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Review

Occurrence of personal care products as emerging chemicals of concern in water resources: A review

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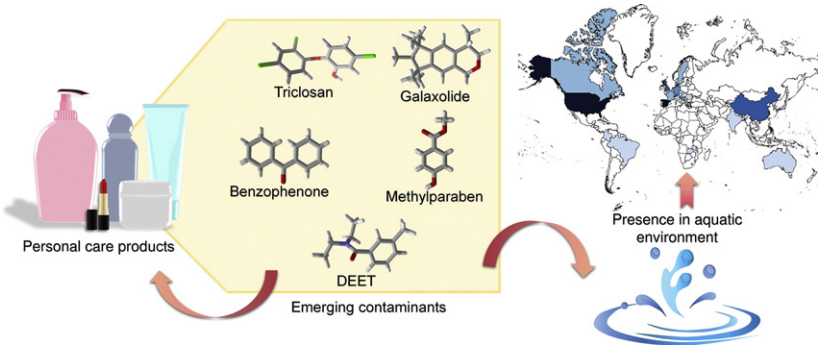
HIGHLIGHTS

- PCPs have been found in all the continents as EPs in aquatic ecosystems.
- Fragrances, insect repellants and antiseptics were the most reported PCPs in water.
- Several PCPs exhibited concentrations above the toxicity threshold for some species.
- The information about the impact of PCPs in groundwater is very limited.

GRAPHICAL ABSTRACT



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ABSTRACT

Personal care products (PCPs) are a diverse group of common household substances used for health, beauty and cleaning purposes. These include disinfectants, fragrances, insect repellents, preservatives and UV filters, among others. Some of them are considered chemicals of emerging concern due to their presence and negative impact on aquatic ecosystems, specially related to endocrine disruption and reproductive disorders. The entry of those chemicals to water bodies occurs mainly through the sewage effluents from wastewater treatment plants due to their incomplete or inefficient removal. The purpose of this review was to collect and analyze data about the incidence and concentrations of PCPs reported as emerging pollutants in different water matrices, including wastewater influents and effluents. Our database is composed of 141 articles with information about 72 PCPs recorded as emerging pollutants in 30 countries, in concentrations ranging from 0.029 ng/L to 7.811 × 10^6 ng/L. Fragrances, antiseptics and sunscreens were the most reported groups. As expected, the largest

Abbreviations: 2-amino-MK, 2-amino musk ketone; 2-amino-MX, 2-amino musk xylene; 2-EHMC, 2-ethylhexyl-p-methoxycinnamate; 2-NP, 2-nonylphenol; 4-amino-MX, 4-amino musk xylene; 4MBC, 4-methylbenzylidenecamphor; 4-NP, 4-nonylphenol; ACN, acetophenone; ADBI, celestolide; AETT, versalide; AHMI, phantolide; AHTN, tonalide; AMA, amino musk xylene; AMB, ambrettolide; AMM, amino musk moskene; ATII, traseolide; BHT, butylated hydroxytoluene; BP, benzophenone; BP-1, benzophenone-1; BP-2, benzophenone-2; BP-3, benzophenone-3; BP-4, benzophenone-4; BS, benzyl salicylate; ChV, chronic value; BPB, butylparaben; CMP, 4-chloro-3-methylphenol; CP, chlorophene; CPD, exaltone; DEET, *N*,*N*-diethyl-m-toluamide; DPMI, cashmeran; EC_{25}, effective concentration to 25% of test organisms; EC_{50}, half maximal effective concentration; EHMC, ethylhexyl methoxycinnamate; EP, emerging pollutants; EPB, ethylparaben; HHCB, galaxolide; HHCB-lactone, galaxolidone; Koc, sediment/water partition coefficient; Kow, *N*-octanol/water partition coefficient; LAS, linear alkylbenzene sulfonates; LC_{50}, median lethal concentration; LOEC, lowest observed effect concentration; MA, musk ambrete; MJD, methyl dihydrojasmonate; MK, musk ketonne; MM, musk moskene; MNT, menthol; MPB, methylparaben; MT, musk tibetene; MTCS, methyltriclosan; Musk MC4, ethylenedodecanedioate; Musk NN, ethylenetridecanedioate; MX, musk xylene; nd, not detected; NEC, no effect concentration; NP1EO, 2-(p-nonylphenoxy) ethanol; NP, nonylphenol; OC, octocrylene; OMC, octyl methoxycinnamate; OT, octyl triazone; OP, 4-tert-octylphenol; OPP, 2-phenylphenol; OTNE, 1-(1,2,3,4,5,6,7,8-octahydro-2,3,8,8-tetramethyl-2-naphthalenyl)ethanone; PCMX, chloroxylenol; PCPs, personal care products; PDL, exaltolide; PNEC, predicted no effect concentration; PPB, propylparaben; PPCPs, pharmaceuticals and personal care products; PRISMA, preferred reporting items for systematic reviews and meta-analyses; SKT, skatol; Tbcr, habanolide; TCC, triclocarban; TCS, triclosan; US-EPA, Environmental Protection Agency of US; WWTPs, wastewater treatment plants.

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Aquatic environment
Wastewater
Endocrine disrupting chemicals

number of PCPs documented as emerging pollutants were found in wastewater treatment plant effluents with a total of 64 compounds, compared to 43 in surface water and 23 in groundwater, which evidence the anthropological contribution of PCPs to water bodies. These molecules were found in all the continents, however, there is a lack of information regarding the presence of emerging pollutants from PCPs in developing countries. Therefore, we suggest further efforts in assessing the occurrence and concentrations of these chemicals in those areas.

Contents

1. Introduction

Water pollution by emerging pollutants (EPs) has gained interest since 1990, however they are not regularly monitored because of the lack of controlling requirements and high analytical cost (Cabeza et al., 2012). These chemicals are released to the environment mainly from anthropogenic sources (Sim et al., 2011), and are defined by the Environmental Protection Agency of US (US-EPA) as new compounds without regulatory status and which impact on the environment and human health is poorly understood (Deblonde et al., 2011). These include a broad range of species such as personal care products (PCPs), pharmaceuticals, nanoparticles, antibiotic resistant genes and industrial compounds, among others (Bo et al., 2016; Magi and Di Carro, 2016).

PCPs along with pharmaceuticals are the two major classes of emerging pollutants from urban sources, contaminating soils and aquatic ecosystems tainted by raw or treated wastewater (Bester, 2004; Blair et al., 2013a; Cabeza et al., 2012; Corada-Fernández et al., 2015; Yang et al., 2011). PCPs include a large number of synthetic chemicals used in everyday products such as soaps, lotions, toothpaste, fragrances, cosmetics and sunscreens (Brausch and Rand, 2011; Comerton et al., 2009; Kolpin et al., 2002). The extensive use of them, improperly disposal, and inefficient treatment of urban wastewater contribute to the contamination of water bodies by PCPs and their metabolites (Basu and Gupta, 2010; Chalew and Halden, 2009; Kolpin et al., 2002; Nakada et al., 2007; Nakada et al., 2006; Okuda et al., 2008; Roberts et al., 2016; Stasinakis, 2012; Sun et al., 2015; Tolls et al., 2009; Ying et al., 2007; Yu et al., 2013). A diagram showing the environmental dynamics and fate of PCPs is presented in Fig. 1.

The largest contributing sources of PCPs to aquatic environments are sewage effluents from wastewater treatment plants (WWTPs) (Blair et al., 2013a; Liu and Wong, 2013), in particular, because several of them cannot be completely degraded by the waste water treatment process (Blair et al., 2015; Blair et al., 2013a; Carballa et al., 2004; Meador et al., 2016; Moldovan, 2006; Ternes et al., 1999). This is concerning, as treated effluents are generally discharged into receiving waters, including small streams, rivers, lakes and groundwater; and there are even places where the wastewater is released into the environment without previous treatment, being directly discharged into riverine habitats or water bodies (Chalew and Halden, 2009; Sodré et al., 2010; Ying and Kookana, 2007; Zhou et al., 2009).

