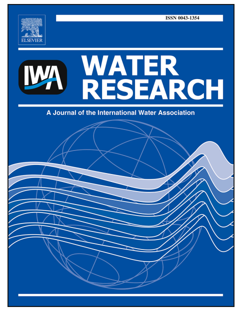
Accepted Manuscript



Pharmaceutical grey water footprint: Accounting, influence of wastewater treatment plants and implications of the reuse

Isabel Martínez-Alcalá, Francisco Pellicer-Martínez, Carmen Fernández-López

PII: S0043-1354(18)30140-4

DOI: 10.1016/j.watres.2018.02.033

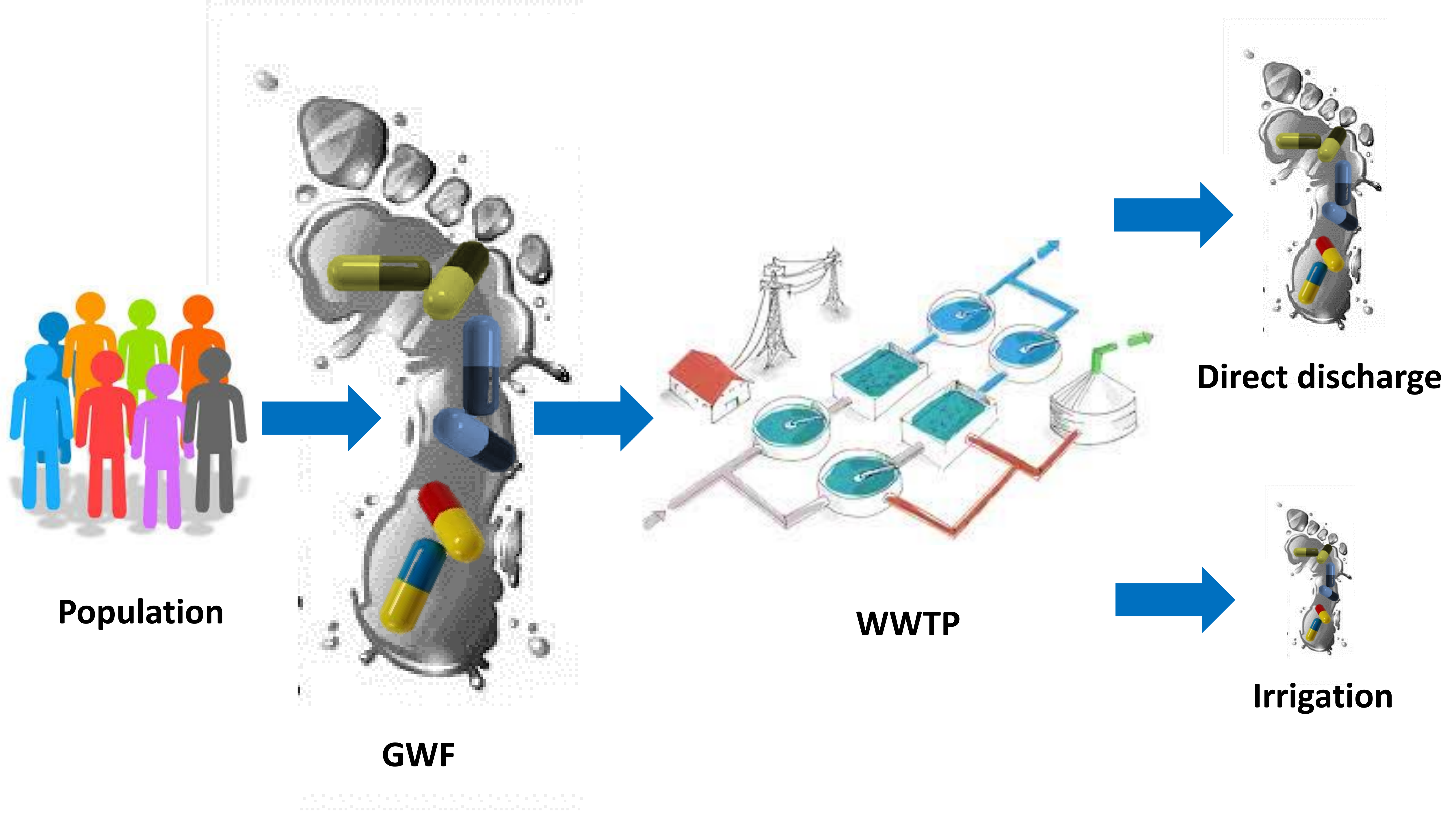
Reference: WR 13585

To appear in: *Water Research*

Received Date: 14 September 2017

Revised Date: 12 February 2018

Accepted Date: 14 February 2018



Population
GWF
WWTP
Direct discharge
Irrigation

Pharmaceutical grey water footprint: accounting, influence of wastewater treatment plants and implications of the reuse.

Martínez-Alcalá, Isabel[a].; Pellicer-Martínez, Francisco[a]*.; Fernández-López, Carmen[a].;

[a] UCAM, Catholic University of Murcia, Campus de los Jerónimos, 135 Guadalupe, 30107 Murcia, Spain.

* fpellicer@ucam.edu

Abbreviations:

WF: water footprint (the sum of three components: green, blue and grey); **GWF:** grey water footprint; **GWF_C:** grey water footprint of conventional pollutants (nitrate, phosphates, organic matter); **GWF_P:** grey water footprint of pharmaceuticals (carbamazepine, diclofenac, ketoprofen, naproxen); **WWTP**: wastewater treatment plant; **Q**: flow discharged into a water body (return of demand); **Ceff**: concentration of a pollutant in a discharge; **Cmax**: maximum acceptable concentration of a pollutant for a water body; **Cnat**: natural concentration of a pollutant in a water body; **CBZ:** carbamazepine; **DCF:** diclofenac; **KTP:** ketoprofen; **NPX:** naproxen; **BOD_5**: Biological oxygen demand; **TN:** total nitrogen; **TP:** total phosphorus; **Al**: Alcantarilla; **CB**: Cabezo Beaza; **Ca**: Calasparra; **CC**: Caravaca de la Cruz; **Ci**: Cieza; **LH**: La Hoya; **MN**: Molina Norte; **ME**: Murcia Este; **PL**: Puerto Lumbreras; **SJ**: San Javier; **SP**: San Pedro; **Ye**: Yecla.

Pharmaceutical grey water footprint: accounting, influence of wastewater treatment plants and implications of the reuse.

Abstract

