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Review

Anthropogenic contaminants of high concern: Existence in water resources and their adverse effects

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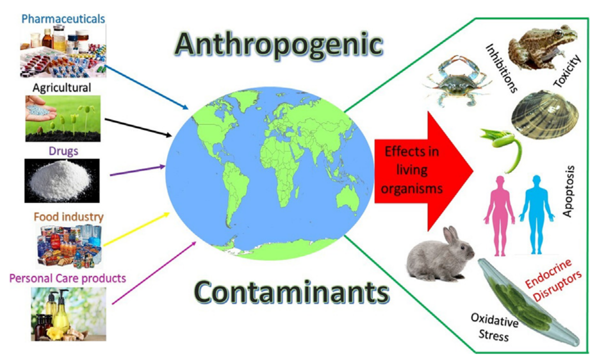
HIGHLIGHTS

- Data of global occurrence of ACs in water resources from 2017 to 2018 was mapped.
- Adverse effects of ACs on living organisms in polluted environments were analyzed.
- ACs occurrence in drinking water reservoirs and bottled water was discussed.
- Challenges and perspectives of ACs occurrence within water bodies are presented.

GRAPHICAL ABSTRACT



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ABSTRACT

Existence of anthropogenic contaminants (ACs) in different environmental matrices is a serious and unresolved concern. For instance, ACs from different sectors, such as industrial, agricultural, and pharmaceutical, are found in water bodies with considerable endocrine disruptors potency and can damage the biotic components of the environment. The continuous ACs exposure can cause cellular toxicity, apoptosis, genotoxicity, and alterations in sex ratios in human beings. Whereas, aquatic organisms show bioaccumulation, trophic chains, and biomagnification of ACs through different entry route. These problems have been found in many countries around the globe, making them a worldwide concern. ACs have been found in different environmental matrices, such as water reservoirs for human consumption, wastewater treatment plants (WWTPs), drinking water treatment plants (DWTPs), groundwaters, surface waters, rivers, and seas, which demonstrate their free movement within the environment in an uncontrolled manner. This work provides a detailed overview of ACs occurrence in water bodies along with their toxicological effect on living organisms. The literature data reported between 2017 and 2018 is compiled following inclusion-exclusion criteria, and the obtained information was mapped as per type and source of ACs. The most important ACs are pharmaceuticals (diclofenac, ibuprofen, naproxen, ofloxacin, acetaminophen, progesterone ranitidine, and testosterone), agricultural products or pesticides (atrazine, carbendazim, fipronil), narcotics and illegal drugs (amphetamines, cocaine, and benzoylecgonine), food industry derivatives (bisphenol A, and caffeine), and personal care products (triclosan, and other related

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surfactants). Considering this threatening issue, robust detection and removal strategies must be considered in the design of WWTPs and DWTPs.

Contents

1. Introduction

Anthropogenic contaminants (ACs) are substances found in the environment due to human activities (Rhind, 2009), and can effects the living organisms, directly or indirectly. Many of these contaminants have now been recognized as endocrine disruptors and can pose human-health related risks, such as hormonal imbalance, metabolism disorders, neurological disorders, immunological disorders, male/female reproductive system imbalance (Garcia-Morales et al., 2015; Barrios-Estrada et al., 2018a; Bilal et al., 2019a). Therefore, ACs containing wastewater treatment methods are of great importance due to the concentration and variety of emerging pollutants derived from

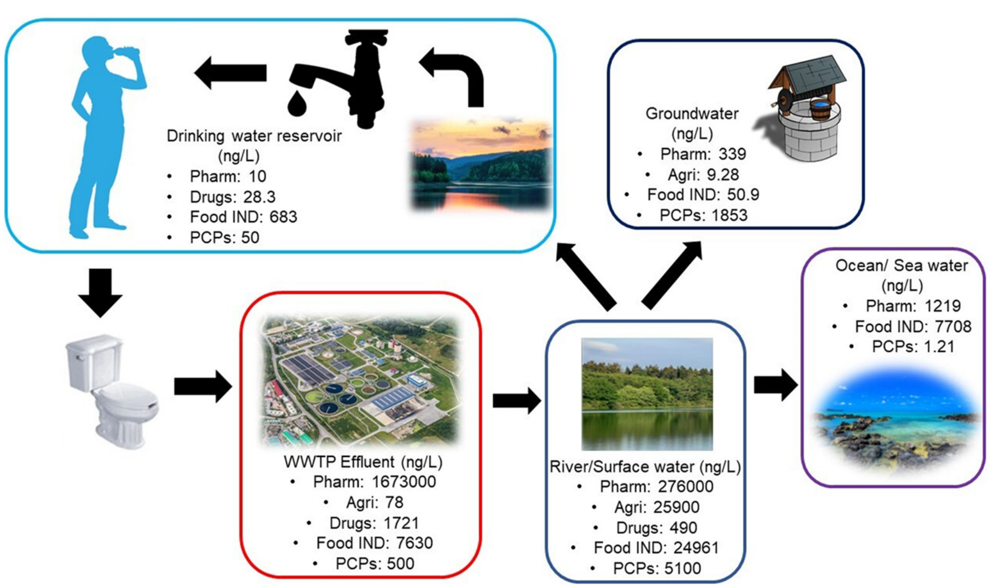

Fig. 1. Maximum concentrations of ACs found in different environmental matrices (Data source SCOPUS 2017–2018). Pharm: Pharmaceuticals, Food IND: Food Industry, Agri: Agricultural. PCPs: Personal care products.

anthropogenic processes (Rodríguez-Delgado et al., 2016; Bilal et al., 2017; Barrios-Estrada et al., 2018b; Bilal and Iqbal, 2019; Bilal et al., 2019b; Bilal et al., 2019c; López-Pacheco et al., 2019). The maximum concentrations of ACs detected in water bodies are shown in Fig. 1. Based on a data reported in Scopus from 2017 to 2018, ACs of high concern from different countries, types, and sources are summarized in Table 1. Some of these contaminants cannot be metabolized easily and thus accumulate in living organisms. From a broader perspective, such accumulation of concerning agents in living species is known as bioaccumulation. Whereas, the passage of the contaminant through various levels of a trophic chain is known as biomagnification (Blowes et al., 2003). The controlled or uncontrolled bioaccumulation and biomagnification of ACs can cause several adverse effects on living beings (Fig. 2).

There are many reports that confirm the persistence/existence of ACs in water bodies of several countries around the world. For instance, the sampling over two periods, i.e., (1) February 2014 and (2) October 2014, was performed in the Guarapiranga reserve in Brazil. In the first period, 31 ACs were detected, while in the second, around 27 ACs were recorded in the Guarapiranga reserve (López-Doval et al., 2017). From the Holtemme river in Germany, a study showed the presence of 86 micropollutants. Out of the total 86, around 50 ACs were detected in the water sample, around 47 in the sediment and 17 in the specimens of *Gammarus pulex* (Inostroza et al., 2017). Other studies also report the presence of ACs in the water reservoir, WWTPs, and vegetated draining ditch in Brazil and Mexico (Estrada-Arriaga et al., 2016; López-Doval et al., 2017; Moeder et al., 2017). The main ACs reported in different studies are pharmaceuticals (diclofenac, ibuprofen, naproxen, ofloxacin, acetaminophen, progesterone ranitidine and testosterone), agricultural products or pesticides (atrazine, carbendazim, and fipronil), narcotics and illegal drugs (amphetamines, cocaine, and benzoylecgonine), food industry derivatives (bisphenol A, caffeine), and personal care products (triclosan, and other related surfactants). However, regardless of their concerning risk, there is no single report available in the literature that discusses all of them at one place with suitable examples. Thus, herein, an effort has been made to fill this literature gap. In addition, various environmentally related matrices, such as water reservoirs, wastewater treatment plants (WWTPs), drinking water treatment plants (DWTPs), groundwaters, surface waters, rivers, and seas, in which ACs were found, are discussed with suitable examples. Following a detailed inclusion-exclusion criterion, the Scopus dataset from the year 2017–2018 was scrutinized and comprehensively summarized in Table 2. Moreover, the obtained information was also mapped using the software ArcGIS 9.3.1 (Esri, USA), as per type and source of ACs (Fig. 3).

Table 1
Range (ng/L) of ACs reported in 2017 and 2018 in Scopus. The obtained data is summarized as per source and type of ACs.

Source	Type	Range (ng/L)	# of reported countries
Drinking water	Pharmaceuticals	10.3	1
	Drugs	0.61–28.3	1
	Food industry	2.4–683	1
	Personal Care Products	1.1–50	1
WTTP effluent	Pharmaceuticals	0.103–1,673,000	9
	Agricultural	78	1
	Drugs	50–1721	3
	Food industry	2.4–7630	4
	Personal Care Products	<0.6–500	4
River/surface water	Pharmaceuticals	0.11–276,000	15
	Agricultural	1–25,900	5
	Drugs	4–490	2
	Food industry	1.7–24,961	7
	Personal Care Products	0.4–5100	8
Ocean/sea water	Pharmaceuticals	0.0038–1219	5
	Food industry	0.03–7708	3
	Personal Care Products	0.0036–1.21	1
Groundwater	Pharmaceuticals	0.33–339	2
	Agricultural	9.28	1
	Food industry	50.9	1
	Personal Care Products	3.7–1853	2

2. Contaminants from pharmaceutical products

2.1. Diclofenac

Diclofenac is a non-steroidal anti-inflammatory drug (NSAID) (Wang et al., 2010). In Europe, diclofenac has been found and reported in many water bodies. In Portugal, concentrations of 972 ng/L were found in WWTPs and rivers (Paíga et al., 2016). In Spain, diclofenac concentration ranged from 1 to 54 ng/L (Silva et al., 2011). More specifically, in the Turia River Basin (Valencia, Spain), diclofenac was found from 6.72 to 940 ng/L (Carmona et al., 2014). In Latin America (Cuernavaca, Mexico), concentrations between 258 and 1398, ng/L were detected (Rivera-Jaimes et al., 2018). In Chinese rivers, a maximum of 717 ng/L diclofenac was found (Wang et al., 2010). In Pakistan, the concentrations were found in the range of 10 to 1800 ng/L (Scheurell et al., 2009). In a WWTP in Turkey, the influent had a diclofenac concentration of 295–1376 ng/L, and the effluent had 119–1012 ng/L, resulting in removal efficiencies from 26 to 60% (Sari et al., 2014). In Malaysia, diclofenac in living organisms, from a river Estuary, was detected in fishes and mollusks samples (1.42 ng/g to 10.76 ng/g of diclofenac) (Omar et al., 2019). Regarding toxicological effects in fauna, it has been found that exposure to diclofenac (200, 2000 and 20,000 ng/L) affects liver activity, decreases lipid peroxidation and reduces the amount of secreted dopamine in the fish *Rhamdia quelen* (Guiloski et al., 2017b). In the freshwater crustaceans, *Daphnia magna,* and *Moina macrocopa*, a reduction in the reproductive rate was observed at a concentration higher than 25 mg/L (Lee et al., 2011). Diclofenac affects the cellular level in the fish *Oryzias latipes* and causes cellular toxicity, apoptosis, genotoxicity and estrogenic effects at the concentrations of 8 ng/L and 1000 ng/L (Hong et al., 2007). Diclofenac can be bio-accumulated and metabolized by animals. For instance, the mussels *Mytilus trossulus* can metabolize diclofenac into its hydroxy-derivative compounds (4-OH and 5-OH diclofenac) (Świacka et al., 2019). Furthermore, diclofenac affects amphibians, by producing morphological abnormalities, and alterations in the cardiac function and swimming performance (Peltzer et al., 2019).