The contamination of the water reservoirs by PCPs is of interest due to their potential toxicity to aquatic ecosystems and human beings, as many of them have been reported as environmental persistent, bioactive, bioaccumulative and endocrine disrupting compounds (Blair et al., 2013b; Cabeza et al., 2012; Celano et al., 2014; Díaz-Cruz and Barceló, 2015; Moldovan, 2006; Niemuth and Klaper, 2015; Yu et al., 2013). In addition, physicochemical properties such as the *n*-octanol/water partition coefficient (Kow), the degradation rate and the organic carbon normalized sediment/water partition coefficient (Koc)

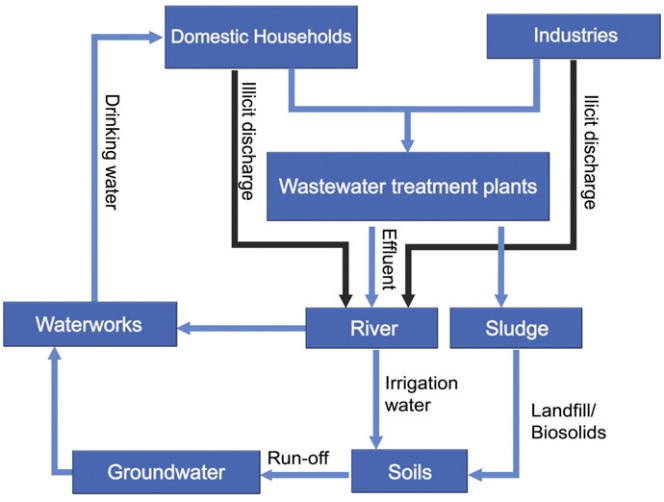


Fig. 1. Sources and pathways of PCPS. Adapted from (Ellis, 2006).

(Yamamoto et al., 2009; Zhao et al., 2013), as well as other features related to their release such as the waste stream flow or the PCPs usage patterns, that vary by region and season, also determine the fate and concentration of these compounds in the environment (Dickenson et al., 2011; Yu et al., 2013).

Owing to the globally use of PCPs and their potential for negative effects in human and wildlife, a rising number of studies assess the presence of these compounds in environmental matrices (Caliman and Gavrilescu, 2009; Onesios et al., 2009; Ternes et al., 2004). Nevertheless, there are a few analysis regarding the presence of PCPs in the aquatic systems (Brausch and Rand, 2011; Ebele et al., 2017). Therefore, this review summarizes the results of a literature search regarding the occurrence and concentrations of EPs found in aquatic ecosystems and WWTPs, belonging to PCPs of daily use.

2. Material and methods

2.1. Literature search and database description

In order to identify the occurrence of PCPs as emerging pollutants in aquatic ecosystems and WWTPs, as well as the demographic distribution of the studies, a literature review was conducted using Google Scholar and Science Direct (Relevo, 2012) from March 7th of 2016 to December 16th 2016. Articles in both English and Spanish, published online were considered.

The literature search was performed using the following keywords: personal care products, wastewater, surface water, groundwater, emerging pollutants, emerging contaminants, emerging concern, PCP and WWTPs, either alone or using the following search query: (personal care products and wastewater) or (personal care products and surface water) or (personal care products and groundwater) or (personal care products and WWTPs) or (PCP and wastewater), or (PCP and surface water) or (PCP and groundwater) or (PCP and WWTPs) or (emerging pollutants and wastewater) or (emerging pollutants and surface water) or (emerging pollutants and groundwater) or (emerging pollutants and WWTPs) and (emerging contaminants and wastewater) or (emerging contaminants and surface water) or (emerging contaminants and groundwater) or (emerging contaminants and WWTPs) or (personal care products and emerging pollutant) or (personal care products and emerging concern) or (PCP and emerging pollutants) or (PCP and emerging concern). In addition, manual searches of the reference sections of the articles selected from Google Scholar and Science Direct databases were carried out to avoid disregarding additional information that may have missed out by the computer-aided method (Meddings et al., 2010; Mylona et al., 2009).

Peer reviewed articles containing concentrations in water matrices of chemicals belonging to personal care products, documented as emerging pollutants according the US-EPA definition, were included as appropriated for analysis (Cooley, 2000). No search limits on study location were used. The selected articles were stored in an internal database and the following information was extracted from each study: compound name, source, place, concentration, date and citation (Deblonde et al., 2011). A PRISMA flow diagram to depict the data collection process is presented in Fig. 2 (Moher et al., 2010).

3. Results

A number of 52 articles were initially collected by the computer-assisted search. After the manual revision of the reference lists, removal of duplicates and validation of the eligibility criteria, a final number of 141 publications were identified as suitable for the analysis and stored in the internal database (Table 1). These studies recorded information of 72 PCPs belonging to the group of emerging pollutants from 30 countries, published between 1996 and 2016.

PCPs identified as EPs in water matrices and their sources are presented in Table 2. These were found in widespread places, across all

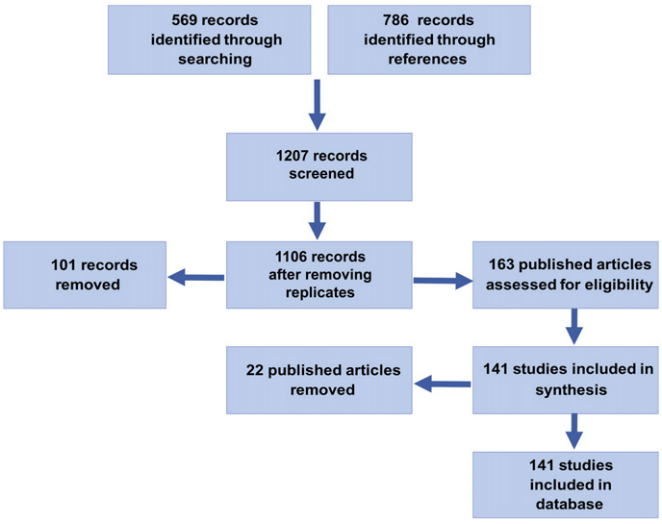


Fig. 2. Systematic research PRISMA flow diagram for PCPs reports in wastewater.

the continents, as shown in Fig. 3 (Beretta et al., 2014; Emnet et al., 2015; Osenbrück et al., 2007; Padhye et al., 2014; Peng et al., 2008; Sorensen et al., 2015; Ying and Kookana, 2007). Spain and United States were the countries with the largest number of PCPs reported as EPs in water with 42 and 36 compounds, followed by United Kingdom and Germany with 22 and 20, respectively.

According to the PCPs classification, galaxolide (HHCB), tonalide (AHTN), celestolide (ADBI) and phantolide (AHMI) were the most reported EPs found in fragrances; triclosan (TCS) and triclocarban (TCC) in disinfectants and antiseptics; *N*,*N*-diethyl-m-toluamide (DEET) in insect repellents; and benzophenone-3 (BP-3) in UV filters.

