Research article

Shadow prices of emerging pollutants in wastewater treatment plants: Quantification of environmental externalities

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A B S T R A C T

Conventional wastewater treatment plants (WWTPs) are designed to remove mainly the organic matter, nitrogen and phosphorus compounds and suspended solids from wastewater but are not capable of removing chemicals of human origin, such as pharmaceutical and personal care products (PPCPs). The presence of PPCPs in wastewater has environmental effects on the water bodies receiving the WWTP effluents and renders the effluent as unsuitable as a nonconventional water source. Considering PPCPs as non-desirable outputs, the shadow prices methodology has been implemented using the output distance function to measure the environmental benefits of removing five PPCPs (acetaminophen, ibuprofen, naproxen, carbamazepine and trimethoprim) from WWTP effluents discharged to three different ecosystems (wetland, river and sea). Acetaminophen and ibuprofen show the highest shadow prices of the sample for wetland areas. Their values are 128.2 and 11.0 €/mg respectively. These results represent a proxy in monetary terms of the environmental benefit achieved from avoiding the discharge of these PPCPs in wetlands. These results suggest which PPCPs are urgent to remove from wastewater and which ecosystems are most vulnerable to their presence. The findings of this study will be useful for the plant managers in order to make decisions about prioritization in the removal of different pollutants.

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1. Introduction

Water stress, due to weather and the overexploitation of water sources, complicates the ability to meet the increasing water demands of contemporary society. Nonconventional water sources, including regenerated water, offer solutions to this problem, particularly in arid and semiarid regions. However, the main problem with the reuse of wastewater treatment plant (WWTP) effluent is the final water quality because of many processes are not designed to remove the chemicals of anthropogenic origin, including pharmaceuticals and personal care products (PPCPs) (Fang et al., 2012; Morais et al., 2014; Santos et al., 2013). Conventional WWTPs are mainly designed for the removal of suspended solids and organic matter (Binelli et al., 2014). As a result, PPCPs leave WWTPs through the “treated” effluent and reach receiving water bodies, where the chemicals spread and accumulate in water, sediment and organisms (Arlos et al., 2015; Carmona et al., 2014; Zenker et al., 2014). In this way, WWTPs become the point of discharge and dispersion of PPCPs in the aquatic ecosystem (Prosser and Sibley, 2013). Kasprzyk-Hordern et al. (2008) estimated that 50% of PPCPs that arrive at WWTPs are discharged through the effluent without any change of their toxic activity. Many authors have analysed the concentrations of PPCPs in rivers and lakes, into which the effluents from WWTPs have been discharged. All of these reports confirmed the presence of PPCPs in receiving water bodies and emphasised the need to address the problem in order to improve water quality for reuse purposes (Baker and Kasprzyk-Hordern, 2013; Blair et al., 2013; Ferguson et al., 2013; Spongberg et al., 2011; Wang et al., 2015; Zenobio et al., 2015).

PPCPs in wastewater are presented in a complex mixture of substances (Yuan et al., 2013) whose toxicity affects even the microbial community found in conventional activated sludge treatment processes (Liu and Wong, 2013). The most commonly found PPCPs in urban wastewater include plasticisers, surfactants, pharmaceuticals, drugs of abuse, hormones, personal care compounds, contrast mediums and sweeteners, among others (Miège et al., 2009; Pal et al., 2014). The occurrence and concentrations of these compounds vary. Ibuprofen is the most commonly detected...
pharmaceutical because of its frequent worldwide consumption (Fang et al., 2012). Many authors have performed studies to identify the specific PPCPs in wastewater samples, analysed their concentrations and examined different options for their elimination (Al Aukidy et al., 2012; Baker et al., 2012; Blair et al., 2015; Collado et al., 2014; Fernández et al., 2014; Godayol et al., 2015; Kumar et al., 2011; Silva et al., 2014). Although the PPCPs found in wastewater vary depending on the study area, overall, the frequencies with which PPCPs appear are greater than 50% (i.e. more than half of PPCPs are found in all samples analysed). From an environmental perspective, PPCPs in WWTP effluents can be considered as indicators of anthropogenic pollution in water bodies (Van Stemvpoort et al., 2013).

One possible way to reduce PPCP levels in water bodies is through tertiary treatment technologies. However, not in all cases WWTPs incorporate tertiary treatment technologies. For example, in Spain only 9% of urban wastewater receives tertiary treatment (AEAS, 2002). This situation makes the presence of PPCPs in the effluent of the WWTPs relevant for water reuse purposes. Hence, it is necessary to quantify overall costs of wastewater treatment processes (including technological improvements in WWTPs) for selecting the proper technology to remove them. Some authors have assessed the efficiency of removing PPCPs by different processes, such as advanced oxidation, ozonisation and activated carbon (Mailler et al., 2016; Rosal et al., 2010; Tang et al., 2014; Zhang and Geißen, 2010). When the characteristics of raw wastewaters that reach the WWTP are known, all of these technologies are able to reduce the PPCP concentration in the effluent substantially (up to 80%). Thus, by monitoring and removing PPCPs, the addition of tertiary treatment to urban WWTPs could be the key step to improving wastewater treatment (Alfonsín et al., 2014). Although technological improvement is the most appropriate solution for improving WWTP effluents, the economic implications of such investments should be considered. The current trend of the economy, in relation to the environment, is to include the environmental externalities within feasibility analysis.