2.2. Ibuprofen

Ibuprofen is an NSAID and an analgesic (Moro et al., 2014). It can be detected as a whole or in parts as metabolites, such as hydroxyibuprofen and carboxyibuprofen, in water bodies (Dvořáková Březinova et al., 2018). Ibuprofen has been reported at the concentration of 13.74 μg/L and its metabolites at the concentration of 130 μg/L, in WWTPs in Spain (Ferrando-Climent et al., 2012). In South Africa, ibuprofen was found at the concentrations of 278, 261, and 170 ng/L, in the water samples from Estuary and seawater (Primrose et al., 2019). In Cameroon, the samples from surface water and groundwater contained ibuprofen at 516 ng/L and 276 ng/L, respectively (Branchet et al., 2019). In the UK, ibuprofen was found in surface water at 6297 ng/L (Letsinger et al., 2019). Exposure to ibuprofen (1 mg/L) can cause a reduction in the growth rate of microorganisms. It can also induce morphological and structural alterations, including a reduction in chlorophyll production and an increase in the production of carotenoids (Moro et al., 2014). In *Navicula* sp. extended time exposure (10 days) to ibuprofen at the concentrations from 10 to 100 mg/L inhibits the photosynthesis rate of the diatom (T. Ding et al., 2017b). In the frog *Pelophylax ridibundus*, ibuprofen (250 ng/L) elevates oxyradicals and produces instability of the lysosomal membrane (Falfushynska et al., 2017). In zebrafish (*Danio rerio*), exposure to ibuprofen (5 to 500 μg/L) reduces the growth rate, reduces the ability to respond to external stimuli and

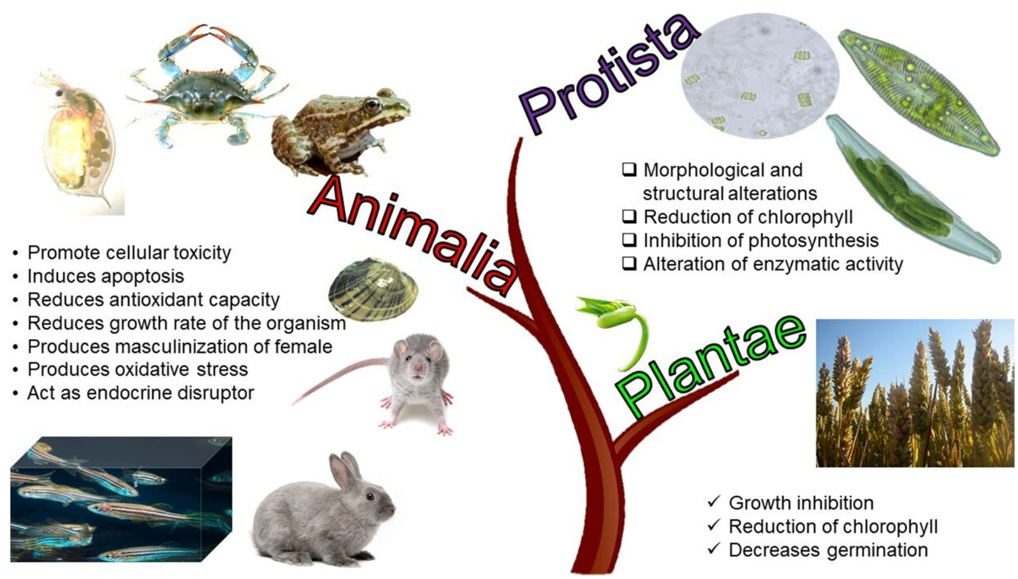

Fig. 2. Adverse effects of ACs on living organisms in a biological kingdom.

movement, and neurotoxic to the embryos (Xia et al., 2017). In zebra mussels, *Dreissena polymorpha*, ibuprofen (100 μg/L) increases the oxidation of lipids, decreases the amount of triglycerides, and antioxidant capacity (André and Gagné, 2017).

2.3. Naproxen

Naproxen is an analgesic and extensively used to treat moderate pain, fever, headache, and inflammation (Neal and Moore, 2017). While, it is considered as a toxic compound for some species, such as *Pseudokirchneriella subcapitata*, *Brachionus calyciflorus* and *Ceriodaphnia dubia*, subject to chronic exposure. The concentrations up to 31.81 mg/L, 0.56 mg/L, and 0.33 mg/L, and its photo-derivatives are considered even toxic than the original molecule in the above-mentioned species (Isidori et al., 2005). In Algiers, on the west side of Mediterranean Sea bay, naproxen has been found at the concentrations between 1220 and 9585 ng/L in wastewater, and 228.3 ng/L in the surface water (Kermia et al., 2016). In Kinmen (Taiwan), naproxen was present at the concentration of 0.3 ng/L in Taihu Lake and 104.3 ng/L in WWTP (Wei-po Lai et al., 2016). Also, it was found from 52.4 to 124.2 ng/L in surface water in Italy (Riva et al., 2019). In Pakistan, 215 to 464 μg/L of this pollutant had been found in pharmaceutical industry wastewater effluents (Ashfaq et al., 2017). The crayfish *Orconectes virilis* has been used to assess the effects of naproxen on marine species. The concentrations of 0.027 μg/L, 2.30 μg/L, and 14.0 μg/L showed a negative effect on the behavior and motility of marine species (Neal and Moore, 2017). Carps exposed at different concentrations of naproxen (10, 50, 100 and 200 μg/L) in their early stages of development, showed alterations in the rate of development, morphology, histopathology, and in some cases, increase in the mortality of organisms (Sehonova et al., 2017). In some microorganisms, such as microalgae *Cymbella* sp. and *Scenedesmus quadricauda*, it has been proven that this compound at 50 and 100 μg/L causes alterations to the amount of chlorophyll, carotenoids, and enzymatic activity (T. Ding et al., 2017a). In adult zebrafishes (*Danio rerio*), naproxen (1 and 100 mg/L) causes an alteration in mRNA expression in the intestine, as well as in the expression of antioxidant genes (Stancová et al., 2015).

2.4. Ofloxacin

Ofloxacin is a quinolone antibiotic used for the treatment of bacterial infections and fertility treatments (Erhart et al., 1998). In Hong Kong, ofloxacin at the concentration of 0.7 ng/L has been found in the water samples from rivers (Deng et al., 2016). In Poyang Lake, the largest freshwater lake in China, ofloxacin has been detected below the quantification limit (H. Ding et al., 2017). Whereas, in the Huangpu River and Taihu Lake (Shanghai, China), ofloxacin is reported at the concentrations of approximately 28.5 ng/L and 33.6 ng/L, respectively (Chen and Zhou, 2014; Xu et al., 2014). Sun et al. (2015) reported the occurrences of pharmaceutically related compounds in drinking water sources of major river watersheds in China. Whereas, the persistence of ofloxacin ranged from 4.33 to 9.43 ng/L in the surface water (Cheng et al., 2014) and 497 ng/L in WWTP (Du et al., 2017). In Shanghai, ofloxacin was found at the concentration of 2936.94 ng/L being the highest in the wastewater (M. H. Wu et al., 2016). In Pakistan, ofloxacin in wastewater was detected at a concentration of 66 μg/L (Ashfaq et al., 2016). Ofloxacin was also found in the range between 12 and 197 ng/L in the northern peninsula of the Antarctic (González-Alonso et al., 2017). In a karst river system (China), ofloxacin was found at a maximum concentration of 308 ng/L (Huang et al., 2019). In aquatic ecosystems, ofloxacin at the concentrations above 10 mg/L can damage autotrophic organisms by reducing the transport of electrons from the photosystems of plant cells. Therefore, it can reduce the metabolism of plants and consequently, the rate of carbon dioxide transformation (Deng et al., 2015). In animals, the ofloxacin exposure at the concentrations of 5, 10, 20, 40, and 80 μg/mL is harmful. For example, in chondrocytes of juvenile rabbits, it causes an increase in oxidative stress, lipid peroxidation, DNA damage, and reduction of antioxidant enzymes (Li et al., 2010).

2.5. Acetaminophen

Likewise, other painkillers, Acetaminophen is an NSAID and used to control mild to moderate pain (Cao et al., 2016). In Central Europe, a study was carried out in subsurface constructed wetlands, where influent concentrations contained >10,000 ng/L of acetaminophen, while in the effluent the overall concentration was <50 ng/L (Chen et al., 2016). In 10 different sampling areas of the Mediterranean sea, it has been recorded in the range between 0.468 and 1.70 ng/L (Brumovský et al., 2017). In a river and a WWTP in China, acetaminophen was found at the concentration of 76.6 ng/L and 75.2 ng/L, respectively (He et al., 2019).

Table 2
Anthropogenic contaminants (ACs) reported in wastewater treatment plants effluent and water resources in 2017 and 2018 (SCOPUS database).

Contaminant	Location	Source	Concentration (ng/L)	Reference
Pharmaceuticals				
Acetaminophen	Antarctic Peninsula	Stream	38	(González-Alonso et al., 2017)
	Canada	WWTP	150–570	(Brown and Wong, 2018)
	China	WWTP	2.9–58.4	(Zhang et al., 2018)
		River	3.1–13.7	(He et al., 2018)
		WWTP	39.8	(Wang et al., 2018)
		Surface water	75	(Yao et al., 2018)
		River	1490	(Zha et al., 2017)
	Colombia	WWTP	25–35,100	(Botero-coy et al., 2018)
	Iran	WWTP	17–441	(Biel-maeso et al., 2018b)
	Italy	River	226	(Mandaric et al., 2017)
	Korea	Coastal area	48	(Kim et al., 2017)
	Saudi Arabia	Sea water	2363	(Ali et al., 2017)
	Spain	Sea water	41.5	(Biel-maeso et al., 2018a)
	Taiwan	Aquaculture ponds	91	(Lai et al., 2018)
Acyclovir	Great Lakes	Lake	1100	(Elliott et al., 2018)
Amantadine	China	Surface water	108.5–1785	(Peng et al., 2018)
Amitriptyline	China	River	4.8	(Wu et al., 2017)
Ampicillin	Vietnam	River	40–164	(Thai et al., 2018)
Aspirin	India	River	1340	(Mutiyar et al., 2018)
Atenolol	Brazil	Surface water	12.6–665	(Ribeiro de Sousa et al., 2018)
	France	Treatment wetlands	1260	(Nuel et al., 2018)
	Iran	WWTP	134–2110	(Biel-maeso et al., 2018b)
	Italy	River	18.1	(Mandaric et al., 2017)
	Korea	Coastal area	85.7	(Kim et al., 2017)
	Spain	Sea water	138.9	(Biel-maeso et al., 2018a)
		WWTP	211	(Afonso-Olivares et al., 2017)
	United Kingdom	River	10.1–100	(Burns et al., 2018)
	USA	Surface water	1700	(Elliott et al., 2018)
Atorvastatin	Italy	River	21.7	(Mandaric et al., 2017)
Azithromycin	China	WWTP	88–680	(Lin et al., 2018b)
	Colombia	WWTP	3020–4120	(Botero-coy et al., 2018)
	Portugal	River	32.12–35.66	(Pereira et al., 2017)
	Spain	Sea water	17.8	(Biel-maeso et al., 2018a)
		Groundwater	4.86–13.01	(Boy-roura et al., 2018)
	Vietnam	River	19–2270	(Thai et al., 2018)
Bezafibrate	China	Groundwater	0.33	(L. Ma et al., 2018)
		Landfill leachates	660	(Sui et al., 2017)
	Italy	River	10.32	(Mandaric et al., 2017)
	Spain	WWTP	260	(Afonso-Olivares et al., 2017)
Bromazepam	China	Surface water	2.58–3.72	(Xiang et al., 2018)
Carbamazepine	Bangladesh	River	8.8	(Hossain et al., 2018)
	Brazil	Surface water	12.6–659	(Ribeiro de Sousa et al., 2018)
	China	WWTP	43.4–672.5	(Zhang et al., 2018)
		WWTP	0.268–57.8	(Wang et al., 2018)
		Groundwater	0.42–1.21	(L. Ma et al., 2018)
		Surface water	69	(Yao et al., 2018)
		Surface water	12.28–83.8	(Xiang et al., 2018)
		Groundwater	18.1	(Yang et al., 2018)
		Surface water	9.78	(Yang et al., 2018)
		Landfill leachates	2120–6270	(Sui et al., 2017)
		River	13.9	(Zha et al., 2017)
		Surface water	1.38–145	(Peng et al., 2018)
	France	Seawater	1.01	(Poi et al., 2018)
		Treatment wetlands	448	(Nuel et al., 2018)
	Great Lakes	Lake	330	(Elliott et al., 2018)
	Hungary	Surface water	60–276,000	(Bókony et al., 2018)
	India	River	1346	(Mutiyar et al., 2018)
	Iran	WWTP	21–657	(Biel-maeso et al., 2018b)
	Italy	Drinking water	10.3	(Riva et al., 2018)
		River	137	(Mandaric et al., 2017)
	Korea	WWTP	1035–11,478	(Ibe et al., 2018)
		River	14–2900	(Ibe et al., 2018)
		Coastal area	4.58–38.6	(Kim et al., 2017)
	Saudi Arabia	Sea water	110	(Ali et al., 2017)
	Spain	Sea water	31.1	(Biel-maeso et al., 2018a)
		WWTP	1290	(Afonso-Olivares et al., 2017)
	United Kingdom	River	8.7–195	(Burns et al., 2018)
	USA	Surface water	330	(Elliott et al., 2018)
Cefalexin	Italy	River	17.1	(Mandaric et al., 2017)
Cefotaxim	Vietnam	River	10– 145	(Thai et al., 2018)
Cefuroxim	Vietnam	River	195–7860	(Thai et al., 2018)
Celestolide	Italy	River	74.3	(Mandaric et al., 2017)
Cimetidine	United Kingdom	River	44	(Burns et al., 2018)
Ciprofloxacin	China	WWTP	2.54–26.2	(Wang et al., 2018)