3.1. Surface water

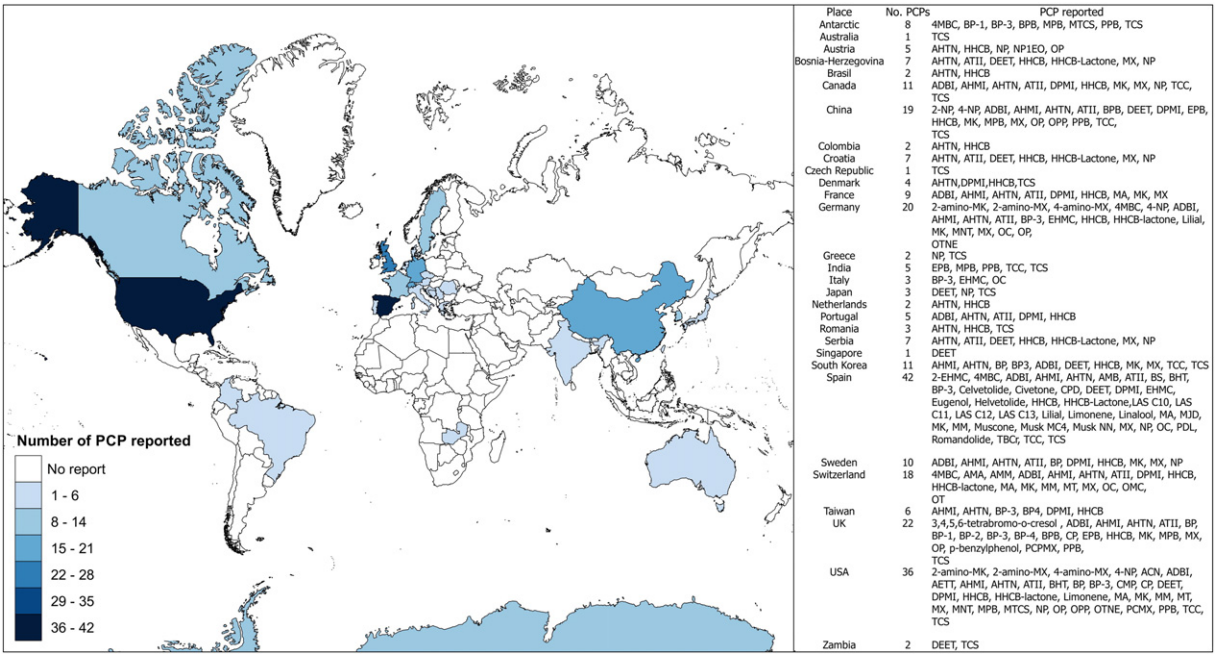
A total of 43 PCPs were reported as EPs on surface water from several countries around the world, such as Australia, Antarctic, China, Czech Republic, Denmark, France, Germany, India, Japan, Romania, Singapore, South Korea, Spain, Switzerland, Taiwan, United Kingdom and United States (Buerge et al., 2003; Carmona et al., 2014; Cavalheiro et al., 2013; Chen et al., 2016; Emnet et al., 2015; Jiang et al., 2014; Kasprzyk-Hordern et al., 2009; Matamoros et al., 2012; Moeder et al., 2010; Moldovan, 2006; Nakada et al., 2007; Padhye et al., 2014; Peng et al., 2008; Ramaswamy et al., 2011; Tran et al., 2014; Ying and Kookana, 2007; Yoon et al., 2010). Depending on the particular compound, concentration ranged from not detected (nd) to 1,293,000 ng/L were found (Kasprzyk-Hordern et al., 2009). HHCB, TCS and TCC were the PCPs most commonly found as EPs in surface water with concentrations up to 13,920 ng/L (Alvarez et al., 2014; Lee et al., 2010), 24,000 ng/L (Blair et al., 2013a; Kasprzyk-Hordern et al., 2009) and 478 ng/L (Blair et al., 2013a; Zhao et al., 2013), respectively. The compounds with the maximum concentrations reported in this category were 4-tert-octylphenol (OP; 1,293,000 ng/L) and chloroxylenol (PCMX; 358,000 ng/L) (Kasprzyk-Hordern et al., 2009). The concentrations reported by country of these and other chemicals of emerging

Table 1
Sources of consulted material with PCP reports on aquatic matrices.

Source	Publications
ScienceDirect	22
Google Scholar	30
Manual revision of the reference lists	89
Total	141

Table 2
List of personal care products compounds.

Compound	Source	Matrix
OPP	Cosmetic	Wastewater, surface water, groundwater
CMP	Cosmetic	Wastewater
BHT	Cosmetic	Wastewater, surface water, groundwater
BPB	Cosmetic	Wastewater, surface water
CP	Cosmetic	Wastewater, surface water
EPB	Cosmetic	Wastewater, surface water, groundwater
MPB	Cosmetic	Wastewater, surface water, groundwater
PPB	Cosmetic	Wastewater, surface water, groundwater
NP1EO	Deodorant stick, soap	Wastewater
3,4,5,6-Tetrabromo-o-cresol	Deodorant stick, soap	Wastewater, surface water
2-NP	Disinfectant/antiseptic	Surface water
4-NP	Disinfectant/antiseptic	Wastewater, surface water, sludge
OP	Disinfectant/antiseptic	Wastewater, surface water, sludge
PCMX	Disinfectant/antiseptic	Wastewater, surface water
MTCS	Disinfectant/antiseptic	Wastewater, surface water
NP	Disinfectant/antiseptic	Wastewater, surface water, groundwater, sludge
p-Benzylphenol	Disinfectant/antiseptic	Wastewater, surface water
TCC	Disinfectant/antiseptic	Wastewater, surface water, groundwater, sludge
TCS	Disinfectant/antiseptic	Wastewater, surface water, groundwater, sludge
OTNE	Fragrances	Wastewater
2-amino-MK	Fragrances	Wastewater
2-amino-MX	Fragrances	Wastewater, surface water
4-amino-MX	Fragrances	Wastewater, surface water, sludge
ACN	Fragrances	Groundwater
AMB	Fragrances	Wastewater, sludge
AMM	Fragrances	Sludge
AMA	Fragrances	Sludge
BS	Fragrances	Wastewater
DPMI	Fragrances	Wastewater, surface water, groundwater, sludge
ADBI	Fragrances	Wastewater, surface water, sludge
Civetone	Fragrances	Wastewater, sludge
Musk MC4	Fragrances	Wastewater, sludge
Musk NN	Fragrances	Wastewater, sludge
Eugenol	Fragrances	Wastewater
PDL	Fragrances	Wastewater, surface water, sludge
CPD	Fragrances	Wastewater, sludge
HHCB	Fragrances	Wastewater, surface water, groundwater, sludge
HHCB-lactone	Fragrances	Wastewater, surface water, sludge
TBCr	Fragrances	Wastewater, sludge
Helvetolide	Fragrances	Wastewater
Lilial	Fragrances	Wastewater
Limonene	Fragrances	Wastewater, surface water
Linalool	Fragrances	Wastewater
MJD	Fragrances	Wastewater, surface water
Muscone	Fragrances	Wastewater, sludge
MA	Fragrances	Wastewater, surface water, groundwater, sludge
MK	Fragrances	Wastewater, surface water, groundwater, sludge
MM	Fragrances	Wastewater, sludge
MT	Fragrances	Wastewater, sludge
MX	Fragrances	Wastewater, surface water, groundwater, sludge
AHMI	Fragrances	Wastewater, surface water, sludge
Romandolide	Fragrances	Wastewater, surface water
AHTN	Fragrances	Wastewater, surface water, groundwater, sludge
ATII	Fragrances	Wastewater, surface water, sludge
AETT	Fragrances	Wastewater
DEET	Insect repellent	Wastewater, surface water, groundwater, sludge
2-EHMC	Sunscreen	Wastewater, surface water
4MBC	Sunscreen	Wastewater, surface water
BP	Sunscreen	Wastewater, surface water
BP-1	Sunscreen	Wastewater, surface water
BP-2	Sunscreen	Wastewater, surface water
BP-3	Sunscreen	Wastewater, surface water, groundwater, sludge
BP-4	Sunscreen	Wastewater, surface water
EHMC	Sunscreen	Wastewater, surface water, groundwater
OC	Sunscreen	Wastewater, surface water, groundwater
OMC	Sunscreen	Wastewater
OT	Sunscreen	Wastewater
LAS C10	Surfactants	Groundwater
LAS C11	Surfactants	Groundwater
LAS C12	Surfactants	Groundwater
LAS C13	Surfactants	Groundwater
MNT	Toothpaste	Wastewater



