Science of the Total Environment 595 (2017) 601–614

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Review

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

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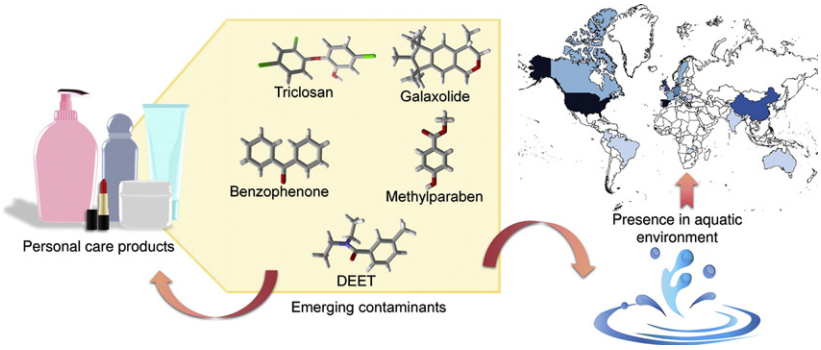
HIGHLIGHTS

- 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



ARTICLE INFO

Article history:
Received 3 February 2017
Received in revised form 26 March 2017
Accepted 31 March 2017
Available online 8 April 2017

Editor: Jay Gan

Keywords:
PCPs
Emerging pollutant

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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http://dx.doi.org/10.1016/j.scitotenv.2017.03.286

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)

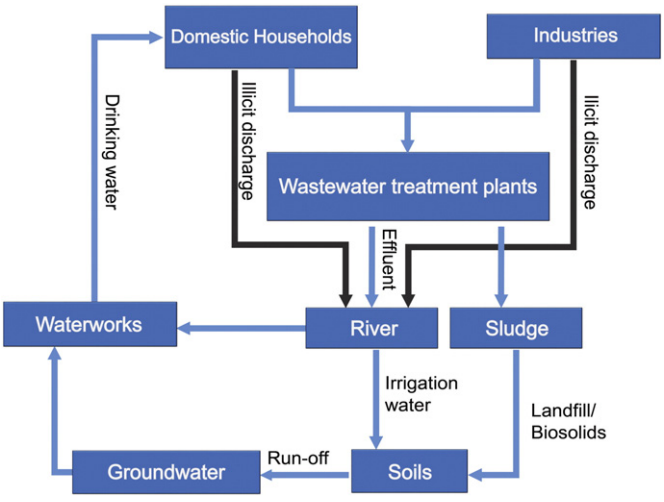

Fig. 1. Sources and pathways of PCPS. Adapted from (Ellis, 2006).