Table 2 (*continued*)

Contaminant	Location	Source	Concentration (ng/L)	Reference
	Colombia	WWTP	446–1070	(Botero-coy et al., 2018)
	Iran	WWTP	48–1450	(Biel-maeso et al., 2018b)
	Korea	Coastal area	1.25	(Kim et al., 2017)
	Spain	Sea water	211	(Biel-maeso et al., 2018a)
		WWTP	89	(Afonso-Olivares et al., 2017)
		Groundwater	30.04–298.29	(Boy-roura et al., 2018)
	Vietnam	River	75–40,900	(Thai et al., 2018)
Citalopram	China	River	5.1	(Wu et al., 2017)
	Italy		93	(Mandaric et al., 2017)
	Portugal		20.70–52.97	(Pereira et al., 2017)
	United Kingdom		71.4	(Burns et al., 2018)
Clarithromycin	Antarctic Peninsula	Glacier drain	20	(González-Alonso et al., 2017)
Clarithromycin	China	WWTP	1.2–342	(Zhang et al., 2018)
			87–160	(Lin et al., 2018b)
	Iran		7640	(Biel-maeso et al., 2018b)
	Italy	River	159	(Mandaric et al., 2017)
	Portugal		24.8–39.1	(Pereira et al., 2017)
	Vietnam		10–55,097	(Thai et al., 2018)
Climbazole	China	Groundwater	67.7	(Yang et al., 2018)
		Surface water	276	(Yang et al., 2018)
Clofibric acid	China	Groundwater	0.85	(L. Ma et al., 2018)
Clomipramine	China	River	3.2	(Wu et al., 2017)
Clotrimazole	China	Surface water	13.6	(Yang et al., 2018)
		Groundwater	3.23	(Yang et al., 2018)
Codeine	India	River	262	(Mutiyar et al., 2018)
	Italy		40.04	(Mandaric et al., 2017)
	United Kingdom		8.0–101	(Burns et al., 2018)
Coprostanol	Vietnam	River	57,800	(Chau et al., 2018)
Cyclophosphamid	China	WWTP	0.103–3.20	(Wang et al., 2018)
Danofloxacin	Spain	Groundwater	26.39–67.78	(Boy-roura et al., 2018)
Desvenlafaxine	Great Lakes	Lake	1200	(Elliott et al., 2018)
	United Kingdom	River	4.6–268	(Burns et al., 2018)
Diazepam	China	Surface water	15.26–79.33	(Xiang et al., 2018)
			2.5–104	(Peng et al., 2018)
	India	River	305	(Mutiyar et al., 2018)
Diclofenac	Antarctic Peninsula	Stream	7761	(González-Alonso et al., 2017)
		Glacier drain	77	
	Brazil	Surface water	4.8–364	(Ribeiro de Sousa et al., 2018)
	China	River	32	(Lin et al., 2018a)
		WWTP	7.9–237.7	(Zhang et al., 2018)
		River	20.2	(He et al., 2018)
		Groundwater	0.84–1.87	(L. Ma et al., 2018)
		Surface water	180	(Yao et al., 2018)
		Groundwater	6.03	(Yang et al., 2018)
		Surface water	45.3	(Yang et al., 2018)
		WWTP	13–59	(Lin et al., 2018b)
		Landfill leachates	4810–19,300	(Sui et al., 2017)
		River	374	(Zha et al., 2017)
	Czech Republic	Surface water	1070	(Marsik et al., 2017)
	France	Treatment Wetlands	7377	(Nuel et al., 2018)
	Germany	Surface water	1.2–486.5	(Fisch et al., 2017)
	Iran	WWTP	38–1020	(Biel-maeso et al., 2018b)
	Italy	River	675	(Mandaric et al., 2017)
	Mediterranean Sea	Sea water	0.02	(Brumovský et al., 2017)
	Pakistan	WWTP	836,000	(Ashfaq et al., 2017)
	Portugal	River	25.13–51.24	(Pereira et al., 2017)
	Saudi Arabia	Sea water	14,020	(Ali et al., 2017)
	Slovenia	WWTP	1.24–25.3	(Cesen et al., 2018)
		River	1.81–158	(Cesen et al., 2018)
	Spain	Sea water	31.9	(Biel-maeso et al., 2018a)
Diltiazem	Italy	River	10.5	(Mandaric et al., 2017)
Dimetridazole	China	Surface water	110	(Yao et al., 2018)
Doxycycline	China	River	32.9	(He et al., 2018)
Enrofloxacin	China	River	2.9	(He et al., 2018)
Erythromycin	China	WWTP	2.4–271.3	(Zhang et al., 2018)
		Surface water	9.2	(Yao et al., 2018)
		Groundwater	57.6	(Yang et al., 2018)
		WWTP	25–99	(Lin et al., 2018b)
	Iran	WWTP	18–359	(Biel-maeso et al., 2018b)
	Italy	River	91.9	(Mandaric et al., 2017)
	Korea	Coastal area	0.196	(Kim et al., 2017)
	Portugal	River	32.89–38.8	(Pereira et al., 2017)
	Spain	Sea water	2.3	(Biel-maeso et al., 2018a)
	China	Surface water	425	(Yang et al., 2018)
	Taiwan	Aquaculture ponds	5.5–57.4	(Lai et al., 2018)

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Table 2 (*continued*)

Contaminant	Location	Source	Concentration (ng/L)	Reference
Estazolam	China	Surface water	0.53–1.06	(Xiang et al., 2018)
Fenbendazole	Korea	Coastal area	0.487–9.69	(Kim et al., 2017)
Fenoprofen	France	Treatment Wetlands	2481	(Nuel et al., 2018)
	Spain	Sea water	7.5	(Biel-maeso et al., 2018a)
Fexofenadine	USA	Surface water	3600	(Elliott et al., 2018)
Fluconazole	China	Groundwater	75.6	(Yang et al., 2018)
		Surface water	121	(Yang et al., 2018)
Flumequine	Taiwan	Aquaculture ponds	1.8–331	(Lai et al., 2018)
Fluoxetine	China	WWTP	2.36–24.8	(Wang et al., 2018)
		River	2.3–42.9	(Wu et al., 2017)
	Iran	WWTP	4–1570	(Biel-maeso et al., 2018b)
Furosemide	Iran	WWTP	161–1990	(Biel-maeso et al., 2018b)
	Italy	River	359	(Mandaric et al., 2017)
Gabapentin	United Kingdom	River	17.4–1445	(Burns et al., 2018)
	Vietnam	WWTP	690–1700	(Nguyen et al., 2018)
Gemfibrozil	Iran	WWTP	518–3720	(Biel-maeso et al., 2018b)
	Italy	River	19.1	(Mandaric et al., 2017)
	China	Landfill leachates	2010–4480	(Sui et al., 2017)
Hydrochlorothiazide	Antarctic Peninsula	Glacier drain	19	(González-Alonso et al., 2017)
Hydrochlorothiazide	Iran	WWTP	280–4430	(Biel-maeso et al., 2018b)
	Italy	River	189.5	(Mandaric et al., 2017)
Ibuprofen	Antarctic Peninsula	Stream	974	(González-Alonso et al., 2017)
	Brazil	Surface water	6.75–373	(Ribeiro de Sousa et al., 2018)
	China	River	2.4–320	(Lin et al., 2018a)
		River	14.3	(He et al., 2018)
		WWTP	26.4–294	(Wang et al., 2018)
		Surface water	590	(Yao et al., 2018)
		WWTP	52–100	(Lin et al., 2018b)
		River	203	(Zha et al., 2017)
	Czech Republic	Surface water	3210	(Marsik et al., 2017)
	France	Treatment Wetlands	3129	(Nuel et al., 2018)
	India	River	2302	(Mutiyar et al., 2018)
	Iran	WWTP	95–751	(Biel-maeso et al., 2018b)
	Italy	River	116	(Mandaric et al., 2017)
	Mediterranean Sea	Sea water	0.063–1.08	(Brumovský et al., 2017)
	Pakistan	WWTP	1,673,000	(Ashfaq et al., 2017)
	Saudi Arabia	Sea water	509	(Ali et al., 2017)
	Spain	Sea water	1219	(Biel-maeso et al., 2018a)
		WWTP	21,700	(Afonso-Olivares et al., 2017)
	China	Groundwater	48.7	(Yang et al., 2018)
		Surface water	292	(Yang et al., 2018)
	Slovenia	WWTP	1.82–35.9	(Cesen et al., 2018)
		River	1.44–46.1	(Cesen et al., 2018)
Indomethacin	Czech Republic	Surface water	69.29	(Marsik et al., 2017)
	Italy	River	28.5	(Mandaric et al., 2017)
	Antarctic Peninsula	Glacier drain	56	(González-Alonso et al., 2017)
Irbesartan	Italy	River	149	(Mandaric et al., 2017)
Ketoprofen	Brazil	River	620	(Honjo et al., 2017)
	China	WWTP	19.7–844	(Wang et al., 2018)
	Czech Republic	Surface water	930	(Marsik et al., 2017)
	France	Seawater	1.56	(Poi et al., 2018)
		Treatment wetlands	319	(Nuel et al., 2018)
	Iran	WWTP	210–5480	(Biel-maeso et al., 2018b)
	Italy	River	193	(Mandaric et al., 2017)
	Mediterranean Sea	Sea water	0.179	(Brumovský et al., 2017)
	Spain	WWTP	1170	(Afonso-Olivares et al., 2017)
	Taiwan	Aquaculture ponds	8.3–24.7	(Lai et al., 2018)
Levamisole	Italy	River	9.44	(Mandaric et al., 2017)
Lidocaine	Great Lakes	Lake	2100	(Elliott et al., 2018)
	USA	Surface water	0.6–431	(Bradley et al., 2017)
		Surface water	2100	(Elliott et al., 2018)
	Vietnam	River	230	(Chau et al., 2018)
Lincomycin	China	River	10.1	(He et al., 2018)
		Groundwater	339	(Yang et al., 2018)
		Surface water	2840	(Yang et al., 2018)
	Korea	Coastal area	438	(Kim et al., 2017)
	Taiwan	Aquaculture ponds	2.9–226	(Lai et al., 2018)
Lorazepam	China	Surface water	3.21–8.27	(Xiang et al., 2018)
Losartan	Brazil	Seawater	0.60–8.70	(Sanzi et al., 2018)
	China	WWTP	19.7–844	(Wang et al., 2018)
	Colombia	WWTP	761–2760	(Botero-coy et al., 2018)
	France	Treatment wetlands	22,867	(Nuel et al., 2018)
	Italy	River	149	(Mandaric et al., 2017)
Mefenamic acid	China	Groundwater	1.86–3.40	(L. Ma et al., 2018)
Meprobamate	USA	Surface water	110	(Elliott et al., 2018)
Metamizole	Spain	WWTP	3810	(Afonso-Olivares et al., 2017)

