the investigated submarine sewage outfalls (SSOs). The ecotoxicological data of the target compounds in waterborne exposures were obtained from previous studies and also from the ECOTOX database of USEPA. The predicted environmental risk assessment suggested a high-risk potential in some of the investigated SSOs (Santos, Buruaem, et al., 2018). In the Slovene aqueous environment, two UV filters (oxybenzone and dioxybenzone), estrone and triclosan, were assessed with RQ methods and the results showed they posed a medium to high environmental risk with RQs between 0.282 (for HM-BP) and 15.5 (for E1) (Česen et al., 2018).

Peng et al. (2018) investigated the complexity and diversity of EPs in surface water in the Yangtze River Delta area and used Screening ecological risk assessment to evaluate the potential ecological risks based on HQ approach. They used the 95th percentiles of measured environmental concentrations (MEC95) (or single concentration) as the MEC values. For EC, they used the 5th percentile of the reported acute ECs (EC05) derived from the ECOTOX database (USEPA).

Emerging methods and novel considerations

With efforts of researchers, new methods and considerations are being introduced to risk assessment of EPs.

A challenge of risk assessment is how to compare divergent field data collected in concentrations expressed on a mass or lipid basis to toxicity levels expressed typically on the basis of volume or mass. Woodburn, Seston, Kim, and Powell (2018) proposed a fugacity approach as a unit conversion to obtain a common basis for comparing concentrations and successfully used this method to assess the probability risk of benthic organisms by applying different matrices (sediment and biota) in comparison to standard chronic toxicity benchmarks.

Nowadays, tests employed to risk assessment of chemicals (including EDCs) rarely address persistent effects arising from early-life exposures. Desirable testing demands fast, mechanism-based approaches, considering the 3R principle (replacement, reduction, and refinement of animal-based tests). NR (nuclear receptor) assays have been a key instrument for testing and assessment of EDCs, but they are mostly based on vertebrate NRs. Santos, Ruivo, Capitão, Fonseca, and Castro (2018) proposed that invertebrate NRs could be replaced by invertebrate nuclear receptors and put forward that the resources are available for implementing a mechanistic-based assessment of EDCs and other EPs across metazoans.

Despite a growing scientific attention on ecological impact of individual of EPs, knowledge gaps remain regarding mixture toxicity and effects on aquatic organisms. Compared to single-compound toxicity, the joint-toxic effects can lead to synergistic or antagonistic interactions, leading to the cocktail effect (Di Poi, Costil, Bouchart, & Halm-Lemeille, 2018). Investigation on EPs should be expanding and is encouraged in finding the appropriate method for environmental risk assessment.

Disturbance of the sea floor caused by pollutants may variate the community of benthos, damaging firstly sensitive species and then the food chains, causing loss of biodiversity. D'Alessandro et al. (2018) revealed that anthracene, zinc and chromium were the most abundant chemical compounds in analyzed sediments sampled at Augusta site located in the MSFD Ionian sub-region of the central Mediterranean Sea, Italy. This finding prods us into paying more attention to the risk assessment of joint contamination of EPs and other pollutants in the future.

Effluent from WWTPs is considered to be one of the major sources, along with agricultural usages and storm runoff. Wastewater effluents increase the nutrient load of receiving water bodies and at the same time, they introduce various EPs that serious affect the local biota. Subirats et al. (2018) investigated the effect of the combined stress of nutrient load and EPs on genes encoding resistance and their studies first demonstrated the contribution of nutrients on the maintenance and spread of antibiotic resistance genes in streambed biofilms under controlled conditions. They also proposed that nutrients could enhance the effect of EPs on the dissemination of antibiotic resistance.

There are many literature reporting environmental risk assessment of EPs. However, after entering the environment, these pollutants may transform into intermediates or metabolites under the interaction with the environment (such as light degradation, oxidation & reduction, and microbial decomposition). The risk analysis of these pollutants remains insufficient.

In a study in Europe, it was found that levels of UV filters HM-BP and DH-BP, estrogen E1 and triclosan in water environment pose a medium/high environmental risk and bisphenol S was quantified in surface water for the first time, while, a novel diclofenac transformation product was quantified >LOQ (limit of quantitation) in surface water and wastewater (Česen et al., 2018).

