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Monetary valuation of salicylic acid, methylparaben and THCOOH in a Mediterranean coastal wetland through the shadow prices methodology

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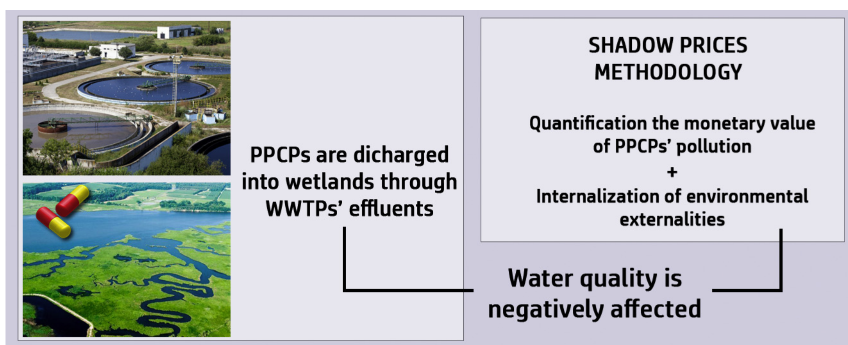
HIGHLIGHTS

- PPCPs discharge through WWTPs effluents affect the quality of water in wetlands.
- It has been obtained the monetary value of PPCPs as status indicator of ESWQ.
- Shadow prices methodology allow to quantify the environmental avoided cost of PPCPs.
- Shadow prices of Salicylic Acid, methylparaben and THCOOH highlight the benefits of removing PPCPs.

GRAPHICAL ABSTRACT



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ABSTRACT

The presence of pharmaceutical and personal care products and drugs of abuse (PPCPs) in wastewater treatment plants (WWTPs) indicates discharge of the effluent may not be suitable for the ecological balance of water ecosystems, such as wetlands. These PPCPs degrade water quality, considered as an ecosystem service (ES), provoking serious environmental impacts. Assessing the monetary value of PPCPs can be used as a proxy for environmental status of the ES of water quality (ESWQ). Considering PPCPs as non-desirable outputs of WWTPs, the shadow prices methodology has been implemented using directional distance function to measure the environmental avoided cost of removing salicylic acid (SA), methylparaben (MP), and THCOOH from WWTPs effluents discharged to Albufera Natural Park (Spain). The SA shows the highest shadow price (138.16 €/μg), followed by THCOOH (48.15 €/μg), and MP (30.66 €/μg). These values are interpreted as the environmental cost that would be avoided if SA, MP, and THCOOH were removed from WWTPs effluents. The non-parametric tests show that wastewater treatment technology, together with population equivalent (as a proxy of the size of urban areas) and seasonality are factors that influence shadow prices obtained. The approach used in this study highlights the use of PPCPs as status indicators of ESWQ quantified in monetary units. As a way to synthesize the essential concepts to implement the shadow prices approach, this study proposes a flow diagram to represent the relationship between all the factors involved in this work. The use of shadow prices methodology proves that removing SA, MP, and THCOOH is associated with a measurable improvement in the ESWQ of Albufera Natural Park. The findings of this study will be useful for plant managers in order to make decisions about the removal of PPCPs in WWTPs effluents.

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1. Introduction

Conservation practices that were implemented to maintain and recover ecosystems have the difficulty of quantifying their benefits for the ecosystems and population. This hampers conservation efforts because trying to assign an economic value to an environmental asset that does not have a market is difficult (Riera et al., 2005). One approach to consider the environmental assets is the concept of Ecosystem Services (ES), which is well received among policy makers and literature studies. The Millennium Ecosystem Assessment (MEA, 2003) defines ES as: "*the benefits people obtain from ecosystems*. *These include provisioning services such as food*, *water*; *regulating services such as regulation of floods*, *drought*, *land degradation*, *and disease*; *supporting services such as soil formation and nutrient cycling*; *and cultural services such as recreational*, *spiritual*, *religious and other nonmaterial benefits*." Hence, taking into account the ES used by a population, activities that cause environmental impacts can be identified (Farley et al., 2014; Nahlik et al., 2012). In such cases, the environmental impact involves changes in ecosystem balance (Kumar et al., 2014).

The most analysed ES are cultural, water, and forest (Quintas-Soriano et al., 2016), on global and regional scales (Perez-Verdin et al., 2016). This study has focused on water ES, which are classified into five groups: (i) supply, (ii) regulation, (iii) soil formation, (iv) treatment capacity, and (v) food production (Bellver-Domingo et al., 2016). Reducing the scale of analysis, Maes et al. (2012) states that the major ES granted by a watershed are as follows: (i) regulation of water flows in episodes of significant floods; (ii) aquifer recharge; (iii) water quality; and (iv) support for aquatic ecosystems. Our work considers the definition of water ES provided by Fregoso (2006): "*they appear in the hydrological cycle*, *as a result of the ecosystem's capacity to store water and thus keep water supply available for society benefit*." Water ES have been analysed by a wide variety of authors (Bark et al., 2016; Dennedy-Frank et al., 2016; Martín-López et al., 2011; Mokondoko et al., 2016; Remme et al., 2015; Tesfaye et al., 2016; Watson et al., 2016), whose results highlight the need of protecting water ES from both the long-term conservation and the population profit point of view.