Emerging pollutants, including pharmaceutical compounds, are producing water pollution problems around the world. Some pharmaceutical pollutants, which mainly reach ecosystems within wastewater discharges, are persistent in the water cycle and can also reach the food chain. This work addresses this issue, accounting the grey component of the water footprint (GWF_P) for four of the most common pharmaceutical compounds (carbamazepine (CBZ), diclofenac (DCF), ketoprofen (KTP) and naproxen (NPX)). In addition, the GWF_C for the main conventional pollutants is also accounted (nitrate, phosphates and organic matter). The case study is the Murcia Region of southeastern Spain, where wastewater treatment plants (WWTPs) purify 99.1% of the wastewater discharges and there is an important direct reuse of the treated wastewater in irrigation. Thus, the influence of WWTPs and reuse on the GWF is analysed. The results reveal that GWF_P, only taking into account pharmaceutical pollutants, has a value of 301 m^3 inhabitant^{-1} year^{-1}; considering only conventional pollutants (GWF_C), this value increases to 4,718 m^3 inhabitant^{-1} year^{-1}. So, the difference between these values is such that in other areas with consumption habits similar to those of the Murcia Region, and without wastewater purification, conventional pollutants may well establish the value of the GWF. On average, the WWTPs reduce the GWF_C by 90% and the GWF_P by 26%. These different reductions of the pollutant concentrations in the treated

effluents show that the GWF is not only due to conventional pollutants, and other contaminants can became critical, such as the pharmaceutical pollutants. The reuse further reduces the value of the GWF for the Murcia Region, by around 43.6%. However, the reuse of treated wastewater is controversial, considering the pharmaceutical contaminants and their possible consequences in the food chain. In these cases, the GWF of pharmaceutical pollutants can be used to provide a first approximation of the dilution that should be applied to the treated wastewater discharges when they are reused for another economic activity that imposes quality restrictions. For the case of agriculture in the Murcia Region, the dilution required is 2 (fresh water) to 1 (treated wastewater), taking into account the pollution thresholds established in this work.