As for novel brominated flame retardants (BFRs), there is little information available about their trophodynamics in the aquatic food web and their subsequent relationships to compound metabolism. After assessed the trophodynamics of seven emerging BFRs in the aquatic food web of Lake Taihu, South China, and measured the metabolic rates of 17 species (including plankton, invertebrates, and fish), Zheng et al. (2018) revealed that ATE(2,4,6-tribromophenyl allyl ether), BTBPE (1,2-bis(2,4,6-tribromophenoxy)ethane) and TBPH (bis(2-ethylhexyl)-3,4,5,6-tetrabromo-phthalate) were resistant to metabolism in all fish microsomes. TBCT (tetrabromo-o-chlorotoluene) and PBBA (pentabromobenzyl acrylate) exhibited significant trophic magnifications in the food web and moreover, both of them showed metabolic resistance in high-trophic-level fish.

Human beings are continuously exposed to EPs through various routes. Therefore, health impact data from biomonitoring (HBM) are vital reference for policymakers to evaluate public health programs. However, there are many limitations in HBM, such as high costs, long time consuming, sampling biases, complexity of data elaboration, etc.). Urban wastewater analysis can be best described as a large-scale urine test and thus wastewater-based epidemiology (WBE) is considered as a complementary tool to overcome some of the limitations in HBM. Gracia-Lor, Rousis, Hernández, Zuccato, and Castiglioni (2018) suggested a panel of new potential WBE biomarkers for monitoring human exposure to some of the most widespread pollutants, including some EPs. Yang et al. (2018) conformed that sucralose, an artificial sweetener and sugar substitute, was a suitable indicator to qualitatively and quantitatively assess domestic wastewater contamination in surface water and groundwater.

Conclusion

Despite much progress has been made in the 2018, significant obstacles still remain restricting the fast and efficient detection for studying the behaviors and removal approaches of EPs. For risk assessment, challenges center around the extrapolation of effects of single EP found in the laboratory or effects observed in individual organism or species in the field to influences of multiple stressors on aquatic organisms in food chains. Therefore, study is needed in the future to explore how these challenges can be addressed to fill knowledge gaps.

Acknowledgments

This work was supported by the Natural Science Foundation of China (No. 51668006), and the National Social Science Foundation Western Project (No. 15XKS018).

References

Abaroa-Pérez, B., Sánchez-Almeida, G., Hernández-Brito, J. J., & Vega-Moreno, D. (2018). In situ miniaturised solid phase extraction (m-SPE) for organic pollutants in seawater samples. *Journal of Analytical Methods in Chemistry*, *2018*, 6. https://doi.org/10.1155/2018/7437031

Abujaber, F., Zougagh, M., Jodeh, S., Ríos, Á., Guzmán Bernardo, F. J., & Rodríguez Martín-Doimeadios, R. C. (2018). Magnetic cellulose nanoparticles coated with ionic liquid as a new material for the simple and fast monitoring of emerging pollutants in waters by magnetic solid phase extraction. *Microchemical Journal*, *137*, 490–495. https://doi.org/10.1016/j.microc.2017.12.007

Asghar, M. A., Zhu, Q., Sun, S., Peng, Y., & Shuai, Q. (2018). Suspect screening and target quantification of human pharmaceutical residues in the surface water of Wuhan, China, using UHPLC-Q-Orbitrap HRMS. *Science of the Total Environment*, *635*, 828–837. https://doi.org/10.1016/j.scitotenv.2018.04.179

Barboza, L. G. A., Dick Vethaak, A., Lavorante, B. R. B. O., Lundebye, A.-K., & Guilhermino, L. (2018). Marine microplastic debris: An emerging issue for food security, food safety and human health. *Marine Pollution Bulletin*, *133*, 336–348. https://doi.org/10.1016/j.marpolbul.2018.05.047

Burket, S. R., Sapozhnikova, Y., Zheng, J. S., Chung, S. S., & Brooks, B. W. (2018). At the intersection of urbanization, water, and food security: Determination of select contaminants of emerging concern in mussels and oysters from Hong Kong. *Journal of Agricultural and Food Chemistry*, *66*(20), 5009–5017. https://doi.org/10.1021/acs.jafc.7b05730

Česen, M., Heath, D., Krivec, M., Košmrlj, J., Kosjek, T., & Heath, E. (2018). Seasonal and spatial variations in the occurrence, mass loadings and removal of compounds of emerging concern in the Slovene aqueous environment and environmental risk assessment. *Environmental Pollution*, *242*, 143–154. https://doi.org/10.1016/j.envpol.2018.06.052