Table 2 (*continued*)

Contaminant	Location	Source	Concentration (ng/L)	Reference
Metformin	Saudi Arabia	Sea water	4801	(Ali et al., 2017)
	United Kingdom	River	45.2–2595	(Burns et al., 2018)
	USA	Surface water	34,000	(Elliott et al., 2018)
	Vietnam	River	8250	(Chau et al., 2018)
Methocarbamol	USA	Surface water	590	(Elliott et al., 2018)
Metoprolol	China	WWTP	16.1–1372.8	(Zhang et al., 2018)
		WWTP	2.26–400	(Wang et al., 2018)
		Surface water	130	(Yao et al., 2018)
		Landfill leachates	5390–14,100	(Sui et al., 2017)
	France	Treatment wetlands	890	(Nuel et al., 2018)
	Italy	River	57.7	(Mandaric et al., 2017)
	USA	Surface water	410	(Elliott et al., 2018)
Metoprolol acid	China	Surface water	7.6–324	(Peng et al., 2018)
Metronidazole	China	Surface water	190	(Yao et al., 2018)
	Italy	River	171	(Mandaric et al., 2017)
Mianserin	China	Surface water	0.11–0.52	(Xiang et al., 2018)
Miconazole	China	Groundwater	2.56	(Yang et al., 2018)
N,N–diethyl–meta toluamide	China	WWTP	22.6–469	(Zhang et al., 2018)
		Groundwater	9.20–15.8	(L. Ma et al., 2018)
N–Acetyl–4–amino antipyrine	China	Surface water	25–213	(Peng et al., 2018)
Nalidixic acid	China	WWTP	4.7–199.7	(Zhang et al., 2018)
Naproxen	Antarctic Peninsula	Stream	333	(González-Alonso et al., 2017)
	Brazil	Surface water	6.67–145	(Ribeiro de Sousa et al., 2018)
		River	340	(Honjo et al., 2017)
	China	River	0.6	(He et al., 2018)
		WWTP	16.8	(Wang et al., 2018)
		Surface water	110	(Yao et al., 2018)
		River	10	(Zha et al., 2017)
		Surface water	4–125	(Peng et al., 2018)
	Colombia	WWTP	432–3160	(Botero-coy et al., 2018)
	Czech Republic	Surface water	1424	(Marsik et al., 2017)
	France	Treatment Wetlands	19,904	(Nuel et al., 2018)
	Iran	WWTP	40–1630	(Biel-maeso et al., 2018b)
	Italy	River	73.1	(Mandaric et al., 2017)
	Mediterranean Sea	Sea water	1.7	(Brumovský et al., 2017)
	Pakistan	WWTP	464,000	(Ashfaq et al., 2017)
	Slovenia	WWTP	2.62–235	(Cesen et al., 2018)
		River	2.98–221	(Cesen et al., 2018)
	Spain	Sea water	95.8	(Biel-maeso et al., 2018a)
		WWTP	872	(Afonso-Olivares et al., 2017)
Nicotine	Korea	River	59–2040	(Ibe et al., 2018)
		WWTP	345–3532	
Nordiazepam	China	Surface water	0.44–1.22	(Xiang et al., 2018)
Norfloxacin	China	WWTP	624	(Wang et al., 2018)
	Colombia	WWTP	350–606	(Botero-coy et al., 2018)
	Iran	WWTP	5–350	(Biel-maeso et al., 2018b)
	Spain	Sea water	207.5	(Biel-maeso et al., 2018a)
	Vietnam	River	45–22,319	(Thai et al., 2018)
Norverapamil	Italy	River	65.5	(Mandaric et al., 2017)
Ofloxacin	China	River	23	(Lin et al., 2018a)
		River	8	(He et al., 2018)
		WWTP	2.88–384	(Wang et al., 2018)
		Groundwater	6.83	(Yang et al., 2018)
		Surface water	43.5	(Yang et al., 2018)
		WWTP	46	(Lin et al., 2018b)
	France	Treatment wetlands	387	(Nuel et al., 2018)
	Iran	WWTP	37–1470	(Biel-maeso et al., 2018b)
	Korea	Coastal area	12.4	(Kim et al., 2017)
	Pakistan	WWTP	81,000	(Ashfaq et al., 2017)
	Spain	Sea water	34.4	(Biel-maeso et al., 2018a)
		Groundwater	18.15	(Boy-roura et al., 2018)
	Vietnam	River	23–85,190	(Thai et al., 2018)
Omeprazole	France	Treatment wetlands	4979	(Nuel et al., 2018)
Oxazepam	China	Surface water	4.95–7.96	(Xiang et al., 2018)
	France	Seawater	1.74	(Poi et al., 2018)
Oxcarbazepine	France	Treatment wetlands	13,727	(Nuel et al., 2018)
Oxytetracycline	China	Surface water	230	(Yao et al., 2018)
	China	Surface water	1880	(Yang et al., 2018)
	Taiwan	Aquaculture ponds	75	(Lai et al., 2018)
Paracetamol	China	River	16	(Lin et al., 2018a)
		Surface water	17.8	(Yang et al., 2018)
	France	Treatment wetlands	19,810	(Nuel et al., 2018)
	India	River	1565	(Mutiyar et al., 2018)
	Mediterranean Sea	Marine water	0.468–1.70	(Brumovský et al., 2017)
	Pakistan	WWTP	64,000	(Ashfaq et al., 2017)

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Table 2 (*continued*)

Contaminant	Location	Source	Concentration (ng/L)	Reference
	Portugal	River	69.15	(Pereira et al., 2017)
	United Kingdom	River	14.3–9822	(Burns et al., 2018)
Paraxanthine	Spain	WWTP	999	(Afonso-Olivares et al., 2017)
Paroxetine	China	River	2.1	(Wu et al., 2017)
Phenacetin	China	River	296	(Zha et al., 2017)
Phenazone	China	Surface water	2.12–66.40	(Peng et al., 2018)
	Italy	River	0.956	(Mandaric et al., 2017)
	Spain	Sea water	309	(Biel-maeso et al., 2018a)
Piroxicam	Italy	River	42.2	(Mandaric et al., 2017)
Pravastatin	Italy	River	40.89	(Mandaric et al., 2017)
Propranolol	Brazil	Surface water	5.46–48.1	(Ribeiro de Sousa et al., 2018)
	China	WWTP	1.9–17.2	(Zhang et al., 2018)
	Iran	WWTP	9–235	(Biel-maeso et al., 2018b)
	Italy	River	57	(Mandaric et al., 2017)
	Korea	Coastal area	11.9	(Kim et al., 2017)
	Spain	Sea water	5.9	(Biel-maeso et al., 2018a)
	United Kingdom	River	64.9	(Burns et al., 2018)
Ranitidine	Iran	WWTP	499–7500	(Biel-maeso et al., 2018b)
	United Kingdom	River	74	(Burns et al., 2018)
Roxithromycin	China	River	1.4–190	(Lin et al., 2018a)
		WWTP	1.9–269	(Zhang et al., 2018)
		Surface water	480	(Yao et al., 2018)
		WWTP	110–210	(Lin et al., 2018b)
Salicylic acid	Brazil	River	5170	(Honjo et al., 2017)
	Germany	Surface water	2.2–51	(Fisch et al., 2017)
	Iran	WWTP	23–419	(Biel-maeso et al., 2018b)
	Italy	River	47.8	(Mandaric et al., 2017)
	Spain	Sea water	977	(Biel-maeso et al., 2018a)
	Vietnam	WWTP	460–660	(Nguyen et al., 2018)
Sertraline	China	River	5	(Wu et al., 2017)
Sotalol	Italy	River	49.4	(Mandaric et al., 2017)
Sparfloxacin	Pakistan	WWTP	19,000	(Ashfaq et al., 2017)
Spiramycin	Iran	WWTP	181–2790	(Biel-maeso et al., 2018b)
Sulfadiazine	Bangladesh	River	0.58	(Hossain et al., 2018)
	China	River	0.93–68	(Lin et al., 2018a)
		WWTP	1.22–41.03	(Zhang et al., 2018)
		WWTP	1.8–57	(Lin et al., 2018b)
		Landfill leachates	540–4690	(Sui et al., 2017)
	Germany	Surface water	0.9–7.6	(Fisch et al., 2017)
Sulfaguanidine	Taiwan	Aquaculture ponds	72.6	(Lai et al., 2018)
Sulfamerazine	Germany	Surface water	0.7–1.2	(Fisch et al., 2017)
Sulfamethazine	China	WWTP	3.7–26	(Lin et al., 2018b)
	China	Landfill leachates	730–2390	(Sui et al., 2017)
Sulfamethizole	Iran	WWTP	11–480	(Biel-maeso et al., 2018b)
	Spain	Sea water	67.1	(Biel-maeso et al., 2018a)
Sulfamethoxazole	Vietnam	River	10–252,082	(Thai et al., 2018)
	Bangladesh	River	7.24	(Hossain et al., 2018)
	China	River	17.4	(He et al., 2018)
		Surface water	380	(Yao et al., 2018)
		Groundwater	25.7	(Yang et al., 2018)
		WWTP	19–43	(Lin et al., 2018b)
		Landfill leachates	2330	(Sui et al., 2017)
		River	320	(Zha et al., 2017)
		Surface water	2.14–57.88	(Peng et al., 2018)
	France	Seawater	1.6	(Poi et al., 2018)
		Treatment wetlands	5118	(Nuel et al., 2018)
	Germany	Surface water	0.6–47.5	(Fisch et al., 2017)
	USA	Lake	1400	(Elliott et al., 2018)
	Hungary	Surface water	1	(Bókony et al., 2018)
	Iran	WWTP	26–633	(Biel-maeso et al., 2018b)
	Italy	River	106.7	(Mandaric et al., 2017)
	Korea	Coastal area	2.2	(Kim et al., 2017)
	Mediterranean sea	Marine water	0.007–0.017	(Brumovský et al., 2017)
	Saudi Arabia	Sea water	62	(Ali et al., 2017)
	Spain	Sea water	99	(Biel-maeso et al., 2018a)
		WWTP	1520	(Afonso-Olivares et al., 2017)
		Groundwater	0.68–28.60	(Boy-roura et al., 2018)
	Taiwan	Aquaculture ponds	2.2–23.2	(Lai et al., 2018)
	United Kingdom	River	33	(Burns et al., 2018)
	USA	Surface water	1400	(Elliott et al., 2018)
Sulfamonomethoxine	China	River	7.4	(He et al., 2018)
	Taiwan	Aquaculture ponds	1.5–98	(Lai et al., 2018)
Sulfaquinoxaline	China	River	4	(He et al., 2018)
Sulfathiazole	Korea	Coastal area	7.01–18.6	(Kim et al., 2017)
Temazepam	China	Surface water	1.15–2.4	(Xiang et al., 2018)
Testosterone	Hungary	Surface water	10	(Bókony et al., 2018)