Place	No. PCPs	PCP reported
Antarctic	8	4MBC, BP-1, BP-3, BPB, MPB, MTCS, PPB, TCS
Australia	1	TCS
Austria	5	AHTN, HHCB, NP, NP1EO, OP
Bosnia-Herzegovina	7	AHTN, ATII, DEET, HHCB, HHCB-Lactone, MX, NP
Brasil	2	AHTN, HHCB
Canada	11	ADBI, AHMI, AHTN, ATII, DPMI, HHCB, MK, MX, NP, TCC, TCS
China	19	2-NP, 4-NP, ADBI, AHMI, AHTN, ATII, BPB, DEET, DPMI, EPB, HHCB, MK, MPB, MX, OP, OPP, PPB, TCC, TCS
Colombia	2	AHTN, HHCB
Croatia	7	AHTN, ATII, DEET, HHCB, HHCB-Lactone, MX, NP
Czech Republic	1	TCS
Denmark	4	AHTN,DPMI,HHCB,TCS
France	9	ADBI, AHMI, AHTN, ATII, DPMI, HHCB, MA, MK, MX
Germany	20	2-amino-MK, 2-amino-MX, 4-amino-MX, 4MBC, 4-NP, ADBI, AHMI, AHTN, ATII, BP-3, EHMC, HHCB, HHCB-lactone, Lilial, MK, MNT, MX, OC, OP, OTNE
Greece	2	NP, TCS
India	5	EPB, MPB, PPB, TCC, TCS
Italy	3	BP-3, EHMC, OC
Japan	3	DEET, NP, TCS
Netherlands	2	AHTN, HHCB
Portugal	5	ADBI, AHTN, ATII, DPMI, HHCB
Romania	3	AHTN, HHCB, TCS
Serbia	7	AHTN, ATII, DEET, HHCB, HHCB-Lactone, MX, NP
Singapore	1	DEET
South Korea	11	AHMI, AHTN, BP, BP3, ADBI, DEET, HHCB, MK, MX, TCC, TCS
Spain	42	2-EHMC, 4MBC, ADBI, AHMI, AHTN, AMB, ATII, BS, BHT, BP-3, Celvetolide, Civetone, CPD, DEET, DPMI, EHMC, Eugenol, Helvetolide, HHCB, HHCB-Lactone,LAS C10, LAS C11, LAS C12, LAS C13, Lilial, Limonene, Linalool, MA, MJD, MK, MM, Muscone, Musk MC4, Musk NN, MX, NP, OC, PDL, Romandolide, TBC, TCC, TCS
Sweden	10	ADBI, AHMI, AHTN, ATII, BP, DPMI, HHCB, MK, MX, NP
Switzerland	18	4MBC, AMA, AMM, ADBI, AHMI, AHTN, ATII, DPMI, HHCB, HHCB-lactone, MA, MK, MM, MT, MX, OC, OMC, OT
Taiwan	6	AHMI, AHTN, BP-3, BP4, DPMI, HHCB
UK	22	3,4,5,6-tetrabromo-o-cresol , ADBI, AHMI, AHTN, ATII, BP, BP-1, BP-2, BP-3, BP-4, BPB, CP, EPB, HHCB, MK, MPB, MX, OP, p-benzylphenol, PCPMX, PPB, TCS
USA	36	2-amino-MK, 2-amino-MX, 4-amino-MX, 4-NP, ACN, ADBI, AETT, AHMI, AHTN, ATII, BHT, BP, BP-3, CMP, CP, DEET, DPMI, HHCB, HHCB-lactone, Limonene, MA, MK, MM, MT, MX, MNT, MPB, MTCS, NP, OP, OPP, OTNE, PCMX, PPB, TCC, TCS
Zambia	2	DEET, TCS

Fig. 3. Countries with reports of PCPs presence in water.

concern found in PCPs and surface water are presented in Table 3 and Supplementary Table 1.

3.2. Groundwater

According to the literature search, twenty-three PCPs have been detected as EPs in groundwater from eight countries (Table 4, Supplementary Table 2). The largest number of chemicals belonging to this group was found in China and Spain. However, the reports for PCPs in groundwater were lower in comparison to those from surface water and wastewater. The presence of sunscreens, insect repellents, antiseptics, antioxidants, preservatives, surfactants and fragrances has been identified among the PCPs found in this matrix (Table 4). Nonetheless, DEET was the most studied PCP in groundwater, being reported in 4 countries (Barnes et al., 2008; Dai et al., 2015; Del Rosario et al., 2014; Tran et al., 2014); and acetophenone (ACN) presented the maximum concentration with 26,700 ng/L (Barnes et al., 2008).

3.3. Wastewater

A total of 64 PCPs were reported in WWTP influents and effluents between 1996 and 2016 (Supplementary Table 3). According to the conducted search, several types of PCPs were found in Antarctic, Australia, Austria, Canada, China, Colombia, Croatia, Bosnia-Herzegovina, Serbia, France, Germany, Greece, India, Italy, Japan, Netherlands, Portugal, Singapore, South Korea, Spain, Sweden, Switzerland, Taiwan, United Kingdom and Unite States (Artola-Garicano et al., 2003; Behera et al., 2011; Cavalheiro et al., 2013; Clara et al., 2005; Dai et al., 2014; Emnet et al., 2015; Klaschka et al., 2013; Kupper et al., 2006; Magi et al., 2013; Meador et al., 2016; Nakada et al., 2007; Ramaswamy et al., 2011; Ricking et al., 2003; Roberts et al., 2016; Salgado et al., 2011; Samaras et al., 2013; Sumner et al., 2010; Terzić et al., 2008; Tran et al., 2014; Vélez et al., 2016; Wang and Ding, 2009).The largest variety of emerging chemicals of concern from PCPs in WWTPs was reported in Spain with 36 compounds, followed by United States and United Kingdom, with 34 and 21, respectively.

Thirty-three fragrances were documented in WWTPs, of which 26 were detected in WWTPs effluents in over ten countries. In this group, HHCB (influents: 1.44–595,480 ng/L, effluents: 0.14–108,000 ng/L) (Chen et al., 2007; Klaschka et al., 2013; Müller and Böhmer, 2006), and AHTN (influents: 0.41–68,120 ng/L, effluents: 0.05–7555 ng/L) (Chen et al., 2007; Müller and Böhmer, 2006; Vallecillos et al., 2014) were the most frequently reported compounds, being found in 16 countries. Other compounds detected after the wastewater treatment process were the antiseptic TCS, which was found in 11 countries (influents: 2.3–463,000 ng/L, effluents: (nd – 82,000 ng/L) (Blair et al., 2013a; Carmona et al., 2014; Kasprzyk-Hordern et al., 2009); the insect repellent DEET present in eight countries (influents:15.1–6900 ng/L, effluents: 6.4–2110 ng/L) (Kim et al., 2007; Loraine and Pettigrove, 2006; Terzić et al., 2008; Tran et al., 2014); the sunscreen BP-3 in detected in six countries (influents: 7–3,975,000 ng/L, effluents: 1.1–2,196,000 ng/L) (Kasprzyk-Hordern et al., 2009; Magi et al., 2013; Trenholm et al., 2008); the preservative methylparaben (MPB) recorded in 4 countries (influents: 1193.9–30,688,000 ng/L, effluents: nd–155,000 ng/L) (Kasprzyk-Hordern et al., 2008; Kasprzyk-Hordern et al., 2009); the flavorant menthol (influents: 15,520 ng/L; effluents <37–900 ng/L) (Klaschka et al., 2013; Lee and Rasmussen, 2006) and the antioxidant butylated hydroxytoluene (BHT) (influents: 47–410 ng/L; effluents nd–519 ng/L) (Godayol et al., 2015; Teijon et al., 2010; Trenholm et al., 2008), both reported in two countries.

In addition, 30 PCPs compounds were detected in sludge from WWTPs at concentrations in the order of ng/g (Supplementary Table 4). The fragrances HHCB (0.2–601,270 ng/g) and AHTN (0.1–107,670 ng/g) (Chen et al., 2007; Wu and Ding, 2010) were the most ubiquitous PCPs in this matrix, being present in over 10 countries.

4. Discussion

4.1. Database construction

This systematic review collects concentration data of PCPs in order to assess the prevalence of these molecules in water. A total of 52 articles published on databases were identified, and their references examined to detect other reports with appropriate information to construct the internal database. A total of 89 additional articles were found through this approach, and thus, resulting in the biggest source of consulted material. Studies of emerging pollutants published in scientific journals were included; but unpublished articles or articles with no peer-revision were not added to the database, besides articles with no concentration data of PCPs were excluded.

Table 3
Maximum and minimum concentration (ng/l) reported in surface water.