D'Alessandro, M., Esposito, V., Porporato, E. M. D., Berto, D., Renzi, M., Giacobbe, S., … Romeo, T. (2018). Relationships between plastic litter and chemical pollutants on benthic biodiversity. *Environmental Pollution*, *242*, 1546–1556. https://doi.org/10.1016/j.envpol.2018.08.002

de Sousa, D. N. R., Mozeto, A. A., Carneiro, R. L., & Fadini, P. S. (2018). Spatio-temporal evaluation of emerging contaminants and their partitioning along a Brazilian watershed. *Environmental Science and Pollution Research*, *25*(5), 4607–4620. https://doi.org/10.1007/s11356-017-0767-7

Di Poi, C., Costil, K., Bouchart, V., & Halm-Lemeille, M.-P. (2018). Toxicity assessment of five emerging pollutants, alone and in binary or ternary mixtures, towards three aquatic organisms. *Environmental Science and Pollution Research*, *25*(7), 6122–6134. https://doi.org/10.1007/s11356-017-9306-9

dos Santos, D. M., Buruaem, L., Gonçalves, R. M., Williams, M., Abessa, D. M. S., Kookana, R., & de Marchi, M. R. R. (2018). Multiresidue determination and predicted risk assessment of contaminants of emerging concern in marine sediments from the vicinities of submarine sewage outfalls. *Marine Pollution Bulletin*, *129*(1), 299–307. https://doi.org/10.1016/j.marpolbul.2018.02.048

Dsikowitzky, L., van der Wulp, S. A., Dwiyitno, , Ariyani, F., Hesse, K. J., Damar, A., & Schwarzbauer, J. (2018). Transport of pollution from the megacity Jakarta into the ocean: Insights from organic pollutant mass fluxes along the Ciliwung River. *Estuarine, Coastal and Shelf Science*, *215*, 219–228. https://doi.org/10.1016/j.ecss.2018.10.017

Fu, L., Lu, X., Tan, J., Wang, L., & Chen, J. (2018). Multiresidue determination and potential risks of emerging pesticides in aquatic products from Northeast China by LC–MS/MS. *Journal of Environmental Sciences*, *63*, 116–125. https://doi.org/10.1016/j.jes.2017.09.010

Gabbana, J. V., de Oliveira, L. H., Paveglio, G. C., & Trindade, M. A. G. (2018). Narrowing the interface between sample preparation and electrochemistry: Trace-level determination of emerging pollutant in water samples after in situ microextraction and electroanalysis using a new cell configuration. *Electrochimica Acta*, *275*, 67–75. https://doi.org/10.1016/j.electacta.2018.04.134

Gago-Ferrero, P., Krettek, A., Fischer, S., Wiberg, K., & Ahrens, L. (2018). Suspect screening and regulatory databases: A powerful combination to identify emerging micropollutants. *Environmental Science & Technology*, *52*(12), 6881–6894. https://doi.org/10.1021/acs.est.7b06598

Ginebreda, A., Sabater-Liesa, L., Rico, A., Focks, A., & Barceló, D. (2018). Reconciling monitoring and modeling: An appraisal of river monitoring networks based on a spatial autocorrelation approach – emerging pollutants in the Danube River as a case study. *Science of the Total Environment*, *618*, 323–335. https://doi.org/10.1016/j.scitotenv.2017.11.020

Gogoi, A., Mazumder, P., Tyagi, V. K., Tushara Chaminda, G. G., An, A. K., & Kumar, M. (2018). Occurrence and fate of emerging contaminants in water environment: A review. *Groundwater for Sustainable Development*, *6*, 169–180. https://doi.org/10.1016/j.gsd.2017.12.009

Golovko, O., Šauer, P., Fedorova, G., Kroupová, H. K., & Grabic, R. (2018). Determination of progestogens in surface and waste water using SPE extraction and LC-APCI/APPI-HRPS. *Science of the Total Environment*, *621*, 1066–1073. https://doi.org/10.1016/j.scitotenv.2017.10.120

Gong, X., Li, K., Wu, C., Wang, L., & Sun, H. (2018). Passive sampling for monitoring polar organic pollutants in water by three typical samplers. *Trends in Environmental Analytical Chemistry*, *17*, 23–33. https://doi.org/10.1016/j.teac.2018.01.002

Gracia-Lor, E., Rousis, N. I., Hernández, F., Zuccato, E., & Castiglioni, S. (2018). Wastewater-based epidemiology as a novel biomonitoring tool to evaluate human exposure to pollutants. *Environmental Science & Technology*, *52*(18), 10224–10226. https://doi.org/10.1021/acs.est.8b01403