Table 2 (*continued*)

Contaminant	Location	Source	Concentration (ng/L)	Reference
Tetracycline	Spain	Sea water	63.3	(Biel-maeso et al., 2018a)
Traimterene	USA	Surface water	380	(Elliott et al., 2018)
Tramadol	France	Treatment wetlands	193,720	(Nuel et al., 2018)
	United Kingdom	River	21–650	(Burns et al., 2018)
	USA	Surface water	860	(Elliott et al., 2018)
Trimethoprim	Bangladesh	River	17.2	(Hossain et al., 2018)
	China	Surface water	4500	(Yao et al., 2018)
		WWTP	6.2–15	(Lin et al., 2018b)
		Landfill leachates	1550–6000	(Sui et al., 2017)
	Germany	Surface water	1.6–17.8	(Fisch et al., 2017)
	Iran	WWTP	33–788	(Biel-maeso et al., 2018b)
	Italy	River	196	(Mandaric et al., 2017)
	Korea	Coastal area	5.3	(Kim et al., 2017)
	Spain	Sea water	10.6	(Biel-maeso et al., 2018a)
		WWTP	31	(Afonso-Olivares et al., 2017)
	Taiwan	Aquaculture ponds	1.5–9.4	(Lai et al., 2018)
	Vietnam	River	16–106,587	(Thai et al., 2018)
Trimipramine	China	River	2.1	(Wu et al., 2017)
Valsartan	Italy	River	344	(Mandaric et al., 2017)
Venlafaxine	China	River	4.1	(Wu et al., 2017)
	Italy	River	197	(Mandaric et al., 2017)
	USA	Surface water	320	(Elliott et al., 2018)
Verapamil	Italy	River	20.81	(Mandaric et al., 2017)
Agricultural				
2–Hydroxyatrazine	Brazil	River	19.4–72.3	(Sposito et al., 2018)
	China	Surface water	22–2680	(Peng et al., 2018)
Acetamiprid	China	Surface water	2.2–58	(Peng et al., 2018)
Aldrin	Brazil	River	6.05	(Yamamoto et al., 2018)
Aminomethylphosphonic acid	Hungary	Surface water	2620–25,900	(Bókony et al., 2018)
Atrazine	Brazil	River	42.1	(Sposito et al., 2018)
	China	Surface water	21.28–1726	(Peng et al., 2018)
	USA	Surface water	810	(Elliott et al., 2018)
Azoxystrobin	China	Surface water	2.5–45	(Peng et al., 2018)
Carbendazim	China	Surface water	45.8	(Yang et al., 2018)
		Groundwater	9.28	(Yang et al., 2018)
		Surface water	108–1785	(Peng et al., 2018)
	Europe	WWTP	78	(Merel et al., 2018)
Dimethoate	China	Surface water	2.1–57	(Peng et al., 2018)
Diuron	Brazil	River	6.2–11.7	(Sposito et al., 2018)
	China	Surface water	1.7–107	(Peng et al., 2018)
Endosulfan	Brazil	River	6.13	(Yamamoto et al., 2018)
Fipronil	Brazil	River	29.2	(Sposito et al., 2018)
Glyphosate	Hungary	Surface water	2360–15,000	(Bókony et al., 2018)
Heptachlor	Brazil	River	1.22–3.53	(Yamamoto et al., 2018)
Hexazinone	Brazil	River	12.7	(Sposito et al., 2018)
Imidacloprid	Brazil	River	31.4	(Sposito et al., 2018)
	China	Surface water	10.9–1886	(Peng et al., 2018)
Imidacloprid urea	China	Surface water	1.1–5238	(Peng et al., 2018)
Isoproturon	China	Surface water	3–847	(Peng et al., 2018)
Malathion	Brazil	River	50.4	(Sposito et al., 2018)
Metalaxyl	China	Surface water	1–30.77	(Peng et al., 2018)
Metolachlor	USA	Surface water	1600	(Elliott et al., 2018)
	China	Surface water	9.44–316	(Peng et al., 2018)
Propiconazole	China	Surface water	1.8–810	(Peng et al., 2018)
Tebuconazole	China	Surface water	3.6–133	(Peng et al., 2018)
Tebuthiuron	Brazil	River	10.4–25	(Sposito et al., 2018)
Terbuthylazine	Hungary	Surface water	330	(Bókony et al., 2018)
Terbutryn	Hungary	Surface water	30	(Bókony et al., 2018)
	China	Surface water	5.9–1687	(Peng et al., 2018)
Thiamethoxam	China	Surface water	2.9–90.8	(Peng et al., 2018)
Drugs				
Benzoylecgonine	Italy	Drinking water	0.61	(Riva et al., 2018)
	Australia	WWTP	117	(Yadav et al., 2018)
Cocaine	Italy	Drinking water	4.44	(Riva et al., 2018)
Codeine	Australia	WWTP	1721	(Yadav et al., 2018)
	Croatia	WWTP	379	(Krizman-matasic et al., 2018)
		River	4	(Krizman-matasic et al., 2018)
	Vietnam	WWTP	50	(Nguyen et al., 2018)
Ketamine	Taiwan	Aquaculture ponds	2.8–10.8	(Lai et al., 2018)
Methadone	Croatia	WWTP	65	(Krizman-matasic et al., 2018)
	Taiwan	Aquaculture ponds	0.3–13.7	(Lai et al., 2018)
Methamphetamine	Taiwan	Aquaculture ponds	20.5–22.7	(Lai et al., 2018)
	Vietnam	WWTP	100–180	(Nguyen et al., 2018)
Morphine	Australia	WWTP	104	(Yadav et al., 2018)

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Table 2 (*continued*)

Contaminant	Location	Source	Concentration (ng/L)	Reference
	Croatia	WWTP	52	(Krizman-matasic et al., 2018)
Nicotine	Italy	Drinking water	28.3	(Riva et al., 2018)
	USA	Surface water	490	(Elliott et al., 2018)
Food industry				
Bisphenol A	Brazil	River	9.9–48.7	(Sposito et al., 2018)
	China	River	1131	(Tan et al., 2018)
		River	23–107	(Niu and Zhang, 2018)
		Surface water	26–720	(Yanhua Liu et al., 2017)
		River	12.75–62.78	(Diao et al., 2017)
		River	1.7–563	(Yan-hua Liu et al., 2017)
	Italy	Drinking water	9.72–683	(Riva et al., 2018)
	Slovenia	WWTP	20.3–118	(Cesen et al., 2018)
	Thailand	Freshwater	50.67	(Ocharoen et al., 2018)
	USA	Surface water	2700	(Elliott et al., 2018)
Caffeine	Brazil	River	20–1040	(Sposito et al., 2018)
		River	27.9–24,961	(Ribeiro de Sousa et al., 2018)
	China	Surface water	3500	(Yao et al., 2018)
		Landfill leachates	1700–349,000	(Sui et al., 2017)
		WWTP	2.42–686	(Wang et al., 2018)
		Surface water	767	(Yang et al., 2018)
		Groundwater	50.9	(Yang et al., 2018)
	Hungary	Surface water	40–90	(Bókony et al., 2018)
	India	River	2640	(Mutiyar et al., 2018)
	Italy	Drinking water	2.4–5.2	(Riva et al., 2018)
	Mediterranean Sea	Marine water	0.030–0.111	(Brumovský et al., 2017)
	Saudi Arabian	Sea water	7708	(Ali et al., 2017)
	Slovenya	WWTP	58–7630	(Cesen et al., 2018)
	Spain	WWTP	166–186	(Biel-maeso et al., 2018a)
		Coastal water	6.1–327.3	(Biel-maeso et al., 2018a)
		Oceanic water	4.3–96.6	(Biel-maeso et al., 2018a)
	Taiwan	Aquaculture ponds	1.8–276	(Lai et al., 2018)
	USA	Surface water	6600	(Elliott et al., 2018)
	Vietnam	Surface water	13,000	(Chau et al., 2018)
		WWTP	1600	(Nguyen et al., 2018)
Di(2–ethylhexyl)adipate	Vietnam	Surface water	440	(Chau et al., 2018)
Diethyl phthalate	China	River	25–310	(Niu and Zhang, 2018)
	Hungary	Surface water	30–250	(Bókony et al., 2018)
	Vietnam	Surface water	7490	(Chau et al., 2018)
Di–n–butyl phthalate	Vietnam	Surface water	4920	(Chau et al., 2018)
Triphenylphosphate	Vietnam	Surface water	140	(Chau et al., 2018)
Personal Care Products				
2–Ethylhexyl methoxycinnamate	Australia	Surface water	8.9–640	(Allinson et al., 2018)
2–Hydroxy–4–methoxybenzophenone	Australia	Surface water	4.3–7.1	(Allinson et al., 2018)
2–Phenoxyethanol	Australia	Surface water	7.6–315	(Allinson et al., 2018)
4–Methylbenzilidene camphor	Australia	Surface water	642	(Allinson et al., 2018)
	China	WWTP	0.442–57.2	(Wang et al., 2018)
	Italy	WWTP	<1.8	(Palmiotto et al., 2018)
		River	61.65	(Mandaric et al., 2017)
Benzophenone	Australia	Surface water	21.8–36.4	(Allinson et al., 2018)
Benzyl salicylate	Australia	Surface water	6	(Allinson et al., 2018)
Benzophenone-1 (BP1)	Germany	Surface water	1.3–2.8	(Fisch et al., 2017)
Benzophenone-3 (BP3)	China	WWTP	8.72	(Wang et al., 2018)
	Germany	Surface water	6.7–11.4	(Fisch et al., 2017)
	Italy	WWTP	4.1	(Palmiotto et al., 2018)
		Drinking water	1.1–5.7	(Riva et al., 2018)
		River	14.3	(Mandaric et al., 2017)
Benzophenone-4 (BP4)	Italy	WWTP	454.7	(Palmiotto et al., 2018)
Butyl paraben	China	Surface water	0.4	(Yang et al., 2018)
DEET	China	Surface water	9.9–574	(Peng et al., 2018)
		WWTP	38.8–57.2	(L. Ma et al., 2018)
		Groundwater	9.20–15.8	(L. Ma et al., 2018)
		Surface water	101	(Yang et al., 2018)
		Groundwater	53.8	(Yang et al., 2018)
	Mediterranean Sea	Marine water	0.506–1.21	(Brumovský et al., 2017)
	Saudi Arabia	Sea water	49	(Ali et al., 2017)
	USA	Surface water	5100	(Elliott et al., 2018)
	Vietnam	WWTP	300–400	(Nguyen et al., 2018)
Ethyl paraben	Australia	Surface water	245	(Allinson et al., 2018)
	China	WWTP	1.9	(W. L. Ma et al., 2018)
Galaxolide	Australia	Surface water	10.2	(Allinson et al., 2018)
HHCB	USA	Surface water	2200	(Elliott et al., 2018)
Lauryl diethanolamide	China	Surface water	6.2–646	(Peng et al., 2018)
Methyl paraben	Australia	Surface water	4–1770	(Allinson et al., 2018)
	China	River	3.2–10.3	(He et al., 2018)
		WWTP	57.6	(W. L. Ma et al., 2018)