Keywords: Grey Water Footprint; Pharmaceuticals; Irrigation; Water Resources Management; Wastewater Treatment Plant; Murcia Region.

1. Introduction

"Emerging pollutants" are defined as contaminants such as chemical and pharmaceutical products applied by consumers that produce pollution of the aquatic environment (Kümmerer, 2011). Examples of emerging pollutants are surfactants, flame-retardants, personal care products, gasoline additives, biocides, polar pesticides, and their degradation products, microplastics, various pollutants tested for or suspected of endocrine disruption and pharmaceutical compounds (Petrie et al., 2015). They can be found in surface and ground waters since the recalcitrant behaviour of some of these pollutants means that they are not easily degraded (Petrie et al., 2015; Wang et al., 2016). Although they are usually found in low concentrations (μg L^{-1}), their effects on the environment in the short or long term are not completely understood (Mandaric et al., 2015). Currently, some of these pollutants are already included in monitoring plans, as in the case of the prioritisation of emerging pollutants initiatives (NORMAN, 2017). Moreover, a broad range of pollutants are controlled by the legislation outlined by the European Commission (Directive 2000/60/EC, Directive 2008/105/EC, Directive 2013/39/EC). Traditionally, these have been chemicals of agricultural or industrial origin. Nevertheless, legislation is expected to include a greater number of derived chemicals, following the recent incorporation of the pharmaceutical compounds 17β-estradiol (E2), 17α-ethinylestradiol (EE2) and diclofenac as priority emerging pollutants in the observation list (Decision 2015/495/EC).

As mentioned before, this list of emerging pollutants includes pharmaceutical compounds that are widely used in human and veterinary medicine. In some cases, the damage to ecosystems is well known; for example, the severe injury of Nepalese and Himalayan vultures due to the veterinary use of diclofenac (Cuthbert et al., 2011). Since 2006, diclofenac has been banned to prevent further declines in vulture populations and a partial recovery has been observed in Nepal (Paudel et al., 2016). Carbamazepine, another pharmaceutical compound, is known to accelerate fish embryonic development, thus disturbing larval behaviour (Qiang et al., 2016). Although the effects of many other pharmaceutical residues are not known, there is a strong concern, as some studies have revealed that large amounts of pharmaceutical compounds are not necessary to provoke considerable damage in the biosphere (Quiang et al., 2016). Not only do they pose a risk to the environment, they can also enter the food chain and affect humans (Prosser and Sibley, 2015). This issue cannot be considered as negligible in areas with scarce water resources where wastewater is often reused, even sometimes directly in irrigation without any treatment (Satterthwaite, 2016).

The growing concern about the existence of pharmaceutical compounds in the aquatic environment has led to widespread measurements of these pollutants, but there are hardly any sets of homogeneous indicators that allow the comparison of the pollution issues across different geographic areas (Jiao et al., 2013). The grey water footprint (GWF) is one of these indicators. The GWF is part of the water footprint, which is composed of the colours green, blue and grey. The green water footprint is the volume of rainwater consumed during the production process (agricultural and forestry products). The blue water footprint is the consumption of water resources (surface and groundwater) or their diversion to another geographic area (transfers). The GWF is defined as the volume of fresh water that is required to assimilate the load of pollutants, based on natural background concentrations and existing ambient water quality standards (Hoekstra et al., 2011). So, the GWF assesses the impacts produced by the pollution load on the aquatic environment in terms of the volume of fresh water. In addition, the GWF can be applied according to a producer or consumer approach, differentiating pollution generated by economic activities from that of domestic consumption habits (Hoekstra et al., 2011).