Hermes, N., Jewell, K. S., Wick, A., & Ternes, T. A. (2018). Quantification of more than 150 micropollutants including transformation products in aqueous samples by liquid chromatography-tandem mass spectrometry using scheduled multiple reaction monitoring. *Journal of Chromatography A*, *1531*, 64–73. https://doi.org/10.1016/j.chroma.2017.11.020

Houtman, C. J., ten Broek, R., & Brouwer, A. (2018). Steroid hormonal bioactivities, culprit natural and synthetic hormones and other emerging contaminants in waste water measured using bioassays and UPLC-tQ-MS. *Science of the Total Environment*, *630*, 1492–1501. https://doi.org/10.1016/j.scitotenv.2018.02.273

Jadhav, S. A., Nisticò, R., Magnacca, G., & Scalarone, D. (2018). Packed hybrid silica nanoparticles as sorbents with thermo-switchable surface chemistry and pore size for fast extraction of environmental pollutants. *RSC Advances*, *8*(3), 1246–1254. https://doi.org/10.1039/C7RA11869D

Kapelewska, J., Kotowska, U., Karpińska, J., Kowalczuk, D., Arciszewska, A., & Świrydo, A. (2018). Occurrence, removal, mass loading and environmental risk assessment of emerging organic contaminants in leachates, groundwaters and wastewaters. *Microchemical Journal*, *137*, 292–301. https://doi.org/10.1016/j.microc.2017.11.008

Könemann, S., Kase, R., Simon, E., Swart, K., Buchinger, S., Schlüsener, M., … Carere, M. (2018). Effect-based and chemical analytical methods to monitor estrogens under the European Water Framework Directive. *TrAC Trends in Analytical Chemistry*, *102*, 225–235. https://doi.org/10.1016/j.trac.2018.02.008

León, V. M., García, I., González, E., Samper, R., Fernández-González, V., & Muniategui-Lorenzo, S. (2018). Potential transfer of organic pollutants from littoral plastics debris to the marine environment. *Environmental Pollution*, *236*, 442–453. https://doi.org/10.1016/j.envpol.2018.01.114

Leusch, F. D. L., Neale, P. A., Arnal, C., Aneck-Hahn, N. H., Balaguer, P., Bruchet, A., … Hebert, A. (2018). Analysis of endocrine activity in drinking water, surface water and treated wastewater from six countries. *Water Research*, *139*, 10–18. https://doi.org/10.1016/j.watres.2018.03.056

Magi, E., Di Carro, M., Mirasole, C., & Benedetti, B. (2018). Combining passive sampling and tandem mass spectrometry for the determination of pharmaceuticals and other emerging pollutants in drinking water. *Microchemical Journal*, *136*, 56–60. https://doi.org/10.1016/j.microc.2016.10.029

McCord, J., Newton, S., & Strynar, M. (2018). Validation of quantitative measurements and semi-quantitative estimates of emerging perfluoroethercarboxylic acids (PFECAs) and hexfluoroprolyene oxide acids (HFPOAs). *Journal of Chromatography A*, *1551*, 52–58. https://doi.org/10.1016/j.chroma.2018.03.047

Mijangos, L., Ziarrusta, H., Olivares, M., Zuloaga, O., Möder, M., Etxebarria, N., & Prieto, A. (2018). Simultaneous determination of 41 multiclass organic pollutants in environmental waters by means of polyethersulfone microextraction followed by liquid chromatography–tandem mass spectrometry. *Analytical and Bioanalytical Chemistry*, *410*(2), 615–632. https://doi.org/10.1007/s00216-017-0763-2

Mijangos, L., Ziarrusta, H., Ros, O., Kortazar, L., Fernández, L. A., Olivares, M., … Etxebarria, N. (2018). Occurrence of emerging pollutants in estuaries of the Basque Country: Analysis of sources and distribution, and assessment of the environmental risk. *Water Research*, *147*, 152–163. https://doi.org/10.1016/j.watres.2018.09.033

Miossec, C., Lanceleur, L., & Monperrus, M. (2018). Adaptation and validation of QuEChERS method for the simultaneous analysis of priority and emerging pollutants in sediments by gas chromatography—Mass spectrometry. *International Journal of Environmental Analytical Chemistry*, *98*(8), 695–708. https://doi.org/10.1080/03067319.2018.1496245

Mirabelli, M. F., & Zenobi, R. (2018). Solid-phase microextraction coupled to capillary atmospheric pressure photoionization-mass spectrometry for direct analysis of polar and nonpolar compounds. *Analytical Chemistry*, *90*(8), 5015–5022. https://doi.org/10.1021/acs.analchem.7b04514