Table 2 (*continued*)

Contaminant	Location	Source	Concentration (ng/L)	Reference
		WWTP	94.4	(Wang et al., 2018)
		Surface water	24.4	(Yang et al., 2018)
		Groundwater	14.9	(Yang et al., 2018)
	Slovenya	WWTP	14.2–52.8	(Cesen et al., 2018)
Octocrylene	Australia	Surface water	2–109	(Allinson et al., 2018)
	China	Surface water	3–258.8	(Peng et al., 2018)
	Germany	Surface water	5.3–30.8	(Fisch et al., 2017)
Octyl salycilate	Australia	Surface water	18–31.6	(Allinson et al., 2018)
Octyldimethyl PABA	Australia	Surface water	0.4	(Allinson et al., 2018)
ODPABA	Italy	River	748	(Mandaric et al., 2017)
PBSA	Germany	Surface water	1.8–836	(Fisch et al., 2017)
	Italy	WWTP	347.7	(Palmiotto et al., 2018)
		Drinking water	50	(Riva et al., 2018)
		Groundwater	3.7–1853	(Castiglioni et al., 2018)
Propyl paraben	Australia	Surface water	237	(Allinson et al., 2018)
	China	WWTP	115	(Wang et al., 2018)
		Surface water	11.9	(Yang et al., 2018)
		Groundwater	9.5	(Yang et al., 2018)
	Slovenya	WWTP	2.44–5.18	(Cesen et al., 2018)
Triclocarban	China	Surface water	180	(Yao et al., 2018)
		WWTP	4.78–500	(Wang et al., 2018)
		Surface water	71.8	(Yang et al., 2018)
		Groundwater	25.8	(Yang et al., 2018)
	India	River	2.2–1119	(Vimalkumar et al., 2018)
	Italy	WWTP	<0.6	(Palmiotto et al., 2018)
	Mediterranean Sea	Marine water	0.0036–0.0442	(Brumovský et al., 2017)
Triclosan	Brazil	River	4.54–61.3	(Ribeiro de Sousa et al., 2018)
	China	River	1.5	(He et al., 2018)
		WWTP	88.8	(Wang et al., 2018)
		Surface water	105	(Yang et al., 2018)
		Groundwater	30.9	(Yang et al., 2018)
	Italy	WWTP	329.7	(Palmiotto et al., 2018)
		Groundwater	32–85	(Castiglioni et al., 2018)
	Mediterranean Sea	Marine water	0.305	(Brumovský et al., 2017)
	Slovenia	WWTP	5.05–12.6	(Cesen et al., 2018)
Benzotriazole Ultraviolet Stabilizer-326 (UV–326)	India	River	5.7	(Vimalkumar et al., 2018)
Benzotriazole Ultraviolet Stabilizer-327 (UV–327)	India	River	9.5	(Vimalkumar et al., 2018)
Benzotriazole Ultraviolet Stabilizer-328 (UV–328)	Australia	Surface water	48.4–216	(Allinson et al., 2018)
	Italy	River	669	(Mandaric et al., 2017)
Benzotriazole Ultraviolet Stabilizer-329 (UV–329)	India	River	31.3	(Vimalkumar et al., 2018)
	Italy	River	553	(Mandaric et al., 2017)
Benzotriazole Ultraviolet Stabilizer-9 (UV–9)	India	River	28.1	(Vimalkumar et al., 2018)

The exposure to acetaminophen at the concentration of 66 mg/kg body weight (bw) has undesirable effects on living organisms, such as alterations in biochemistry and histopathology in the liver of rats (Mossa et al., 2012). It has also been demonstrated that with 5 and 15 mg/kg bw exposure to acetaminophen in the early stages of development affects the neurotransmission associated with the *medulla oblongata* (Blecharz-Klin et al., 2015a), or can directly affect the spinal cord (Blecharz-Klin et al., 2015b). Also, in rats, acetaminophen at 10 and 50 mg/kg bw causes the reduced synthesis of amino acids in brain cells (Blecharz-Klin et al., 2014). At concentrations of 5 and 15 mg/kg bw of acetaminophen damage the cerebellum of developing rats (Blecharz-Klin et al., 2016). While exposure to 66 and 100 mg/kg bw decrease in the quantity and quality of sperm (Abedi et al., 2017). In *Rhamdia quelen* exposure to acetaminophen at the concentration of 0.25 μg/L causes a reduction in the levels of hemoglobin, hematocrit, and testosterone. In addition, it also causes hepatotoxicity and disruption in the hypothalamic-pituitary-gonadal axis (Guiloski et al., 2017a). In plants like wheat (*Triticum aestivum L.*), acetaminophen causes growth inhibition at 200 mg/L, reduces the accumulation of chlorophyll and the synthesis of soluble proteins at 1.4 to 22.4 mg/L and 11.2 to 22.4 mg/L, respectively. Acetaminophen also induces the activity of peroxidase and superoxide dismutase at concentrations ranging from 1.4 to 22.4 mg/L and damages the antioxidant defensive system (An et al., 2009). In the saltwater clam *Ruditapes philippinarum*, acetaminophen at 0.05 mg/L causes elevated oxidative stress, the alteration of superoxide dismutase (SOD) and reduced/oxidized glutathione (GSH/GSSG) (Correia et al., 2016).

2.6. Progesterone

Progesterone is a steroidal hormone involved in the female reproductive process. It can regulate the activity of a reproductive system, thus used for in vitro fertilization treatments (Dante et al., 2013). Its excessive consumption ultimately finds the way to water bodies through different routes. For instance, the activated sludge from a WWTPs in China contained progesterone in the range of 0.9–237 ng/g (Q. Wu et al., 2016). In an earlier study, Liu et al. (2015) reported the presence of 0.47 ng/L of progesterone in the South China Sea. In France, progesterone ranging from a few ng/L to 199 ng/L was found in 75% of the water samples collected from the Rhône-Alpes region (Vulliet and Cren-Olive, 2011). Several studies have been conducted to determine the effects caused by steroid hormones. For example, in mosquitofish *Gambusia affinis*, exposure for 42 days to small doses of progesterone (4–410 ng/L) caused the masculinization of female fish, reduced the fertility of females, altered the transcription of genes related to reproduction, detoxification of the liver, and alterations in ovaries, liver and gills (Hou et al., 2017). In the pond snail, *Lymnaea stagnalis*, progesterone at 10 ng/L changes the quantity and quality of fertilized and viable eggs (Zrinyi et al., 2017), affecting the reproduction rates of the species.

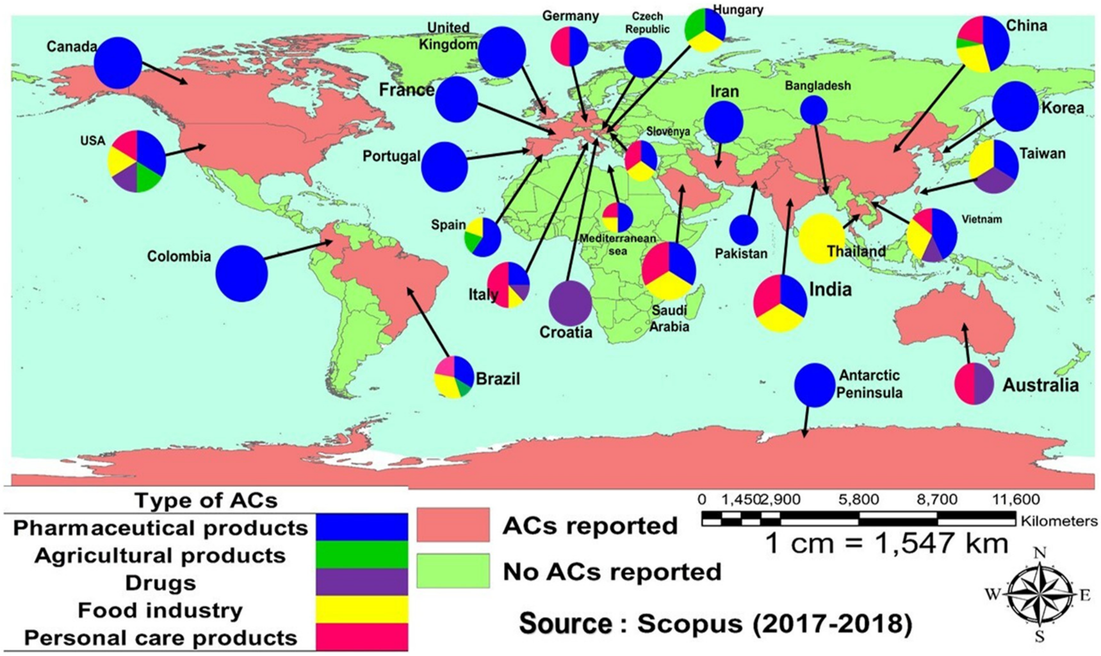

Fig. 3. Map of countries with possible existence of ACs. ACs were classified as per type. Figure was mapped using the software ArcGIS 9.3.1 (Esri, USA). (Data source SCOPUS 2017–2018).

3. Pollutants from agricultural products

3.1. Atrazine

Atrazine is an herbicide which is used to kill weeds in various crops, such as sugar cane, corn, pineapple, and sorghum, among others (Wirbisky and Freeman, 2017). Because it is soluble in water, it can reach to surface and groundwater bodies by surface runoff, underground runoff, infiltration and/or accidental spillage during improper handling (EPA, 2017a). Due to its potential to filtrate through the soil, this compound has been found in drinking water reserves at the concentrations of 0.42 ppb (Stayner et al., 2017). Exposure to 30 μg/L of atrazine had negative effects in the zebrafish (*Danio rerio*, wild-type AB strain). It can cause the loss of methylation in the DNA and lead to the loss of genome protection (Wirbisky-Hershberger et al., 2017). Exposure to 10 mg/L of atrazine can changes the number of copies of some genes, as well as alterations of gene expression (Wirbisky and Freeman, 2017). It has also been proven that exposure to atrazine (300 ng/L) increases the probability of cancer, angiogenesis, and neuronal alterations (Wirbisky et al., 2016). In the crayfish *Cherax quadricarinatus,* the exposure to 2.5 mg/L of atrazine in the juvenile stage causes an imbalance in the sexual ratios by increasing the female proportions, which affects the reproductive rates of the species (Mac Loughlin et al., 2016).