Place	Compound	Min-max concentration reported	Reference
Antarctic	4MBC	<3.2–45.1	(Emnet et al., 2015)
	BP-1	<0.8–10.3	(Emnet et al., 2015)
	BP-3	<2.6–88.4	(Emnet et al., 2015)
	BPB	<0.5–2.3	(Emnet et al., 2015)
	MPB	<0.8–37.4	(Emnet et al., 2015)
	MTCS	<0.2[a]	(Emnet et al., 2015)
	PPB	<0.8–3	(Emnet et al., 2015)
	TCS	<0.5–1.7	(Emnet et al., 2015)
Australia	TCS	14–75	(Emnet et al., 2015)
China	2-NP	35–33,231	(Peng et al., 2008)
	OPP	7.0–2506	(Peng et al., 2008)
	4-NP	28.1–8890	(Zhao et al., 2009)
	OP	1–2470	(Zhao et al., 2009)
	BPB	<0.1–5.3	(Yu et al., 2011)
	EPB	0.2–23.1	(Yu et al., 2011)
	HHCB	3.5–32	(Hu et al., 2011)
	MPB	Nd–1062	(Peng et al., 2008) (Yu et al., 2011)
	MK	<0.18–34.6	(Hu et al., 2011; Lv et al., 2009)
	MX	<0.09[a]	(Lv et al., 2009)
	DEET	<0.2–107	(Yang et al., 2013)
	AHMI	Nd–27.4	(Hu et al., 2011)
	PPB	1.2–2142	(Peng et al., 2008; Yu et al., 2011)
	AHTN	2.3–26.7	(Hu et al., 2011)
	ATII	1.22–2.8	(Hu et al., 2011)
	TCC	<1.58–478	(Zhao et al., 2013)
	TCS	0.6–1023	(Peng et al., 2008; Zhao et al., 2009)
Czech Republic	TCS	<50–>100	(Chen et al., 2016)
Denmark	AHTN	9–13	(Matamoros et al., 2012)
	DPMI	3–5	(Matamoros et al., 2012)
	HHCB	15–57	(Matamoros et al., 2012)
	TCS	4–60	(Matamoros et al., 2012)
France	DPMI	22–42	(Cavalheiro et al., 2013)
	ADBI	<11[a]	(Cavalheiro et al., 2013)
	HHCB	<84[a]	(Cavalheiro et al., 2013)
	MA	<8[a]	(Cavalheiro et al., 2013)
	MK	<10[a]	(Cavalheiro et al., 2013)
	AHMI	<9[a]	(Cavalheiro et al., 2013)
	AHTN	<32[a]	(Cavalheiro et al., 2013)
	ATII	<8[a]	(Cavalheiro et al., 2013)
Germany	2-amino-MX	1–4	(Gatermann et al., 1998)
	4-amino-MX	2–3	(Gatermann et al., 1998)
	4-NP	Nd–485	(Bolz et al., 2001)
	4MBC	235–2592	(Moeder et al., 2010)
	BP-3	40–83 ± 11	(Moeder et al., 2010).
	ADBI	<10–20	(Dsikowitzky et al., 2002; Fromme et al., 2001)
	EHMC	150[a]	(Meador et al., 2016)
	HHCB	<3–1590	(Bester, 2005; Fromme et al., 2001)
	HHCB-lactone	<10–300	(Bester, 2005)
	MK	1[a]	(Gatermann et al., 1998).
	MX	0.5[a]	(Gatermann et al., 1998)
	OC	3052–4319	(Moeder et al., 2010)
	OP	0.8–54	(Kuch and Ballschmiter, 2001)
	AHMI	<10–70	(Dsikowitzky et al., 2002; Fromme et al., 2001)
	AHTN	<1–530	(Bester, 2005; Fromme et al., 2001)
	ATII	70[a]	(Fromme et al., 2001)
India	EPB	2.47–147	(Ramaswamy et al., 2011)
	MPB	3.43–22.8	(Ramaswamy et al., 2011)
	PPB	38.6–57.0	(Ramaswamy et al., 2011)
	TCS	944–944	(Ramaswamy et al., 2011)
Japan	DEET	36[a]	(Nakada et al., 2007)
Romania	HHCB	172.1–313.7	(Moldovan, 2006)
	AHTN	80.9–106.4	(Moldovan, 2006)
	TCS	38.2–56.7	(Moldovan, 2006)
Singapore	DEET	1.4–527	(Tran et al., 2014)
South Korea	BP	50–59	(Yoon et al., 2010)
	HHCB	100–13,920	(Lee et al., 2010)
	MK	<10–420	(Lee et al., 2010; Yoon et al., 2010)
	MX	<5[a]	(Lee et al., 2010)
	DEET	2.0–88	(Kim et al., 2007; Yoon et al., 2010)
	AHTN	50–2800	(Lee et al., 2010)
	TCS	1.0–29	(Yoon et al., 2010)
Spain	2-EHMC	14–153	(Gómez et al., 2009)
	4MBC	17–140	(Gómez et al., 2009)
	BP-3	<12–79	(Matamoros and Salvadó, 2012)
	BHT	11–564	(Gómez et al., 2009)
	DPMI	0.49–1377	(Arbulu et al., 2011; Ramírez et al., 2012)
	ADBI	<0.20–96	(Arbulu et al., 2011; Ramírez et al., 2012)
	PDL	178–2544	(Arbulu et al., 2011)
	HHCB	3.1–2184	(Arbulu et al., 2011; Ramírez et al., 2012)
	HHCB-lactone	10–36	(Ramírez et al., 2012)
	MJD	18–255	(Matamoros and Salvadó, 2012)
	MA	<8[a]	(Cavalheiro et al., 2013).
	MK	0.80–41	(Posada-Ureta et al., 2012; Ramírez et al., 2011)
	MX	0.55–23	(Gómez et al., 2009; Ramírez et al., 2011)
	NP	440[a]	(Pintado-Herrera et al., 2013)
	OC	13–283	(Gómez et al., 2009; Pintado-Herrera et al., 2013)
	AHMI	0.27–<9	(Cavalheiro et al., 2013; Ramírez et al., 2011)
	Romandolide	73–306	(Arbulu et al., 2011)
	AHTN	0.34–194	(Gómez et al., 2009; Ramírez et al., 2011)
	ATII	17[a]	(Cavalheiro et al., 2013)
	4–5.7	4–5.7	(Robles-Molina et al., 2014)
	TCC	4–13	(Carmona et al., 2014)
	TCS	1–157	(Carmona et al., 2014; Gómez et al., 2009)
Switzerland	HHCB	<2–564	(Buerge et al., 2003)
	AHTN	<1–186	(Buerge et al., 2003)
Taiwan	BP-3	82.5–100.5	(Jiang et al., 2014)
	BP-4	80.5–107	(Jiang et al., 2014)
UK	3,4,5,6-tetrabromo-o-cresol	21–140,000	(Kasprzyk--Hordern et al., 2008; Kasprzyk--Hordern et al., 2009)
	OP	<305–1,293,000	(Kasprzyk-Hordern et al., 2008; Kasprzyk-Hordern et al., 2009)
	BP	6–9	(Kasprzyk-Hordern et al., 2008)
	BP-1	<300–17,000	(Kasprzyk-Hordern et al., 2009)
	BP-2	<4–26,000	(Kasprzyk-Hordern et al., 2008; Kasprzyk-Hordern et al., 2009)
	BP-3	28–44,000	(Kasprzyk-Hordern et al., 2008; Kasprzyk-Hordern et al., 2009)
	BP-4	10–323,000	(Kasprzyk-Hordern et al., 2008; Kasprzyk-Hordern et al., 2009)
	BPB	<300–16,000	(Kasprzyk-Hordern et al., 2009)
	CP	5–16,000	(Kasprzyk-Hordern et al., 2008; Kasprzyk-Hordern et al., 2009)
	PCMX	<124–358,000	(Kasprzyk-Hordern et al., 2008; Kasprzyk-Hordern et al., 2009)

Table 3 (*continued*)

Place	Compound	Min-max concentration reported	Reference
	EPB	6–15,000	(Kasprzyk-Hordern et al., 2008; Kasprzyk-Hordern et al., 2009)
	HHCB	6–28	(Kasprzyk-Hordern et al., 2009)
	MPB	6–350,000	(Kasprzyk-Hordern et al., 2008; Kasprzyk-Hordern et al., 2009)
	p-Benzylphenol	47–58,000	(Kasprzyk-Hordern et al., 2008; Kasprzyk-Hordern et al., 2009)
	PPB	6–22,000	(Kasprzyk-Hordern et al., 2008; Kasprzyk-Hordern et al., 2009)
	AHTN	3–10	(Sumner et al., 2010)
TCS	10–24,000	(Kasprzyk--Hordern et al., 2008; Kasprzyk--Hordern et al., 2009)	
USA	2-Amino-MX	0.69[a]	(Osemwengie and Gerstenberger, 2004)
	4-Amino-MX	0.21–0.48	(Osemwengie and Gerstenberger, 2004)
	4-NP	41[a]	(Meador et al., 2016)
	BP	360–790	(Loraine and Pettigrove, 2006)
	ADBI	0.029[a]	(Peng et al., 2014)
	HHCB	Nd–4.7 ± 2.5	(Alvarez et al., 2014; Osemwengie and Gerstenberger, 2004; Peng et al., 2014)
	MK	0.081[a]	(Peng et al., 2014)
	MX	0.049[a]	(Peng et al., 2014)
	DEET	Nd–1616.5	(Alvarez et al., 2014; Dougherty et al., 2010)
	NP	53.4–185.6	(Padhye et al., 2014)
	AHMI	0.52[a]	(Peck and Hornbuckle, 2004)
	AHTN	0.08–1.0 ± 1.8	(Osemwengie and Gerstenberger, 2004; Peck and Hornbuckle, 2004)
	ATII	0.081–0.57	(Osemwengie and Gerstenberger, 2004)
	Limonene	Nd–46	(Alvarez et al., 2014)
	TCC	Nd–75	(Blair et al., 2013a; Kumar et al., 2010)
	TCS	Nd–105.8	(Blair et al., 2013a; Padhye et al., 2014)

Nd; Not detected.
[a] Mean concentration.