Nagy-Kovács, Z., László, B., Fleit, E., Czichat-Mártonné, K., Till, G., Börnick, H., … Grischek, T. (2018). Behavior of organic micropollutants during river bank filtration in Budapest, Hungary. *Water*, *10*(12), 1861. https://doi.org/10.3390/w10121861

Omar, T. F. T., Aris, A. Z., Yusoff, F. M., & Mustafa, S. (2018). Occurrence, distribution, and sources of emerging organic contaminants in tropical coastal sediments of anthropogenically impacted Klang River estuary, Malaysia. *Marine Pollution Bulletin*, *131*, 284–293. https://doi.org/10.1016/j.marpolbul.2018.04.019

Osorio, V., Schriks, M., Vughs, D., de Voogt, P., & Kolkman, A. (2018). A novel sample preparation procedure for effect-directed analysis of micro-contaminants of emerging concern in surface waters. *Talanta*, *186*, 527–537. https://doi.org/10.1016/j.talanta.2018.04.058

Peng, Y., Fang, W., Krauss, M., Brack, W., Wang, Z., Li, F., & Zhang, X. (2018). Screening hundreds of emerging organic pollutants (EOPs) in surface water from the Yangtze River Delta (YRD): Occurrence, distribution, ecological risk. *Environmental Pollution*, *241*, 484–493. https://doi.org/10.1016/j.envpol.2018.05.061

Philip, J. M., Aravind, U. K., & Aravindakumar, C. T. (2018). Emerging contaminants in Indian environmental matrices – A review. *Chemosphere*, *190*, 307–326. https://doi.org/10.1016/j.chemosphere.2017.09.120

Polyakova, O. V., Artaev, V. B., & Lebedev, A. T. (2018). Priority and emerging pollutants in the Moscow rain. *Science of the Total Environment*, *645*, 1126–1134. https://doi.org/10.1016/j.scitotenv.2018.07.215

Qi, C., Huang, J., Wang, B., Deng, S., Wang, Y., & Yu, G. (2018). Contaminants of emerging concern in landfill leachate in China: A review. *Emerging Contaminants*, *4*(1), 1–10.

Rimayi, C., Odusanya, D., Weiss, J. M., de Boer, J., & Chimuka, L. (2018). Contaminants of emerging concern in the Hartbeespoort Dam catchment and the uMngeni River estuary 2016 pollution incident, South Africa. *Science of the Total Environment*, *627*, 1008–1017. https://doi.org/10.1016/j.scitotenv.2018.01.263

Rocha, A. C., Camacho, C., Eljarrat, E., Peris, A., Aminot, Y., Readman, J. W., … Almeida, C. M. (2018). Bioaccumulation of persistent and emerging pollutants in wild sea urchin *Paracentrotus lividus*. *Environmental Research*, *161*, 354–363. https://doi.org/10.1016/j.envres.2017.11.029

Rocío-Bautista, P., Pino, V., Ayala, J. H., Ruiz-Pérez, C., Vallcorba, O., Afonso, A. M., & Pasán, J. (2018). A green metal–organic framework to monitor water contaminants. *RSC Advances*, *8*(55), 31304–31310. https://doi.org/10.1039/C8RA05862H

Sanganyado, E., Rajput, I. R., & Liu, W. (2018). Bioaccumulation of organic pollutants in Indo-Pacific humpback dolphin: A review on current knowledge and future prospects. *Environmental Pollution*, *237*, 111–125. https://doi.org/10.1016/j.envpol.2018.01.055

Santos, M. M., Ruivo, R., Capitão, A., Fonseca, E., & Castro, L. F. C. (2018). Identifying the gaps: Resources and perspectives on the use of nuclear receptor based-assays to improve hazard assessment of emerging contaminants. *Journal of Hazardous Materials*, *358*, 508–511. https://doi.org/10.1016/j.jhazmat.2018.04.076

Škrbić, B. D., Kadokami, K., Antić, I., & Jovanović, G. (2018). Micro-pollutants in sediment samples in the middle Danube region, Serbia: Occurrence and risk assessment. *Environmental Science and Pollution Research*, *25*(1), 260–273. https://doi.org/10.1007/s11356-017-0406-3

Sposito, J. C. V., Montagner, C. C., Casado, M., Navarro-Martín, L., Jut Solórzano, J. C., Piña, B., & Grisolia, A. B. (2018). Emerging contaminants in Brazilian rivers: Occurrence and effects on gene expression in zebrafish (Danio rerio) embryos. *Chemosphere*, *209*, 696–704. https://doi.org/10.1016/j.chemosphere.2018.06.046