In recent years, numerous studies have assessed the GWF for conventional pollutants such as nitrate, phosphates and organic matter (Liu et al., 2012; Wu et al., 2016; Cazcarro et al., 2016; Gil et al., 2017; Pellicer-Martínez and Martínez-Paz, 2018; Quinteiro et al., 2018). Nevertheless, scarce information is available about the emerging pollutants, especially regarding the GWF produced by the presence of pharmaceuticals in the wastewater releases into aquatic ecosystems, since they are the main sources of these pollutants. So, this issue is less important in areas where WWTPs eliminate part of these pollutants, thus reducing the GWF. Although these facilities are not planned to completely eliminate pharmaceutical pollutants, for some of them they are able to lower the concentration found in the influent by almost 90% (Arriaga et al., 2016; Fernández-López et al., 2016; Rozas et al., 2016; Wang et al., 2016; Díaz-Garduño et al., 2017; Martínez-Alcalá et al., 2017), in particular when the WWTPs have tertiary treatments (Zhang et al., 2015; Wang et al., 2016; Díaz-Garduño et al., 2017). Unfortunately, the residual water is usually not purified by a WWTP in many geographic areas. For example, less than 1% of wastewater is treated on the African continent (http://www.wri.org/our-work/project/eutrophication-and-hypoxia/sources-eutrophication). Therefore, some of the wastewaters along with their pollutants finally end up in the environment or are reused without any treatment for other activities such as irrigation. In both kinds of area (with or without WWTPs), the GWF can assess the pollution from pharmaceuticals in terms of the volume of fresh water consumption, helping water boards in two ways. On the one hand, once the GWF is assessed, this value can be used to analyse the sustainability of the pollution problems. For example, when the flows in receiving water bodies exceed the GWFs, the water bodies can withstand the pollution loads that they receive (Hoekstra et al., 2011). But, when the flows are lower than the GWFs, the pollution cannot be supported and the GWF must be reduced (Pellicer-Martínez and Martínez-Paz, 2016a). On the other hand, as GWF values quantify the volumes of fresh water that are necessary to reduce the pollutants of an effluent to certain levels, they can show the order of magnitude of the volume with which it would be necessary to mix this effluent so as to be able to reuse it for other economic activities.

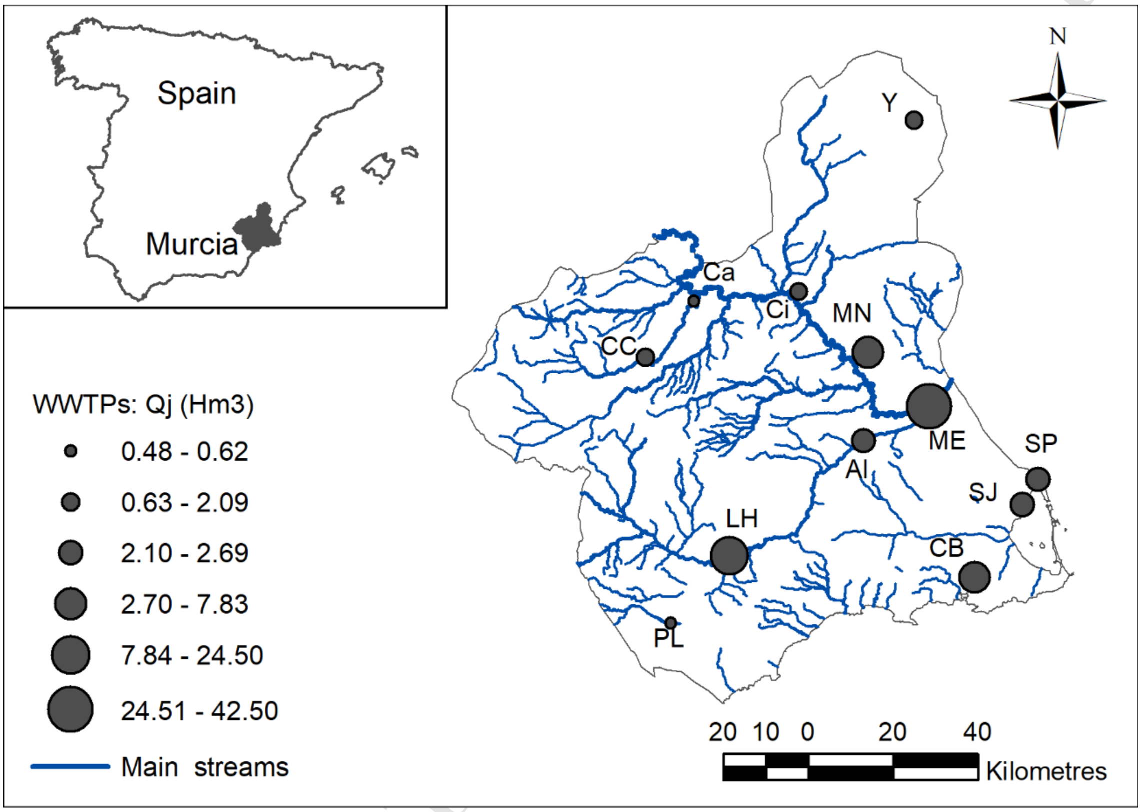
This work has as its main and novel target the accounting of the GWF of pharmaceutical pollutants (GWF_P) following their consumption, focusing on the discharge of these substances into the aquatic environment in the wastewater of several municipalities. The four pharmaceuticals studied are carbamazepine (CBZ), diclofenac (DCF), ketoprofen (KTP) and naproxen (NPX). These compounds are the most-common pharmaceutical pollutants according to their consumption in several European countries, their behaviour during wastewater treatment and the frequency with which they are detected in WWTPs (Camacho-Muñoz et al., 2009). Additionally, GWFs were also accounted considering conventional pollutants (GWF_C) such as nitrate, phosphates and organic matter. This study was conducted in the Murcia Region, in the southeast of Spain. This geographic area has a very-productive irrigated agriculture and, given the scarcity of water, a large number of WWTPs have been built in order to increase the availability of good-quality water to be reused in this economic activity (Ródenas and Albacete, 2014). So, the effects of water treatment and reuse on the GWF are analysed for all pollutants (pharmaceutical and conventional). Finally, the implications of pharmacological pollutants with respect to the management of water resources, and in particular the reuse of wastewater in irrigation, are discussed.

