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Review

Occurrences and removal of pharmaceuticals and personal care products (PPCPs) in drinking water and water/sewage treatment plants: A review

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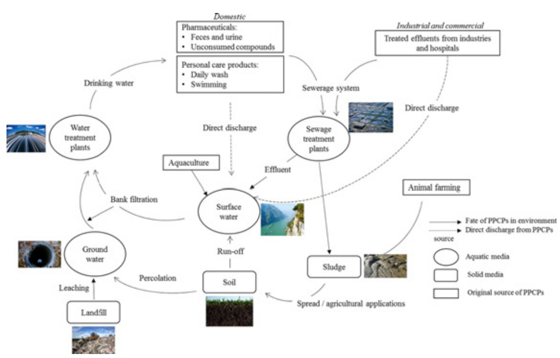
HIGHLIGHTS

- There is a large variation in PPCP removal in STPs and WTPs (−157–100%).
- PPCP removal is dependent on compound characteristics and process-specific factors.
- Advanced treatment technologies are effective for PPCP removal.

GRAPHICAL ABSTRACT



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ABSTRACT

In recent years, many of micropollutants have been widely detected because of continuous input of pharmaceuticals and personal care products (PPCPs) into the environment and newly developed state-of-the-art analytical methods. PPCP residues are frequently detected in drinking water sources, sewage treatment plants (STPs), and water treatment plants (WTPs) due to their universal consumption, low human metabolic capability, and improper disposal. When partially metabolized PPCPs are transferred into STPs, they elicit negative effects on biological treatment processes; therefore, conventional STPs are insufficient when it comes to PPCP removal. Furthermore, the excreted metabolites may become secondary pollutants and can be further modified in receiving water bodies. Several advanced treatment systems, including membrane filtration, granular activated carbon, and advanced oxidation processes, have been used for the effective removal of individual PPCPs. This review covers the occurrence patterns of PPCPs in water environments and the techniques adopted for their treatment in STP/WTP unit processes operating in various countries. The aim of this review is to provide a comprehensive summary of the removal and fate of PPCPs in different treatment facilities as well as the optimum methods for their elimination in STP and WTP systems.

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Contents

1. Introduction

In recent decades, pharmaceuticals and personal care products (PPCPs) have been recognized as contaminants of emerging concern because of their persistent presence in aquatic environments. The term "PPCPs" broadly refers to any product with healthcare or medical purposes for humans and/or animals. Interest in the safety issue of PPCPs has been steadily increased over the past 30 years (Schumock et al., 2014). PPCPs are known to be released into aquatic environments through multiple pathways, including domestic wastewater, hospital discharges, improper manufacturer disposal, sewage treatment plants (STPs), and water treatment plants (WTPs) (Leung et al., 2012; Liu and Wong, 2013). Compared with domestic sewage, hospital effluents generally exhibit higher detection frequencies and concentrations of pharmaceuticals (Kosma et al., 2010; Oliveira et al., 2015). The excreted PPCPs may either retain their original concentrations and structures or be mobilized and converted into other active (or inactive) compounds during their lifespan in aquatic matrices.

PPCPs are generally present in surface water, groundwater, drinking water, and sewage at concentrations of parts-per-trillion (ng/L) to parts-per-billion (μg/L) (Dai et al., 2015). However, the removal efficiency of PPCPs in conventional STPs is low (Behera et al., 2011), because the most commonly used treatment system in secondary STPs (i.e., activated sludge process (ASP)) is originally designed for the removal of organic matter (i.e., BOD) and suspended solids to meet the minimum discharge standard (Hua et al., 2008; Tsang, 2015). STPs have been identified as a primary source of PPCPs in the aquatic environment (Focazio et al., 2008; Padhye et al., 2014). Although the concentration of PPCPs in sewage influent is relatively low, PPCPs that are present as either individual molecules or as complexes may exert considerably toxic or inhibitory effects on activated sludge bacteria, resulting in deteriorated removal efficiency (Thomaidi et al., 2015, 2016).

Regulation of PPCPs has been strictly enforced and implemented to minimize their consumptions (Daughton, 2002). However, the use of these products is unlikely to be restricted because of their beneficial properties for humans and animals (Jones et al., 2005). Extensive profiling of PPCPs has been pursued in aquatic environments (Boxall et al., 2012). However, data on their metabolites, by-products, and degradation products are very limited (Miao et al., 2005; Borova et al., 2014).The fates and removal mechanisms of PPCPs in STPs and WTPs have not been fully understood (Stasinakis et al., 2013; Blair et al., 2015). Thus, numerous analytical methods have been developed to assess the profiles and occurrence patterns of PPCPs during the last decade (Evgenidou et al., 2015).

Several review articles have reported the ecotoxicological effects of PPCPs (Brausch and Rand, 2011) and their occurrences in various water bodies, including groundwater (Lapworth et al., 2012), surface water and wastewater (Liu and Wong, 2013), and STPs (Feng et al., 2013; Evgenidou et al., 2015). However, such studies have generally been limited to single/few treatment plants and the removal performance of the corresponding unit process. This review initially focuses on the profiles of common PPCPs in both natural and artificial environments. It is then extended to discuss the performance of PPCP removal of different treatment systems employed at each unit process in STPs and WTPs in different regions, and describe the advanced treatment methods available for effective PPCP removal. Findings from over 200 studies of 219 STPs and WTPs in the US, Asia, and Europe are summarized and discussed (Tables 2a–4b). Considering that differences in the operational and experimental conditions of studies may influence the results, the detailed operating conditions of various STPs and WTPs and their relevant experimental information are presented in Supplementary materials (Tables S1 and S2).

1.1. Classification of PPCPs

PPCPs can be classified into multiple groups according to their properties and purposes. Pharmaceuticals generally include antibiotics, hormones, analgesics, anti-inflammatory drugs, blood lipid regulators, β-blockers, and cytostatic drugs. Personal care products (PCPs) include preservatives, bactericides/disinfectants, insect repellents, fragrances, and sunscreen ultraviolet (UV) filters (Kosma et al., 2010; Liu and Wong, 2013). The typical classification of PPCPs and the representative compounds are summarized in Table 1 (Esplugas et al., 2007; Liu and Wong, 2013). To date, >3000 PPCPs have been used for the medical treatment of both humans and animals and for the enhancement of their living standards (Muthanna and Plósz, 2008). Numerous drugs are hydrolyzed or metabolized to form water-stabilized metabolites