Starling, M. C. V. M., Amorim, C. C., & Leão, M. M. D. (2019). Occurrence, control and fate of contaminants of emerging concern in environmental compartments in Brazil. *Journal of Hazardous Materials*, *372*, 17–36. https://doi.org/10.1016/j.jhazmat.2018.04.043

Subirats, J., Timoner, X., Sànchez-Melsió, A., Balcázar, J. L., Acuña, V., Sabater, S., & Borrego, C. M. (2018). Emerging contaminants and nutrients synergistically affect the spread of class 1 integron-integrase (intI1) and sul1 genes within stable streambed bacterial communities. *Water Research*, *138*, 77–85. https://doi.org/10.1016/j.watres.2018.03.025

Sun, R., Luo, X., Li, Q. X., Wang, T., Zheng, X., Peng, P., & Mai, B. (2018). Legacy and emerging organohalogenated contaminants in wild edible aquatic organisms: Implications for bioaccumulation and human exposure. *Science of the Total Environment*, *616–617*, 38–45. https://doi.org/10.1016/j.scitotenv.2017.10.296

Sun, S., Chen, Y., Lin, Y., & An, D. (2018). Occurrence, spatial distribution, and seasonal variation of emerging trace organic pollutants in source water for Shanghai, China. *Science of the Total Environment*, *639*, 1–7. https://doi.org/10.1016/j.scitotenv.2018.05.089

Taheran, M., Naghdi, M., Brar, S. K., Verma, M., & Surampalli, R. Y. (2018). Emerging contaminants: Here today, there tomorrow! *Environmental Nanotechnology, Monitoring & Management*, *10*, 122–126. https://doi.org/10.1016/j.enmm.2018.05.010

Tomai, P., Martinelli, A., Morosetti, S., Curini, R., Fanali, S., & Gentili, A. (2018). Oxidized buckypaper for stir-disc solid phase extraction: evaluation of several classes of environmental pollutants recovered from surface water samples. *Analytical Chemistry*, *90*(11), 6827–6834. https://doi.org/10.1021/acs.analchem.8b00927

Trček, B., Žigon, D., Zidar, V. K., & Auersperger, P. (2018). The fate of benzotriazole pollutants in an urban oxic intergranular aquifer. *Water Research*, *131*, 264–273. https://doi.org/10.1016/j.watres.2017.12.036

Vystavna, Y., Frkova, Z., Celle-Jeanton, H., Diadin, D., Huneau, F., Steinmann, M., … Loup, C. (2018). Priority substances and emerging pollutants in urban rivers in Ukraine: Occurrence, fluxes and loading to transboundary European Union watersheds. *Science of the Total Environment*, *637–638*, 1358–1362. https://doi.org/10.1016/j.scitotenv.2018.05.095

Woodburn, K. B., Seston, R. M., Kim, J., & Powell, D. E. (2018). Benthic invertebrate exposure and chronic toxicity risk analysis for cyclic volatile methylsiloxanes: Comparison of hazard quotient and probabilistic risk assessment approaches. *Chemosphere*, *192*, 337–347. https://doi.org/10.1016/j.chemosphere.2017.10.140

Yang, Y.-Y., Zhao, J.-L., Liu, Y.-S., Liu, W.-R., Zhang, Q.-Q., Yao, L., … Ying, G.-G. (2018). Pharmaceuticals and personal care products (PPCPs) and artificial sweeteners (ASs) in surface and ground waters and their application as indication of wastewater contamination. *Science of the Total Environment*, *616–617*, 816–823. https://doi.org/10.1016/j.scitotenv.2017.10.241

Yuan, B., Benskin, J. P., Chen, C.-E.-L., & Bergman, Å. (2018). Determination of chlorinated paraffins by bromide-anion attachment atmospheric-pressure chemical ionization mass spectrometry. *Environmental Science & Technology Letters*, *5*(6), 348–353. https://doi.org/10.1021/acs.estlett.8b00216

Zheng, G., Wan, Y., Shi, S., Zhao, H., Gao, S., Zhang, S., … Zhang, Z. (2018). Trophodynamics of emerging brominated flame retardants in the aquatic food web of Lake Taihu: Relationship with organism metabolism across trophic levels. *Environmental Science & Technology*, *52*(8), 4632–4640. https://doi.org/10.1021/acs.est.7b06588