2. Material and methods

2.1. Study area

The Murcia Region is located in southeastern Spain (Iberian Peninsula). It has an extension of 11,313 km^2 and is entirely within the Segura River Basin (Grindlay et al., 2011). The climate of this region is semi-arid Mediterranean, with an average annual temperature of 18 ºC and scarce annual rainfall, around 300 mm (Aparicio et al., 2017). Despite the scarce natural water resources, there is strong use of water for urban (including tourism along the coast), industrial and irrigation purposes (CHS, 2016). In fact, the consumption has increased in recent years, exceeding the limits of natural resources and resulting in a structural water deficit with an unsustainable tendency, as highlighted in hydrological planning (CHS, 2016). Due to the almost-constant shortage, important water-management measures have been taken in order to match growing requirements and water availability. This scarcity has been addressed through two strategies: modernisation of supply facilities, which has enabled the attainment of higher levels of profitability, and the use of non-conventional resources. Regarding the latter, there are important transfers from the Tagus River Basin (Kroll et al., 2013), very-extensive use of groundwater (Martínez-Paz and Perni, 2011), desalination plants along the coast (Lapuente, 2012) and significant direct reuse of treated wastewater effluents in irrigation (Figure 1).

Figure 1. Location of Murcia Region and the geographic situation of the 12 WWTPs studied. WWTPs codes and location: Alcantarilla (Al); Cabezo Beaza (CB); Calasparra (Ca); Caravaca de la Cruz (CC); Cieza (Ci); La Hoya (LH); Molina Norte (MN); Murcia Este (ME); Puerto Lumbreras (PL); San Javier (SJ); San Pedro (SP); Yecla (Ye).



The irrigated crops in Murcia Region have a millennial tradition, due to the combination of a benign climate with very-favourable land for agriculture (Gil-Olcina, 2009). Under these circumstances, irrigated agriculture has expanded and modernised in recent decades, becoming one of the most-profitable agricultural businesses worldwide (Martínez-Paz et al., 2016). In this regard, the irrigated area is currently about 188,534 hectares, representing 17% of this geographic area (INE, 2012). In addition, in terms of economic agricultural exports (vegetables and fruits), this region is ranked third in Spain despite its small size (Cerdá et al., 2016). Achieving these milestones with such scarce resources has been possible due to a complex and rational system of exploitation of water resources that connects the main irrigated areas with several sources of water. So, in the case of a lack of water from one source, it is possible to resort to another. Among these, wastewater has become a basic source because it is practically constant over time. In fact, 99.1% of wastewater is treated, 105-115 Hm^3 $year^{-1}$ during the period 2011-15 (ESAMUR, 2017), representing 10% of the natural water resources per year (CHS, 2016). Despite the high quality of the treated wastewater, it is possible to further improve some of its physical-chemical parameters due to connections in the complex system of exploitation that allow the mixing of water from different sources. For example, the salinity of wastewater from coastal municipalities is reduced using water from the transfer and the quality of desalinated water is improved by mixing it with treated wastewater. These physical-chemical parameters are usually conditioned by the type of land that receives the water or by the type of crop, as is the case of citrus with boron in desalinated water (Güler et al., 2015).