Table 4
Maximum and minimum concentration reported in groundwater.

Place	Compound	Min-max concentration reported	Reference
Canada	TCC	12[a]	(Gottschall et al., 2012)
	TCS	19[a]	(Gottschall et al., 2012)
China	OPP	8.8[a]	(Peng et al., 2014)
	EPB	12.5[a]	(Peng et al., 2014)
	HHCB	24.9[a]	(Lv et al., 2009)
	MPB	83.2[a]	(Peng et al., 2014)
	MK	<0.18[a]	(Lv et al., 2009)
	MX	<0.09[a]	(Lv et al., 2009)
	DEET	546[a]	(Dai et al., 2015)
	PPB	22.5[a]	(Peng et al., 2014)
	AHTN	19.6 ± 0.8[a]	(Lv et al., 2009)
	TCC	36.2[a]	(Peng et al., 2014)
	TCS	39.9[a]	(Peng et al., 2014)
European Union	DEET	9[a]	(Loos et al., 2010)
	NP	83[a]	(Loos et al., 2010)
France	AHTN	1–50	(Lopez et al., 2015)
	HHCB	1–50	(Lopez et al., 2015)
	MA	439[a]	(Lopez et al., 2015)
	MK	209–1304	(Lopez et al., 2015)
	MX	400–475	(Lopez et al., 2015)
Germany	HHCB	3.0–19.0	(Osenbrück et al., 2007)
Singapore	DEET	5.8–298.4	(Tran et al., 2014)
Spain	BP-3	7.23[a]	(Cabeza et al., 2012)
	BHT	134.78[a]	(Cabeza et al., 2012)
	DPMI	413–573	(Arbulu et al., 2011)
	EHMC	35.31[a]	(Cabeza et al., 2012)
	HHCB	42.9–338	(Arbulu et al., 2011; Cabeza et al., 2012)
	OC	8.42[a]	(Cabeza et al., 2012)
	AHTN	7.5[a]	(Cabeza et al., 2012)
	LAS C10	8.6–19.2	(Valdes-Abellan et al., 2013)
	LAS C11	34.1–86	(Valdes-Abellan et al., 2013)
	LAS C12	15.7–47.6	(Valdes-Abellan et al., 2013)
	LAS C13	7.7–66.6	(Valdes-Abellan et al., 2013)
USA	ACN	nd-26,700	(Barnes et al., 2008)
	DEET	2.3–13,500	(Barnes et al., 2008; Dougherty et al., 2010)
	TCS	Nd- < 1000	(Barnes et al., 2008)
Zambia	TCS	Nd-30	(Sorensen et al., 2015)

Nd; Not detected.
[a] Mean concentration.

Additional articles that contained relevant findings of concentration of PCPs in aquatic environments may have been missed during the search due to a mismatch between their title or abstract keywords and the search keywords used; or the publications were not found on the references of the documents selected from Science Direct and Google Scholar. Other limitation could be that some articles reported compounds that belonged to these groups but were not classified as EPs, hence the importance to perform a text mining in order to identify these chemicals.

4.2. Database description

The interest in PCPs as emerging chemicals of concern has increased in recent decades. The frequency of reports by year included in our database is presented in Fig. 4. The most commonly monitored PCPs as EPs in water matrices were HHCB and AHTN. However, other compounds belonging to fragrances, antiseptics, sunscreens and insect repellents were also regularly detected. In contrast, the occurrence and concentrations in water and wastewater of preservatives, antioxidants, surfactants and flavorants present in cosmetics and cleansing products has been less studied and monitored. Some of them are 2-nonylphenol (2-NP), ACN, 4-chloro-3-methylphenol (CMP), helvetolide and octyl methoxycinnamate (OMC), LAS C10, LAS C11, LAS C12 and LAS C13 (Arbulu et al., 2011; Barnes et al., 2008; Kupper et al., 2006; Peng et al., 2008; Valdes-Abellan et al., 2013; Yu et al., 2006). Therefore, further assessment of the presence and impact of these compounds on human health, biota and environment is fully recommended (Carbajo et al., 2015; Mathieu-Denoncourt et al., 2015; van der Veen and de Boer, 2012).

Most of the information listed in our database was reported from North America, Europe and some Asian countries such as China and Korea. This indicates that even when there is a growing interest in assessing the presence of these contaminants in water, there are few reports in zones such as South America, Asia and Africa. Thus, is necessary to carry out studies to increase the knowledge of occurrence and incidence of PCPs in this places, and determine the possible ecotoxicology effects in the aquatic environment.

4.3. Surface water

A broad range of countries reported the occurrence of PCPs as EPs on surface water, located in Antarctic, Europe, America and Asia continents. However, the highest concentrations were mostly reported from United Kingdom (Supplementary Table 1). In addition, the

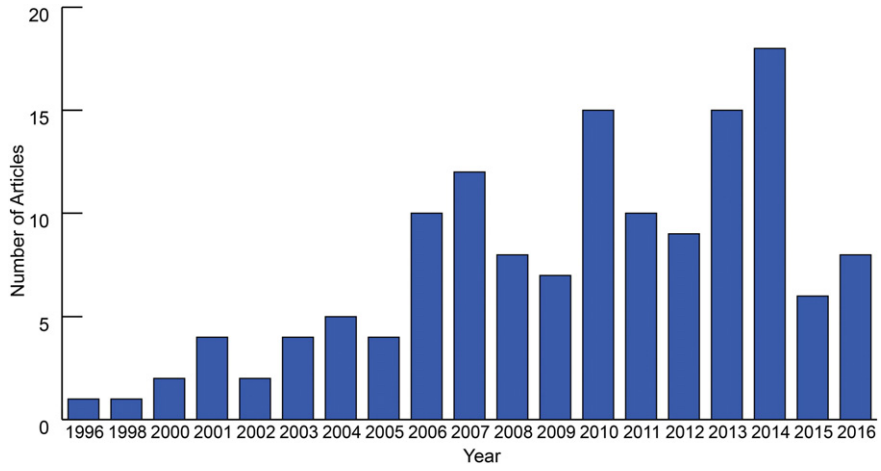


Fig. 4. Articles of PCPs during years.

compound TCS was found at concentrations up to 24,000 ng/L in this country (Kasprzyk-Hordern et al., 2009). It is interesting, as this level has been reported to be toxic for microalgaes such as *Selenastrum capricornutum* (phytoplankton) (Half maximal effective concentration (EC_{50}): 4460 ng/L), *Scenedesmus subspicatus* (microalgae) (EC_{50}:1400 ng/L), *Aphanizomenon flos-aquae* (cyanobacteria) (EC_{50}: 970 ng/L), *Pseudokirchneriella subcapitata* (diatom) (EC_{25}: 3400 ng/L), as well as for the amphibian *Rana pipiens* (LOEC: 2300 ng/L) (Fraker and Smith, 2004; Orvos et al., 2002; Tatarazako et al., 2003; Yang et al., 2008). Besides, there are reports indicating the presence of the antiseptic OP at concentrations up to 1,293,000 ng/L (Kasprzyk-Hordern et al., 2009), which have been proved to be a lethal concentration for the fish *Oryzias latipes* (LC_{50} up to 940,000 ng/L) (Gray and Metcalfe, 1999), and the sunscreen BP-4 with a maximum concentration of 323,000 ng/L (Kasprzyk-Hordern et al., 2009), which surpasses the predicted no effect concentration (PNEC) for *Daphnia magna* (planktonic crustacean) (50,000 ng/L) (Fent et al., 2010). This may represent an ecotoxicological risk for aquatic ecosystems. Therefore, the monitoring and regulation of these pollutants in this area is suggested.

According to our database, the concentrations for the most reported PCPs as EPs in this matrix (Supplementary Table 1), such as HHCB and TCC, are under the EC_{50} for *Acartia tonsa* (planktonic copepod), fishes *Danio rerio*, *O. latipes*, *D. magna*, *Mysidopsis bahia* (crustacean), *P. subcapitata* and *Ceriodaphnia dubia* (water flea) species (Consortium T, 2002; Daughton and Jones-Lepp, 2001; Gooding et al., 2006; Van Dijk, 1997; Yamauchi et al., 2008). However, they could have negative effects on microbiota, because of their bioaccumulation (Coogan et al., 2007), potential alterations on fecundity, growth and development of exposed species (Pedersen et al., 2009; Wagner et al., 1995; Wilkinson et al., 2016). For this reason, it is necessary to continue monitoring the presence of these compounds in surface waters.