Specifically, this study considers the ES of water quality (ESWQ) provided by wetlands. Wetlands are ecosystems that provide many ES – flood control, aquifer recharge, water purification, food, habitats for different species, and cultural significance (MEA, 2003) – whose long-term continuity can be affected by environmental impacts. Coastal wetlands are usually close to urban areas; this situation threatens the ESWQ because of pollution of water bodies (Andreu et al., 2016). The ESWQ has been analysed in the literature by authors, such as Jessop et al. (2015) and Momblanch et al. (2017). During recent years, there has been an increase in the number of WWTPs built to solve eutrophication problems in wetlands that receive the WWTPs effluents (Bellver-Domingo and Hernández-Sancho, 2017). Until recently, the presence of nutrients (nitrogen and phosphorus) in water was interpreted as indicator of its quality (Martín-López et al., 2014). However, the progress made in the analytical methods for water samples has revealed the presence of hazardous chemicals (of human origin) whose chemical structure prevents its removal. These chemicals are the emerging pollutants, also known as pharmaceutical and personal care products (PPCPs). The PPCPs presence has extended worldwide. Specifically in the European countries have been detected high levels of PPCPs (such as hormones and painkillers) both in surface and groundwater (Schröder et al., 2016). As a result, there are serious environmental impacts on the aquatic organisms in those water bodies with highly influenced by urban areas (Ortiz de García et al., 2013; Petrie et al., 2015). Wetlands are ecosystems particularly sensitive to PPCPs' impacts for two main reasons: the low renewal rate of water and effluents discharge (Prosser and Sibley, 2015). Hence, WWTPs become a dissemination point of PPCPs into wetlands and other water ecosystems, such as rivers (Bellver-Domingo et al., 2017). Furthermore, PPCPs adversely affect the ESWQ in wetlands, and several studies highlight that current wastewater technology is insufficient to remove PPCPs from wastewater (Andrés-Costa et al., 2017; Baker and Kasprzyk-Hordern, 2013; Binelli et al., 2014; Campo et al., 2016; Ccanccapa et al., 2016; Ferguson et al., 2013; Zenobio et al., 2015). Hence, PPCPs can be considered as the new status indicators of ESWQ (Van Stempvoort et al., 2013).

Considering PPCPs the new status indicators of ESWQ is a novelty in the environmental research field. The ESWQ lacks market value, making the calculation of its monetary value difficult (Gómez-Baggethun and Muradian, 2015). However, ESWQ is essential for physical, chemical, and biological processes of water ecosystems (Bark et al., 2016). In fact, the need for a holistic view of ES linking economic and environmental research has been the motivation for this study. Obtaining the monetary value of PPCPs – considered as non-desirable outputs of wastewater treatment processes – allows us to quantify their environmental relevance and internalise them into decision-making processes (following the Water Framework Directive guidelines) (Loft et al., 2015). Hence, ESWQ can be used as new units of analysis to implement monetary valuation methodologies (Sutton and Anderson, 2016). From policy and environmental points of view, the monetary value obtained becomes a reference value which ensures the maintenance and conservation of ESWQ in those wetlands close to urban areas. At the same time, this monetary value of ESWQ also ensures that the reuse of WWTPs effluents does not cause environmental impacts but PPCPs would be removed.

Monetary valuation methodologies for ES have been extensively researched (Ahtiainen et al., 2015; Chaikumbung et al., 2016; Doherty et al., 2014; Ezebilo, 2016; Franzén et al., 2016; Garcia et al., 2016; Gren, 2013; Jiang et al., 2015; Kallis et al., 2013; Madani and Khaleghi, 2015; Momblanch et al., 2016; Remme et al., 2015; Rupérez-Moreno et al., 2015). One of the basic foundations of these methodologies is to quantify the monetary marginal change of ES (Alam et al., 2016), meaning that these are methodologies required to quantify which improvements in ES compensate the loss of their utility with the aim to ensure ES long-term conservation. Through the implementation of monetary valuation methodologies, an advantage in the development of concrete measures to manage ES have been achieved. Monetary value obtained can be included into feasibility analysis – such as cost-benefit analysis (Bark et al., 2016) – with the aim to assess the feasibility of a concrete measure under different scenarios (Busch et al., 2012). This step implies internalisation of environmental externalities and elaboration of concrete management measures that will make changes in the behaviour of ES users possible, as well as improvements in long-term environmental status of ES (Kumar et al., 2014).

Taking into account that ESWQ needs to be conserved, PPCPs are considered as non-desirable outputs of wastewater treatment process; so, they have to be removed from WWTPs. This action has an associated environmental avoided cost, because PPCPs would not be discharged into wetlands. The environmental avoided cost is obtained using shadow prices methodology. Shadow prices methodology has been commonly applied to industrial processes (Coggins and Swinton, 1996; Färe et al., 2005; Färe et al., 2006; Reig-Martínez et al., 2001; Wei et al., 2013; Zhou et al., 2015). However, the scope of the methodology is being expanded to assess the environmental avoided cost of non-desirable outputs of WWTPs. Under this scope, WWTPs are considered as productive processes whose desirable output is the treated wastewater, which should be of suitable quality. Under this approach, the most researched pollutants are nitrogen and phosphorus (Bellver-Domingo and Hernández-Sancho, 2017; Molinos-Senante et al., 2011; Molinos-Senante et al., 2010) and CO_2 (Molinos-Senante et al., 2013a; Molinos-Senante et al., 2015). On the other hand, PPCPs are being given increased attention in the shadow prices approach (Bellver-Domingo et al., 2017; Molinos-Senante et al., 2013b).

The presence of PPCPs in WWTPs effluents negatively affects the ESWQ in wetlands, causing significant impacts on the ecosystem (Bellver-Domingo et al., 2017). Considering this issue as starting point,