Including environmental externalities in feasibility analysis allows to quantify properly the costs of wastewater treatment. However, determine monetary value of environmental externalities is not an easy process. There are many limitations that must be overcome, like the own complexity of ecosystem and the lack of standard methodology for monetary valuation (Kallis et al., 2013).

To begin with, it is required a proper identification of the environmental externalities and environmental goods and services that are being evaluated as well as the selection of the suitable methodology for the valuation purposes (Lamarque et al., 2011). Those environmental goods and services which provide tradable goods are easy to value (as wood production) due to their market value. However not all environmental goods and services have market value. Water quality, for example, is a significant part of ecosystems without market value. Poor water quality means a serious deterioration of ecosystems, including loss of biodiversity. Hence, for achieve a proper assessment of environmental externalities, the monetary valuation of ecosystems should include not only the environmental goods and services with market value but those without this market value. Obtaining the monetary value of these environmental goods and services aims to raise awareness about the importance of an ecosystem, through the calculation of monetary value of a good and ecosystem service that lacks a market (Kallis et al., 2013). Hence, this monetary value is associated with an efficient use of the resource since the managers know its significance (Wallace, 2007). Monetary valuation is associated to a behavioural change in the use and management of environmental goods and services (Kumar et al., 2013). This reasoning is based on taking into account that we are within a market society, where the best way for society to internalize the importance of an environmental good or service is by giving it monetary value (Aznar-Bellver and Estruch-Guitart, 2012). Thanks to the monetary valuation, it is possible to frame the scale of provision of environmental goods and services, helping to delimit the scope in which planning and management processes will be developed (Kumar et al., 2013).

There are a wide range of valuation methods, but the most common of them are summarized below. Stated preference methods (as contingent valuation and choice experiment) use a survey for knowing the willingness to pay of respondents (He et al., 2015; Rupérez-Moreno et al., 2015). Revealed preference methods (as travel cost and hedonic price methods) consider that the monetary value can be obtained from existing markets (Ezebilo, 2016; Zhang et al., 2015). Cost-based methods consider that the damage of ecosystems modify the capacity of ecosystems to regulate the environment (as flood protection). Hence, the monetary value of ecosystems is calculate from the economic cost that would be necessary for recover them (Jackson et al., 2014; Remme et al., 2015; Yao et al., 2016). Benefit transfer methods consider that the monetary value of an ecosystem is the same that the monetary value of other ecosystem located in a different place (Chaikumbung et al., 2016; Madani and Khaleghi, 2015). These methodologies for monetary valuation of ecosystems show the range of option available in the case of PPCPs in WWTPs effluents, the implementation of previous methodologies would be complicated because PPCPs have no market value.

One methodological option for valuing environmental externalities without market value is the shadow price methodology. This method represents the environmental damage that PPCPs are causing through the discharge of WWTPs effluents into water bodies. According this methodology, production processes generate marketable (desired) outputs as well as nonmarketable byproducts that adversely affect the environment. The shadow price approach is used to calculate the monetary value of PPCPs as non-desirable outputs. The monetary value obtained can be included in the decision-making process during the economic valuation of ecosystem services (Zhou et al., 2014), Molinos-Senante et al. (2013) calculated shadow prices for PPCPs in their analysis of ozonation processes for eliminating these pollutants from effluents discharged in sensitive and non-sensitive areas. The shadow prices obtained in sensitive areas are 11.06 €/kg (for galaxolide), 13.98 €/kg (for tonalide), 44.46 €/kg (for sulfamethoxazole) 53.47 €/kg (for diclofenac) and 93.76 €/kg (for ethinylestradiol), and results in non-sensitive areas ranged from 8.67 €/kg (for galaxolide), 10.98 €/kg (for tonalide), 34.95 €/kg (for sulfamethoxazole), 42.20 €/kg (for diclofenac) and to 73.73 €/kg (for ethinylestradiol). Overall, the environmental benefit of eliminating PPCPs was greater for sensitive areas, where conservation actions are necessary.

The main aim of this paper is to obtain the monetary value of the environmental externalities associated to PPCPs existing in WWTP effluents, through using the shadow prices methodology. The obtained results can be used as proxy of environmental benefit related to the removal of PPCPs in WWTPs effluents. The secondary objective is to analyse the relationship between the shadow prices of PPCPs and the results of toxicological risk assessments in the literature. It has been sought to confirm the connection between the shadow price methodology and the degree of environmental impact showed by the selected PPCPs. This paper contributes to the literature of valuing environmental externalities calculating the monetary value of removal the PPCPs in the effluent of wastewater treatment processes; which could be included in feasibility analyses and decision-making processes.
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