On the other hand, articles that presented new and mixed methods to detect PCPs were observed in our database Downs et al., 2016. This shows the interest for developing advanced monitoring techniques for the detection of PCPs chemicals in aquatic biota in order to have good precision, accuracy and low detection limits for the analysis of trace levels of these EPs.

4.4. Groundwater

The concentrations registered for PCPs from groundwater are lower than the reported in other water matrices (Table 4). This could be due to factors such as the pollutants transport, the chemical properties of the molecules or their biodegradability (Gottschall et al., 2012). In addition, some of them belong to the group of endocrine disrupting compounds, such as TCS, MPB, ethylparaben (EPB) and propylparaben (PPB) (Boberg et al., 2010; Peng et al., 2014; US-EPA, 2008). This has become a matter of growing concern, since groundwater supplies drinking water in many regions (Postigo and Barceló, 2015). Besides, these compounds could be more persistent and difficult to eliminate as a result of relatively reduced redox conditions and lack of photodegradation than occur in surface waters (Peng et al., 2014).

The endocrine disruptor TCS has been reported to be toxic to aquatic bacteria and biofilm algae causing an increase of mortality, with a no effect concentration (NEC) of 210 ng/L (Ricart et al., 2010); and inhibition of the photosynthetic efficiency (NEC: 420 ng/L) (Peng et al., 2014; Ricart et al., 2010) and growth (Yang et al., 2013). In addition, it should be noted that contamination of groundwater resources by EPs is relatively poorly understood compared to other freshwater resources (Lapworth et al., 2012; Molins-Delgado et al., 2016; Peng et al., 2014). Hence, further research is required to better assess the effects and possible impacts that these compounds could produce in this matrix.

4.5. Wastewater

According to the information compiled in our internal database, artificial musks were the most frequently listed compounds detected in sewage and sludge. HHCB and AHTN were the most common musks in wastewater, whose vast presence in WWTPs influents suggest the extensive use of these chemicals in everyday products.

The majority of the reports in this matrix were from municipal WWTPs with contributions from domestic and industrial releases; from primary, secondary, and in some cases, tertiary treatment systems (Arbulu et al., 2011; Bartelt-Hunt et al., 2009; Vélez et al., 2016; Ying and Kookana, 2007). All the PCPs detected on WWTP influents were also found after the wastewater treatment in concentrations ranging from 0.1 to 6,325,000 ng/L; except CNP, which was not detected in WWTPs effluents (Kasprzyk-Hordern et al., 2009; Osemwengie and Gerstenberger, 2004), suggesting an inefficient removal in most of the cases (Supplementary Table 4).

WWTPs with conventional treatment systems presented the highest concentrations of PCPs in their effluents, reaching values up to 17,600 ng/L (Vélez et al., 2016). On the other hand, WWTPs that operate with activated sludge (11,007 ng/L) (Vallecillos et al., 2013), biological (2766 ng/L) (Rosal et al., 2010) and tertiary treatments (684 ng/L) (Meador et al., 2016) are more effective to reduce concentrations of PCPs (Supplementary Table 3). In addition, differences between discharged concentrations could be influenced by the stream volume, population size and seasonal variation, among others (Deblonde et al., 2011).

Table 5
Maximum concentrations of most ubiquitous PCPs in wastewaters and toxicity prediction with ECOSAR.

Molecule	ECOSAR class	Species assayed	Test (endpoint)	Predicted toxicity (ng/L)	Max. conc. reported in WWTP effluents (ng/L)	Reference
HHCB	Neutral organics	Fish	LC_{50} (96-h)	30,000	108,000	(Klaschka et al., 2013)
		Daphnid	LC_{50} (48-h)	30,000		
		Green algae	EC_{50} (96-h)	100,000		
		Fish	ChV	5000		
		Daphnid	ChV	10,000		
		Green algae	ChV	60,000		
		Fish (SW)	LC_{50} (96-h)	40,000		
		Mysid	LC_{50} (96-h)	2000		
		Fish (SW)	ChV	600,000		
		Mysid (SW)	ChV	41		
		Earthworm	LC_{50} (14-day)	162440000[a]		
AHTN	Neutral organics	Fish	LC_{50} (96-h)	30,000	7555	(Vallecillos et al., 2014)
		Daphnid	LC_{50} (48-h)	20,000		
		Green algae	EC_{50} (96-h)	90,000		
		Fish	ChV	4000		
		Daphnid	ChV	7000		
		Green algae	ChV	60,000		
		Fish (SW)	LC_{50} (96-h)	30,000		
		Mysid	LC_{50} (96-h)	1300		
		Fish (SW)	ChV	53,000		
		Mysid (SW)	ChV	32.1		
		Earthworm	LC_{50} (14-day)	159190000[a]		
TCS	Phenols	Fish	LC_{50} (96-h)	480,000	82,000	(Kasprzyk-Hordern et al., 2009)
		Daphnid	LC_{50} (48-h)	470,000		
		Green algae	EC_{50} (96-h)	1,660,000		
		Fish	ChV	70,000		
		Daphnid	ChV	90,000		
		Green algae	ChV	760,000		
		Fish (SW)	LC_{50} (96-h)	130,000		
		Earthworm	LC_{50} (14-day)	21920000[a]		
		Lemna gibba	EC_{50} (7-day)	170,000		
DEET	Amides	Fish	LC_{50} (96-h)	37,370,000	2110	(Loraine and Pettigrove, 2006)
		Daphnid	LC_{50} (48-h)	36,540,000		
		Green algae	EC_{50} (96-h)	1,240,000		
		Fish	ChV	70,000		
		Daphnid	ChV	2,430,000		
		Green algae	ChV	1,300,000		
		Fish (SW)	LC_{50} (96-h)	33,100,000		
		Mysid (SW)	LC_{50} (96-h)	2,270,000		
BP-3	Phenols	Fish	LC_{50} (96-h)	2,750,000	2,196,000	(Kasprzyk-Hordern et al., 2009)
		Daphnid	LC_{50} (48-h)	1,630,000		
		Green algae	EC_{50} (96-h)	6,470,000		
		Fish	ChV	350,000		
		Daphnid	ChV	310,000		
		Green algae	ChV	2,980,000		
		Fish (SW)	LC_{50} (96-h)	930,000		
		Earthworm	LC_{50} (14-day)	50,460,000		
		Lemna gibba	EC_{50} (7-day)	1,340,000		
MPB	Esters	Fish	LC_{50} (96-h)	20,430,000	155,000	(Kasprzyk-Hordern et al., 2009)
		Daphnid	LC_{50} (48-h)	42,490,000		
		Green algae	EC_{50} (96-h)	18,090,000		
		Fish	ChV	1,540,000		
		Daphnid	ChV	29,080,000		
		Green algae	ChV	4,630,000		
		Fish (SW)	LC_{50} (96-h)	31,090,000		
		Mysid	LC_{50} (96-h)	30,630,000		
		Fish (SW)	ChV	4,450,000		
		Mysid (SW)	ChV	2,268,910,000		
		Earthworm	LC_{50} (14-day)	1,988,560,000		
Menthol	Neutral organics	Fish	LC_{50} (96-h)	7,380,000	900	(Lee and Rasmussen, 2006)
		Daphnid	LC_{50} (48-h)	4,760,000		
		Green algae	EC_{50} (96-h)	6,010,000		
		Fish	ChV	840,000		
		Daphnid	ChV	660,000		
		Green algae	ChV	2,090,000		
		Fish (SW)	LC_{50} (96-h)	9,370,000		
		Mysid	LC_{50} (96-h)	2,730,000		
		Fish (SW)	ChV	2,360,000		
		Mysid (SW)	ChV	160,000		
		Earthworm	LC_{50} (14-day)	195,360,000		
BHT	Phenols	Fish	LC_{50} (96-h)	190,000	579	(Godayol et al., 2015)
		Daphnid	LC_{50} (48-h)	220,000		
		Green algae	EC_{50} (96-h)	760000[a]		
		Fish	ChV	30,000		
		Daphnid	ChV	42,000		
		Green algae	ChV	340,000		
		Fish (SW)	LC_{50} (96-h)	50,000		
		Earthworm	LC_{50} (14-day)	11820000[a]		
		Lemna gibba	EC_{50} (7-day)	60,000		

SW: Salt water. LC_{50}: median lethal concentration. EC_{50}: half maximal effective concentration. ChV: Chronic value.
[a] Chemical may not be soluble enough to measure this predicted effect.