3.2. Carbendazim

Carbendazim is a broad-spectrum fungicide used for pests control in agriculture (Andrade et al., 2016). In China, the maximum dietary exposure of carbendazim (0.26 mg/person/day) through consumption of the residues existing in tomato crops has been reported (Li et al., 2016). In the water flea *Daphnia magna*, carbendazim at 5 to 50 μg/L had serious ecotoxicity repercussions. It causes genotoxicity, DNA damage, and reduces the rate of reproduction (Silva et al., 2015). In the zebrafish (*Danio rerio*), carbendazim at 20 and 100 μg/L induces apoptosis by up-regulation of the genes *p53*, *Mdm2*, *Bbc3,* and *Cas8*. It is also immunotoxic and alters the endocrine system in embryonic cells (Jiang et al., 2014). The exposure of carbendazim in a range of 4–500 μg/L produces different trends in gene expression at larval stages (Jiang et al., 2015), as well as locomotor abnormalities and other alterations in the behavior of the species at 160 ng/L (Andrade et al., 2016). The combined effects of intra- and interspecific competition for food and exposure to carbendazim (400, 800 and 1200 μg/L) were analyzed in some species (Del Arco et al., 2015). Aquatic invertebrates have a low tolerance for carbendazim. For example, in the flatworm *Dugesia lugubris*, 50% of the population died after 96 h exposure to 25 μg/L of carbendazim (Van Wijngaarden et al., 1998). At high concentrations (>33 μg/L), the organisms of the taxa *Cladocera*, *Copepod,* and *Rotatoria* suffered a reduction in their populations (Van Den Brink et al., 2000).

3.3. Fipronil

Fipronil is an insecticide used for the control of veterinary and agricultural pests (Stark and Vargas, 2005). Fipronil is leached into the environment through anthropogenic activities, such as crop spraying or the medical treatment of dogs for the control of fleas since the water used after these activities is released untreated into the environmental matrices (Teerlink et al., 2017). In the river Elbe (Germany), fipronil and two of its derivatives were found in a concentration of 0.5 to 1.6 ng/L. The same study detected fipronil in eel's muscle (4.05 ± 3.73 ng/g) and in liver tissue (19.91 ± 9.96 ng/g) (Michel et al., 2016), which demonstrates the bioaccumulation in animals. In surface water from Florida (USA), fipronil has been found at the concentrations ranging from 0.5 to 207.3 ng/L (Wu et al., 2015).

In the blue crab *Callinectes sapidus,* fipronil in a range from 10 to 500 ng/L alter the gene expression, such as decrease of Vtg (vitellogenin) and EcR (ecdysone receptor). These effects were found to be salinity-dependent (Goff et al., 2017). In the water flea *Daphnia pulex*, exposure to increasing concentrations of fipronil (0–80 μg/L) can reduce the survival in the first, second, third and fourth stages of juvenile development (Stark and Vargas, 2005). In amphibians, like *Eupemphix nattereri* tadpoles, fipronil (35–180 μg/kg in water and sediment) increase the oxidative stress and lipid peroxidation (Gripp et al., 2017). The exposure up to 15 mg/kg/day of fipronil can alter the cytochrome P450 enzymatic activity and liver damage in rats (Caballero et al., 2015). In the Japanese rice fish (medaka) *Oryzias latipes*, fipronil (0.1

to 910 μg/L) caused sub-lethal alterations in embryos, such as tail deformities and reduced hatching (Wagner et al., 2017). In the Caspian white fish (*Rutilus frisii*), fipronil (750 mg/kg bw intraperitoneal route) caused acute toxicity along with histopathological alterations to specific organs (Ardeshir et al., 2017).

4. Contaminants from narcotics and other drugs

Narcotics are used to induce human reactions like the stimulation of the central nervous system, analgesia, and narcosis (Fig. 4). The use of this kind of substances is usually regulated by governments due to their adverse human-health related effects (Argoff et al., 2009).

4.1. Amphetamines

Amphetamines are substances that stimulate the central nervous system. They are sympathomimetic type amines, and their mechanism of action involves the physiological pathways of several neurotransmitters, including dopamine, serotonin, and adrenaline. The effects in the human body of the consumption of these substances include an increase in blood pressure, increase in heart rate, the sensation of alertness, high stimulation, improvement of intellectual performance, and feelings of great amounts of energy, accompanied by the decrease in fatigue, sleep, and hunger. Amphetamines can cause dependence. The medical use of amphetamines is for the treatment of narcolepsy and attention deficit in children, at a recommended dose (Robledo, 2008). The existence of amphetamines in different environmental matrices, including WWTPs confirms their anthropogenic origin. The possible accumulation of 4.7 ng/g of amphetamine was recorded in aquatic species, specifically in freshwater mussels (*Lasmigona costata*) from the Great River in Ontario, Canada (de Solla et al., 2016). In the Puget estuary in Washington, organisms of two species, i.e., (1) Pacific staghorn sculpin (*Leptocottus armatus*) and (2) Chinook salmon (*Oncorhynchus tshawytscha*), were collected to identify the bioaccumulated substances. The study found that these species bioaccumulate 245 and 25 ng/g of amphetamine, respectively (Meador et al., 2017). Around 9.7 ng/L of amphetamine was found in the water, 3.3 ng/g in the sediment and 60 ng/g in mussels collected from 5 different places in the bay of San Francisco, California (Klosterhaus et al., 2013). This implies that following the bioaccumulation and passing through the food chain, it can be biomagnified. In the zebrafish (*Danio rerio*), amphetamine (5 and 10 mg/L) has an effect of hypermobility of the fish and increase in erratic movements such as a change in the direction of movements, as well as an increase in freezing bouts (Kyzar et al., 2013).

4.2. Cocaine

Cocaine, an illegal substance, was found in surface water and wastewater treatment plants in Belgium, which leads to the direct exposure to animals and plants (García-Cambero et al., 2015; van Nuijs et al., 2009a). Around 28 rivers and 37 WWTPs have been found contaminated with cocaine concentrations ranging from <1 to 753 ng/L. Those concentrations were used to estimate the amount of cocaine abuse by the population>. These were correlated to >1.8 g/day of cocaine for every 1000 people (van Nuijs et al., 2009a). Exposure to cocaine (0.3 μg/L) and its metabolites changes the protein profile, alter the transport of lipids and stress response in zebrafish embryos (Parolini et al., 2017a). In *Dreissena polymorpha*, cocaine (40 ng/L) causes DNA damage, reduces the stability of the lysosomal membrane, increases the number of micronucleated cells, and cellular apoptosis (Binelli et al., 2012). The consumption or exposure to cocaine (20 mg/kg bw) can modify the lipid profile, the main regulators of the neuronal structure and function, of the brain in mice (Lin et al., 2017).

4.3. Benzoylecgonine

Benzoylecgonine is the main metabolite of cocaine and an analgesic from the pharmaceutical industry (Efeoglu et al., 2013). Several studies have been reported the existence of Benzoylecgonine in different water bodies, around the globe. For example, around 10 to 1019 ng/L in the surface waters in Brazil (Campestrini and Jardim, 2017), around 37 to 2130 ng/L in 30 Belgian WWTPs (van Nuijs et al., 2009b), and

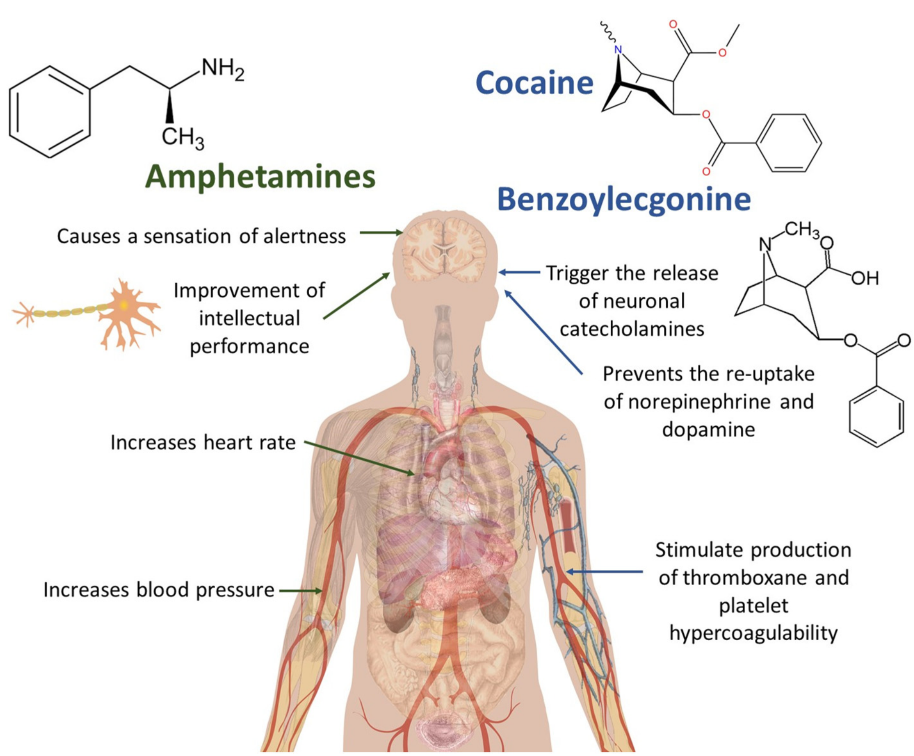

Fig. 4. Effects of amphetamines, cocaine and bencoylecgonine on the human body.

14.7 ng/L of benzoylecgonine in 3 London rivers (Wilkinson et al., 2017). In the species, *Daphnia magna*, exposure to benzoylecgonine (500 ng/L and 1000 ng/L), induces oxidative stress and inhibits acetylcholine transferase. This is related to the swimming pattern and reproductive capacity of the species (Parolini et al., 2017b). In riparian plants and irrigated crops, this contaminant at a concentration of 1 ng/L alters the mitochondrial activity along with a reduction in the germination (García-Cambero et al., 2015). Benzoylecgonine can be transmitted from pregnant rats to their fetuses through maternal blood. Benzoylecgonine was administered to animals by an intravenous bolus dose of 1 mg/kg bw, followed by an infusion at a rate of 0.2 mg/kg bw/min, showing that exposure can cause an organism to pass it on to their offspring (Morishima et al., 2001). In *Dreissena polymorpha*, it was determined that exposure to benzoylecgonine (500 and 1000 ng/L) affects the stability of the lysosomal membrane and imbalances the defense enzyme activity, which implies an increase of oxidative stress (Parolini et al., 2013).

5. Contaminants from the food industry

Caffeine is the main component of coffee, energy drinks, and some medications used for chronic diseases (Gracia-Lor et al., 2017). The caffeine found in the environment is due to anthropogenic activities (Valenzuela, 2010). In the sea water of the coast of Spain, the existence of caffeine was reported at the concentrations of 857 ng/L (Dafouz et al., 2018). A study of ten WWTPs across Europe found that the amount of caffeine discharged due to consumption by humans was between 37 and 320 mg/person/day (Gracia-Lor et al., 2017). Exposure to caffeine has repercussions on the health of living organisms. Exposure to caffeine (19.41 mg/L) at the larval stage of *Galleria mellonella* affects the behavior and development, as well as increase the abundance of peptides associated with brain trauma (Maguire et al., 2017). In mice, it was determined that exposure to caffeine at the concentration of 2 mg/100 g bw affects embryonic development by causing a minor malformation of the phalanges of the developing limbs (Lashein et al., 2016). In zebrafish, exposure to 48.54 μg/L causes cellular damage, increases apoptosis, mitochondrial damage, and morphological abnormalities in the early stages of development (Rah et al., 2017).

