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Review

Urban wastewater treatment plants as hotspots for the release of antibiotics in the environment: A review

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ABSTRACT

Urban wastewater treatment plants (UWTPs) are among the main sources of antibiotics' release into various compartments of the environment worldwide. The aim of the present paper is to critically review the fate and removal of various antibiotics in wastewater treatment, focusing on different processes (*i.e.* biological processes, advanced treatment technologies and disinfection) in view of the current concerns related to the induction of toxic effects in aquatic and terrestrial organisms, and the occurrence of antibiotics that may promote the selection of antibiotic resistance genes and bacteria, as reported in the literature. Where available, estimations of the removal of antibiotics are provided along with the main treatment steps. The removal efficiency during wastewater treatment processes varies and is mainly dependent on a combination of antibiotics' physicochemical properties and the operating conditions of the treatment systems. As a result, the application of alternative techniques including membrane processes, activated carbon adsorption, advanced oxidation processes (AOPs), and combinations of them, which may lead to higher removals, may be necessary before the final disposal of the effluents or their reuse for irrigation or groundwater recharge.

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1. Introduction

During the last years, it is recognized that antibiotics constitute a new class of water contaminants of emerging concern with adverse effects on the aquatic life (Kolpin et al., 2002; Kümmerer, 2009; Fatta-Kassinos et al., 2011a). The generic term "antibiotic" is used herein to denote any class of organic molecule that inhibits or kills microbes by specific interactions with bacterial targets, without any consideration of the source of the particular compound or class (Davies and Davies, 2010). Investigations for the occurrence of various antibiotics in wastewater effluents have been conducted in several European countries (Jones et al., 2001; Heberer, 2002; Miao et al., 2004; Batt et al., 2007; Gulkowska et al., 2008; Kümmerer, 2009; Fatta-Kassinos et al., 2011a). Because of the intensive use of antibiotics for human (domestic and hospital use), veterinary and agriculture purposes, these compounds are continuously released into the environment from anthropogenic sources, such as urban wastewater treatment plants (UWTPs), which are considered as one of the main 'hotspots' of potential evolution and spreading of antibiotic resistance into the environment (Hirsch et al., 1999; Diaz-Cruz et al., 2003; Brown et al., 2006; Kümmerer, 2009; Czekalski et al., 2012; Le Corre et al., 2012). The presence of antibiotics in environmentally relevant concentration levels has been associated to chronic toxicity and the prevalence of resistance to antibiotics in bacterial species (Schwartz et al., 2006; Kümmerer, 2009).

The number of studies focusing on the chronic toxicological assessment of antibiotics in the environment is constantly increasing with the aim to bridge the various knowledge gaps (*i.e.* relevant endpoints to be considered in chronic bioassays) associated with these issues. Boxall (2004) and Kümmerer (2009) represent two comprehensive review articles regarding the ecotoxicity of antibiotics. Thomulka and McGee (1993) determined for example the toxicity of a number of antibiotics (*e.g.* novobiocin, tetracycline, chloramphenicol, nalidixic acid, ampicillin, streptomycin) on *Vibrio harveyi* in two bioassay methods. Almost no toxic effects were found after short incubation times when luminescence was used as an endpoint. However, in a long-term assay using reproduction as the endpoint, a toxic effect in environmentally relevant concentrations was detected for almost all the examined antibiotics. These results are in accordance with the observations of Froehner et al. (2000) concerning chloramphenicol, nalidixic acid and streptomycin. The chronic toxicity of several groups of antibiotics toward *Vibrio fischeri* is also presented in a study by Backhaus and Grimme (1999). The chronic bioluminescence inhibition assay was shown to be sensitive against many of the high volume antibiotics used for veterinary purposes and in aquaculture. Furthermore, exposure to antibiotics may have adverse effects on the reproductive system in the early life stages of different organisms like the freshwater flea *Daphnia magna* and the crustacean *Artemia salina* (Macrì et al., 1988; Wollenberger et al., 2000). In the study by Kim et al. (2007), sulfonamides (*i.e.* sulfamethoxazole, sulfachloropyridazine, sulfathiazole, sulfamethazine, sulfadimethoxine), and trimethoprim, were examined for their acute aquatic toxicity by employing a marine bacterium (*V. fischeri*), a freshwater flea (*D. magna*) and the Japanese medaka fish (*Oryzias latipes*). In this study, *D. magna* was in general the most susceptible in terms of effective/lethal concentrations-E/LC_{50}, among the test organisms.

Moreover, the extensive use of antibiotics has contributed to the development of antibiotic resistance genes and bacteria, reducing the therapeutic potential against human and animal pathogens (Kemper, 2008). The consequences are particularly worrying as bacteria in the aquatic environment can be continually exposed to antibiotic residues (Rosal et al., 2010). The biological treatment process creates an environment potentially suitable for resistance development and spreading, because bacteria are continuously exposed to