The concentration of some PCPs found in WWTPs effluents are above the chronic toxicity threshold for some species, such as HHCB (up to 108,000 ng/L) (Kasprzyk-Hordern et al., 2009) that affects *A. tonsa* (EC_{50}: 59,000 ng/L), *Neopachyloides spinipes* (harpacticoid) (LOEC: 20,000 ng/L), and *D. magna* (NOEC: 10,000 ng/L) (Carlsson and Norrgren, 2004; Grützner, 1995;

Table 6
Maximum concentrations of PCPs reported in surface waters that exceed the toxicity prediction by ECOSAR.

Molecule	ECOSAR class	Species assayed	Test (endpoint)	Predicted toxicity (ng/L)	Max. conc. reported in surface water (ng/L)	Reference
HHCB	Neutral organics	Fish	LC_{50} (96-h)	30,000	13,920	(Lee et al., 2010)
		Daphnid	LC_{50} (48-h)	30,000		
		Green algae	LC_{50} (96-h)	100,000		
		Fish	EC_{50}	5000		
		Daphnid	ChV	10,000		
		Green algae	ChV	60,000		
		Fish (SW)	LC_{50} (96-h)	40,000		
		Mysid	LC_{50} (96-h)	2000		
		Fish (SW)	ChV	600,000		
		Mysid (SW)	ChV	41		
		Earthworm	LC_{50} (14-day)	162440000[a]		
AHTN	Neutral organics	Fish	LC_{50} (96-h)	30,000	2800	(Lee et al., 2010)
		Daphnid	LC_{50} (48-h)	20,000		
		Green algae	EC_{50} (96-h)	90,000		
		Fish	ChV	4000		
		Daphnid	ChV	7000		
		Green algae	ChV	60,000		
		Fish (SW)	LC_{50} (96-h)	30,000		
		Mysid	LC_{50} (96-h)	1300		
		Fish (SW)	ChV	53,000		
		Mysid (SW)	ChV	32.1		
		Earthworm	LC_{50} (14-day)	159190000[a]		
2-NP	Phenols	Fish	LC50 (96-h)	36,000	33,231	(Peng et al., 2008)
		Daphnid	LC50 (48-h)	63,000		
		Green algae	EC50 (96-h)	197,000		
		Fish	ChV	6000		
		Daphnid	ChV	12,000		
		Green algae	ChV	88,000		
		Fish (SW)	LC50 (96-h)	8000		
		Earthworm	LC50 (14-day)	4478700[a]		
		Lemna gibba	EC50 (7-day)	9000		
3,4,5,6-tetrabromo-o-cresol	Phenols	Fish	LC50 (96-h)	130000[a]	140,000	(Kasprzyk-Hordern et al., 2009)
		Daphnid	LC50 (48-h)	197000[a]		
		Green algae	EC50 (96-h)	637000[a]		
		Fish	ChV	22,000		
		Daphnid	ChV	37,000		
		Green algae	ChV	286000[a]		
		Fish (SW)	LC50 (96-h)	30,000		
		Earthworm	LC50 (14-day)	13026000[a]		
		Lemna gibba	EC50 (7-day)	38,000		
4-NP	Phenols	Fish	LC50 (96-h)	36,000	8890	(Zhao et al., 2009)
		Daphnid	LC50 (48-h)	63,000		
		Green algae	EC50 (96-h)	197,000		
		Fish	ChV	6000		
		Daphnid	ChV	12,000		
		Green algae	ChV	88,000		
		Fish (SW)	LC50 (96-h)	8000		
		Earthworm	LC50 (14-day)	4,787,000		
		Lemna gibba	EC50 (7-day)	9000		
OP	Phenols	Fish	LC50 (96-h)	116,000	1,293,000	(Kasprzyk-Hordern et al., 2009)
		Daphnid	LC50 (48-h)	150,000		
		Green algae	EC50 (96-h)	503,000		
		Fish	ChV	19,000		
		Daphnid	ChV	28,000		
		Green algae	ChV	227,000		
		Fish (SW)	LC50 (96-h)	29,000		
		Earthworm	LC50 (14-day)	8773000[a]		
		Lemna gibba	EC50 (7-day)	37,000		
PCMX	Phenols	Fish	LC50 (96-h)	3,041,000	358,000	(Kasprzyk-Hordern et al., 2009)
		Daphnid	LC50 (48-h)	1,599,000		
		Green algae	EC50 (96-h)	6,512,000		
		Fish	ChV	369,000		
		Daphnid	ChV	304,000		
		Green algae	ChV	3,011,000		
		Fish (SW)	LC50 (96-h)	1,088,000		
		Earthworm	LC50 (14-day)	44,764,000		
		Lemna gibba	EC50 (7-day)	1,593,000		

SW: Salt water. LC_{50}: median lethal concentration. EC_{50}: half maximal effective concentration. ChV: Chronic value.
[a] Chemical may not be soluble enough to measure this predicted effect.

Wüthrich, 1996); BP-4 (up to 6,325,000 ng/L) (Kasprzyk-Hordern et al., 2009) that exceeded the LOEC of *Oncorhynchus mykiss* (fish) (4,897,000 ng/L) (Kunz et al., 2006), as well as all the benzophenone-derived compounds reported by Kasprzyk-Hordern et al. (2009), which presented concentrations that could cause coral bleaching (2280 ng/L) (Downs et al., 2016).

Toxicological studies of some EPs have been performed in aquatic species as indicated before, however, the risk and effects associated with the occurrence of other PCPs in water is still unknown, due to the lack of ecotoxicological data. Therefore, prediction programs have been implemented to evaluate the potential toxicity of chemicals, such as ECOSAR, a computer program developed and applied by the US EPA for the prediction of aquatic toxicity in fish, aquatic invertebrates, and green algaes (Cash and Nabholz, 2001).

Toxicity predictions on ECOSAR (Table 5) show that some aquatic species could be potentially affected by the maximum concentrations reported for the most abundant PCPs in WWTPs effluents, such as HHCB (108,000 ng/L) (Klaschka et al., 2013), which exceeds fish, daphnid and mysid LC_{50} and chronic value (ChV), as well as green algae is above EC_{50} and ChV values. Similarly, AHTN (7555 ng/L) (Vallecillos et al., 2014) surpass fish and daphnid ChV, and mysid LC_{50} and ChV; BP-3 (2,196,000 ng/L) (Kasprzyk-Hordern et al., 2009) exceeds fish and daphid LC_{50} and ChV, and *lemna gibba* EC_{50}, and TCS (82,000 ng/L) (Kasprzyk-Hordern et al., 2009) is above fish ChV.

The WWTPs effluents could increase the concentration of PCPs on aquatic environments, particularly in effluent-dominant rivers whose dilution capacity and self-purifying processes are not able to mitigate the potential risk to aquatic life (Kasprzyk-Hordern et al., 2009). Additionally, the concentrations reported for some PCPs in surface water surpasses EC_{50}, LC_{50} and ChV values predicted for a variety of species by ECOSAR, such as of HHCB, AHTN, 2-NP, 3,4,5,6-tetrabromo-o-cresol, 4-NP, OP, and PCMX (Table 6). This evidences the need to regulate these compounds in order to prevent a further incursion into aquatic environments.

5. Conclusion

In this review, a systematic research was performed, only selecting the articles that contained concentrations in water matrices of PCPs explicitly reported as EPs. PCPs have been found in all the continents in aquatic ecosystems, even at concentrations above the toxicity threshold for some species. Additional efforts should be made to assess the occurrence and impact of these chemicals in water bodies from South America, Asia and Africa; as well as in groundwater reservoirs over the world due to the limited information available. Fragrances, antiseptics, sunscreens and insect repellents were the most commonly monitored compounds, while preservatives, antioxidants and flavorants present in cosmetics and cleansing products has been less studied as EPs in water matrices. The polycyclic musks HHCB and AHTN, as well as the endocrine disruptor TCS were the most frequently found compounds, then its assessment and regulation is suggested.

Conflict of interest

The authors declare that there is no conflict of interest.

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