Bisphenol A (BPA) is a chemical used in the plastic and epoxy resin industry (Staniszewska et al., 2015; Bilal et al., 2019a). BPA is used to manufacture the food packaging material, baby toys, plastic wares, compact discs, and medical instruments. The way that humans are exposed to this pollutant is through the consumption of food that has been stored in a container with BPA (NIH, 2017). In Taihu Lake, China, the concentrations of BPA and eight analogs in surface waters ranged from 49.7 to 3480 ng/L. It has been found that BPA can accumulate through the food chain (Q. Wang et al., 2017). In India, BPA was found in surface water at the concentrations from 54 to 1950 ng/L (Yamazaki et al., 2015), whereas, in the Baltic region, it was found in a range of <5.0 to 277 ng/L in rivers and the coastal zone (Staniszewska et al., 2015). The consequences of exposure to BPA (5, 25 and 125 μg/kg bw) in rats include a significant decrease in daily weight gain, an increase in gamma globulin, induced damage in the liver, and promotion of death of liver cells (Kazemi et al., 2017). BPA, at concentrations of 8.6 mg/L in water and at 13.5 mg/L in sediment, in *Asellus aquaticus* acts as an endocrine disruptor (Plahuta et al., 2015). In rats, the exposure to BPA (10 mg/kg bw) caused female rats to reach puberty at a younger age with a possible effect on the reproductive functions (Shi et al., 2017).

6. Personal care products

6.1. Triclosan

Triclosan is an antimicrobial present in the formulations of a large number of personal care products, such as antibacterial gels and toothpaste (Z. Wang et al., 2017). In the USA, the use of triclosan in personal care products is regulated by the FDA (EPA, 2017b). Triclosan has been found in some sediments of rivers in China (0.10–64.9 ng/g) (Z. F. Chen et al., 2018). In Minnesota, USA, it was found in surface water (0.005–0.31 μg/L), WWTPs (0.13–2.90 μg/L) and in surface sediments (0.9–672 μg/L) (Lyndall et al., 2017). The effects in organisms exposed to 580 ng/L of triclosan include the increase of oxidative stress in the species *Dreissena polymorpha* (Riva et al., 2012). Also, triclosan reduces the lifespan, survival rate, and fecundity in *Brachionus havanaensis* and *Plationus patulus* at a concentration of 6.25 μg/L (González-Pérez et al., 2018). In the frog *Pelophylax nigromaculatus* it can disrupt gonadal differentiation and development, affecting the sex ratios of the species at a concentration of 0.868 μg/L (J. Chen et al., 2018). In a study, triclosan was administrated to mice at 10, 100 and 200 mg/kg diet/day, inducing tumors in mice by involving receptors CAR and PPARα, which mediate the process that increases the synthesis of DNA in the liver (Z. Wang et al., 2017).

6.2. Surfactants

There are different types of surfactants used in personal care products and likewise, triclosan, are regulated by the FDA (EPA, 2017b). Some of the most used are alkyl sulfates. For example, sodium lauryl ether sulfate (SLS), an anionic surfactant, is a mixture of linear primary alkyl ether sulfates (AES) used as an emulsifying agent in household cleaning products. SLS concentration is generally from 0.01% to 50% in cosmetic products and 1%–30% in cleaning products. However, the concentration of SLS in domestic wastewater can vary between 0.4 and 12 mg/L (Marks et al., 2015). One of the problems with SLS is that in WWTPs it causes a decrease in the floccus size of activated sludge. In addition, it becomes toxic to microorganisms by binding to enzymes, structural proteins, and phospholipids, or by changing the hydrophobicity of the bacterial cell (Paulo et al., 2017). Studies show that different concentrations of SLS may affect aquatic organisms, for example, a concentration of 4.68 mg/L causes growth inhibition of marine microalga *Dunaliella salina* (Sibila et al., 2008), and 2.10 mg/L inhibits the freshwater microalgae *Pseudokirchneriella subcapitata* (Pavlić et al., 2005).

7. Human consumption of anthropogenic contaminants and their presence in drinking water reservoirs

ACs have been found in drinking water reservoirs, WWTP, DWTP, and in places where humans are in contact with these contaminated water resources (Fawell and Nieuwenhuijsen, 2003). For example, water from some rivers is used as drinking water, such as the Yangtze River in China. In this river, triclosan was found at the concentrations of 1.85 ng/L, and it was estimated that the daily intake of triclosan is of 0.03 ng/kg bw/day in children and 0.02 ng/kg bw/day in teenagers and adults (X. Ma et al., 2018). In Vietnam, drinking water also contains some pesticides such as butachlor (0.47 μg/L) and fipronil (0.04 μg/L). The source of contamination by pesticides may be by direct contact with the pesticide or by infiltration (Toan et al., 2013). As in the case of groundwater from the River Ganges Basin (India), several ACs have been detected, including acetaminophen, at the concentration of 1.92 ng/L, caffeine at 208 ng/L, carbamazepine at 27.2 ng/L, sulfamethoxazole at 3.49 ng/L, diclofenac at 1.56 ng/L, naproxen at 2.37 ng/L, ibuprofen at 49.4 ng/L, and triclosan at 10.2 ng/L (Sharma et al., 2019). In Milan, groundwater was analyzed after drinking water treatment, and the analysis profile revealed 10.3 ng/L of carbamazepine, 0.61 ng/L of benzoylecgonine, 4.44 ng/L of cocaine, 683 ng/L of BPA and 5.2 ng/L of caffeine (Riva et al., 2018). Additional studies are included in Table 2.

Groundwater in Sub-Saharan Africa was reported to contain 335 ng/L of carbamazepine, 276 ng/L of ibuprofen, 518 ng/L of diclofenac, 111 ng/L of acetaminophen and 1285 ng/L of sulfamethoxazole (Branchet et al., 2019). A lake in Brazil (Guarapiranga), contained 179 ng/L of benzoylecgonine and 12 ng/L of cocaine. Also, in Brazil, drinking water from rivers that supply five cities contain 652 ng/L of benzoylecgonine and 22 ng/L of cocaine (Campestrini and Jardim, 2017). In China, two recent studies found the following ACs before and after the water treatment process in a DWTP (expressed as AC maximum concentration in raw water to AC concentration in effluent): 37.1 to 6.4 ng/L of acetaminophen, 1.01 to 0.65 ng/L of carbamazepine, 14.2 to 3.8 ng/L of caffeine, 12.0 to 5 ng/L of indomethacin, 4.3 to 2.5 ng/L of lincomycin, 35.4 to 5.4 ng/L of sulfamethoxazole, 17.0 to 3.7 ng/L of trimethoprim (Lin et al., 2016), and 34.9 to 6.5 ng/L of BPA (Zhang et al., 2019). In a DWTP in Taiwan, BPA was found at the concentration of 38 ng/L after water treatment. Based on these results, it was estimated that the daily intake of BPA per person is between 4.3 and 76 ng/day, considering that a person consumes 2 L of water daily (Chen et al., 2013). Water samples from DWTP in Madrid (Spain) were analyzed and found contaminated with ACs, such as methylparaben (9.87–85.89 ng/L), ethylparaben (11.97 ng/L) and BPA (5123 ng/L) (Alda et al., 2018). Another study carried out in a DWTP that treats water from the Mediterranean Llobregat River (Spain). Acetaminophen, carbamazepine, hydrochlorothiazide, thiabendazole, diltiazem, norverapamil, BPA, and propyl-paraben were detected even after the treatment process (Gabarrón et al., 2016). The ACs removal in treated water from a WTP in the area of Gdańsk (Poland) was determined, and the results are expressed as concentration range and % of compound removal from untreated water): 4.9–5.6 ng/L (0.0%) of ranitidine, 9.3–44.0 ng/L (44.5%) of acetaminophen, 12.7–158.7 ng/L (61.3%) of caffeine, 2.1–6.0 ng/L (88.9%) of carbamazepine, 114.3 ng/L (−298.8%) of diclofenac and 5.7–223.6 ng/L (21.2%) of ibuprofen (Kot-Wasik et al., 2016). Drinking water samples obtained from a local water supply system in Brazil were analyzed (Sodré et al., 2018). The samples were found to contain 3.3 ng/L of atrazine and 16 ng/L of caffeine (Sodré et al., 2018). In Croatia, drinking water samples obtained from municipal water supplies contained 5–68 ng/L of atrazine (Fingler et al., 2017). In Ohio, USA, the atrazine concentration in drinking water was monitored (2006–2008), and it was detected in a range of 0–15.7 μg/L (Almberg et al., 2018).

Furthermore, commercial bottled waters from France and other European countries contain several ACs, i.e., diclofenac, sulfamethoxazole, carbamazepine, ofloxacin, ibuprofen, acetaminophen, caffeine, metformin (12 ng/L), salicylic acid (16 ng/L) and gabapentine (12 ng/L) (Lardy-Fontan et al., 2017). In Thailand, some commercial canned carbonated drinks and plastic-bottled waters were analyzed. In both types of test samples, BPA was found at the concentrations of 51–340 and 30 ng/L, respectively (Chailurkit et al., 2017). While, in Lebanon, bottled water contained 1.37 ng/L of BPA (Dhaini and Nassif, 2014). In Vietnam, it was reported that 10 brands of bottled water contained some ACs from the agricultural sector, including fenobucarb, isoprothiolane, pretilachlor, fipronil, hexaconazole and azoxystrobin (Chau et al., 2015). A study on the food diet of 50 North Carolina (USA) adults, found BPA at 0.062 ng/mL in 38% of solid food and 4% of drinking water samples. It was estimated that people are consuming up to 10.7 ng/kg/day (Morgan et al., 2018). A study carried out in China with 12 adults (25 years old), ACs detected in urine with 3.5 μg of triclosan/g creatinine and 2.75 μg of BPA/g creatinine (Li et al., 2013).

8. Challenges and threats

The amount of ACs found in different water bodies alarms to consider the pollution plume that is derived from various anthropogenic activities. This is not only damaging for humans but also for many other aquatic species, alike. Although the processes of the current wastewater treatment plants can reduce the pollutant load. However, the above-discussed examples reflect that treated effluents discharged into water bodies have considerable concentrations of different ACs. Thus, more robust strategies are needed for complete removal of various types of ACs. This is even highly requisite in rural areas where there is no such wastewater disposal. The filtration process (groundwater) or storage of water in reservoirs for human consumption is carried out through the flow of water in an endorheic and exorheic basin, thus making it possible for certain ACs to return to the population due to the currents of drinking water treatments. The map proposed, shows that ACs are present at detectable levels in water bodies all over the world. Since these pollutants have been found even in the polar zones, where the production of ACs is considered minimal. For all these reasons, it is necessary to optimize and redesign the treatment of waste and drinking waters for the effective removal of ACs in a safe and eco-friendly way.

9. Concluding summary

In summary, the presence of ACs in different environmental matrices needs more attention, planning of mitigation strategies, and implementation of strategic measures to detect and remove effectively. Unless otherwise, their free movement can cause uncontrol spread throughout the environment and damage various habitats. Until recently, ACs had not been actively addressed as a major environmental concern. In addition, the data discussed above with suitable examples show that the methods used are not sufficient for the removal of ACs. Clearly, more studies are needed to effectively regulate and evaluate the number of hazardous substances found in different environmental matrices around the globe. Besides effective removal, adverse effects on different organisms should also be considered with care. Although the information obtained is of great importance, the studies so far do not reflect the magnitude of the current problem with ACs, as was shown anthropogenic contaminants occurrence around the globe in 2017 and 2018 found in water bodies give the idea that the occurrence of ACs happens around the globe. The majority of the ACs reviewed in this article are endocrine disruptors, which cause changes in behavior, cellular toxicity, genotoxicity, and alter the sex ratios in organisms. These types of contaminants are already affecting the biodiversity hotspots worldwide. Furthermore, they also affect the trophic chain at all levels through bioaccumulation and biomagnification.

Declaration of Competing Interest

The authors declare no conflict of interest.

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