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Review

A review on the occurrence of micropollutants in the aquatic environment and their fate and removal during wastewater treatment

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HIGHLIGHTS

- Micropollutants occur in the aquatic environment all over the world.
- There is a large variation in micropollutant removal (12.5–100%) in WWTPs.
- Micropollutant removal is dependent on compound- and process-specific factors.
- Advanced treatment technologies achieve better micropollutant removal.

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ABSTRACT

Micropollutants are emerging as a new challenge to the scientific community. This review provides a summary of the recent occurrence of micropollutants in the aquatic environment including sewage, surface water, groundwater and drinking water. The discharge of treated effluent from WWTPs is a major pathway for the introduction of micropollutants to surface water. WWTPs act as primary barriers against the spread of micropollutants. WWTP removal efficiency of the selected micropollutants in 14 countries/regions depicts compound-specific variation in removal, ranging from 12.5 to 100%. Advanced treatment processes, such as activated carbon adsorption, advanced oxidation processes, nanofiltration, reverse osmosis, and membrane bioreactors can achieve higher and more consistent micropollutant removal. However, regardless of what technology is employed, the removal of micropollutants depends on physico-chemical properties of micropollutants and treatment conditions. The evaluation of micropollutant removal from municipal wastewater should cover a series of aspects from sources to end uses. After the release of micropollutants, a better understanding and modeling of their fate in surface water is essential for effectively predicting their impacts on the receiving environment.

Contents

Abbreviations: AOP, advanced oxidation process; ASFBBR, aerated submerged fixed bed bioreactor; BAC, biological activated carbon; CAFO, concentrated animal feeding operation; CAS, conventional activate sludge; DBP, di-butyl phthalate; DEET, N,N-Diethyl-meta-toluamide; DEHP, di(2-ethylhexyl) phthalate; DMP, di-methyl phthalate; DOM, dissolved organic matter; EDC, endocrine disrupting compound; GAC, granule activated carbon; HRT, hydraulic retention time; IFAS, fixed film activated sludge; K_d, solid-water distribution coefficient; k_H, Henry's law constant; K_{OW}, octanol–water partition coefficient; MBBR, moving bed biofilm reactor; MBR, membrane bioreactor; MF, microfiltration; NF, nanofiltration; NOM, natural organic matter; NSAID, nonsteroidal anti-inflammatory drug; PAC, powdered activated carbon; PCP, personal care product; pK_a, acid dissociation constant; PNEC, predicted no effect concentration; PPCP, pharmaceutical and personal care product; RO, reverse osmosis; SAnMBR, submerged anaerobic membrane bioreactor; SBBGR, sequencing batch biofilter granular reactor; SRT, sludge retention time; TCEP, tris(2-chloroethyl) phosphate; TCPP, tris(1-chloro-2-propyl) phosphate; UF, ultrafiltration; WWTP, wastewater treatment plant.

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1. Introduction

Over the last few decades, the occurrence of micropollutants in the aquatic environment has become a worldwide issue of increasing environmental concern. Micropollutants, also termed as emerging contaminants, consist of a vast and expanding array of anthropogenic as well as natural substances. These include pharmaceuticals, personal care products, steroid hormones, industrial chemicals, pesticides and many other emerging compounds. Micropollutants are commonly present in waters at trace concentrations, ranging from a few ng/L to several μg/L. The 'low concentration' and diversity of micropollutants not only complicate the associated detection and analysis procedures but also create challenges for water and wastewater treatment processes.

Current wastewater treatment plants (WWTPs) are not specifically designed to eliminate micropollutants. Thus, many of these micropollutants are able to pass through wastewater treatment processes by virtue of their persistency or/and the continuous introduction. In addition, precautions and monitoring actions for micropollutants have not been well established in most WWTPs (Bolong et al., 2009). Consequently, many of these compounds may end up in the aquatic environment, becoming threats to wildlife and spelling trouble for drinking water industry. The occurrence of micropollutants in the aquatic environment have been frequently associated with a number of negative effects, including short-term and long-term toxicity, endocrine disrupting effects and antibiotic resistance of microorganisms (Fent et al., 2006; Pruden et al., 2006). To date, discharge guidelines and standards do not exist for most micropollutants. Some countries or regions have adopted regulations for a small number of micropollutants. For example, environmental quality standards for a minority of micropollutants (e.g. nonylphenol, bisphenol A, DEHP and diuron) have been stipulated in Directive 2008/105/EC (European Parliament and The Council, 2008). Nonylphenol and nonylphenol ethoxylates have also been recognized as toxic substances by the Canadian government (Canadian Environmental Protection Act, 1999). Other micropollutants, such as pharmaceutical and personal care products (PPCPs) and steroid hormones, are not included in the list of regulated substances yet. To set regulatory limits for micropollutants, further research on biological responses to these compounds (both acute and chronic effects) is of particular importance. Furthermore, scientific community and regulatory agencies should gain insight into not only the impact of individual micropollutants, but also their synergistic, additive, and antagonistic effects.

Several review papers have been published with regard to the occurrence of micropollutants in different water bodies such as wastewater (Deblonde et al., 2011) and groundwater (Lapworth et al., 2012), as well as treatment methods for micropollutant removal (Bolong et al., 2009). In addition, Verlicchi et al. (2012) reviewed the pharmaceutical removal efficiency in conventional activated sludge systems and in MBR fed by municipal wastewater, while Liu et al. (2009) focused on the physical, chemical and biological removal of endocrine disrupting compounds (EDCs). However, no attempt has been made to provide a comprehensive summary of the occurrence of miscellaneous micropollutants in aquatic systems as well as the removal of micropollutants in conventional and advanced treatment processes. In this review, we systematically summarized the recent occurrence of various micropollutants in the aquatic environment and delineated the behavior and removal of micropollutants during conventional as well as advanced wastewater treatment processes.

2. Occurrence of micropollutants in the aquatic environment

Sources of micropollutants in the environment are diverse and many of these originate from mass-produced materials and commodities. Table 1 summarizes the sources of the major categories of micropollutants in the aquatic environment.

The recent occurrence (2008 to date) of the micropollutants in the aquatic environment has been reviewed in terms of their aqueous concentrations in different types of waters, including wastewater, surface water, groundwater and drinking water. Of all aqueous media, WWTP influent and effluent are comprehensively reviewed. The collected data consist of the studies performed in a number of countries/regions, including Austria, China, EU-wide, France, Germany, Greece, Italy, Korea, Spain, Sweden, Switzerland, Western Balkan Region, UK and US. In general, the investigated micropollutants can be divided into six categories namely pharmaceuticals, personal care products, steroid hormones, surfactants, industrial chemicals and pesticides.

2.1. Occurrence of micropollutants in WWTPs

Occurrence data of micropollutants in WWTP influent and effluent from recent studies (2008–present) are summarized in Table 2. As can be noted from the table, the reported concentrations of micropollutants in WWTP influent and effluent reveal significant spatial and temporal variations, which are essentially due to a number of factors, including the rate of production, specific sales and practices, metabolism (excretion rate), water consumption per person and per day, the size of