As a whole, the 12 WWTPs studied here purify 70% of the region's wastewater, thus adequately representing the Murcia Region (Figure 1). The main treatments are conventional activated sludges, extended-aeration activated sludge processes and membrane bioreactors. All of them include tertiary treatment as the end point of the purification process. Of the treated wastewater, 34.4% is reused directly for irrigation, 60.2% is reused indirectly (1.60% by percolation into aquifers, while 58.6% is discharged into rivers, later being reused in wells or in derivations downstream) and 7.40% is discharged into the Mediterranean Sea (CHS, 2016).

2.2. Grey Water Footprint accounting

The GWF is calculated as follows (Hoekstra et al., 2011, Pellicer-Martínez and Martínez-Paz., 2016b):

$$\begin{cases} \mathrm{GWF_j} = \max_{\mathrm{k}} \left[\dfrac{\mathrm{Q_j} \cdot \mathrm{Ceff_{j,k}}}{(\mathrm{Cmax_k} - \mathrm{Cnat_k})} \right] \\ \mathrm{GWF_j} = 0 \qquad\qquad \forall\, k\text{: } \mathrm{Cmax_k} \leq \mathrm{Cnat_k} \end{cases} \qquad (1)$$

Eq. (1) provides the GWF for an effluent (j) contaminated by several pollutants (k) for a reference time interval. This equation is applied for each pollutant (k) considered, and the maximum volume of fresh water required by one pollutant is the value of the GWF of this effluent, since it can dilute the rest of the pollutants such that they become harmless (Hoekstra et al., 2011; Wang and Wu, 2014). In Eq. (1), Q_j is the flow of effluent (j); $Ceff_{j,k}$ are the concentrations of the (k) pollutants considered in the effluent (j); $Cmax_k$ is the maximum concentration permitted in the receiving water body for each pollutant (k); and $Cnat_k$ is the natural concentration of the same pollutants (k) in the receiving water body, which must be zero in the case of non-natural compounds (Hoekstra et al., 2011).

The GWF definition applies to discharges into water bodies, such as direct wastewater releases or discharges from WWTPs into natural streams (Morera et al., 2016). It is also applied to determine the GWF generated by the sweeping along of pollutants by surface runoff or by infiltration in aquifers, as in the case of excess fertiliser application to crops (Mekonnen and Hoekstra, 2015). Therefore, if a return from a water use is reused in another economic activity, preventing pollutants from reaching water bodies (or reducing considerably the load of pollutants), it does not generate a GWF. For example, the reuse of treated wastewater in irrigation (without adding industrial fertilisers) would be like another treatment step, as the green filters prevent the nutrients from reaching wet areas or aquifers (Fowdar et al., 2017). This is possible because the pollutant load of nutrients from treated wastewater is usually less than the needs of the crops. So, a GWF is generated only when industrial fertilisers are added and their excess ends up in a body of water, not when treated wastewater is used alone.

In this case study, the reference time interval is the year 2015, Q_j are data from the previously-mentioned 12 WWTPs (ESAMUR, 2017) and it is assumed that the inflows and effluents for each WWTP are the same. $Ceff_{j,k}$ are the concentrations of the pharmaceutical pollutants (CBZ, CBZ, KTP and NPX) obtained from Fernández-López et al. (2016). Conventional pollutants (nitrate, phosphates and organic matter) are measured as the total nitrogen (TN), total phosphorus (TP) and BOD_5, respectively (ESAMUR, 2017).

Regarding $Cmax_k$, there is neither legal restriction nor a unanimously-recognized criterion for pharmaceutical pollutants. Therefore, the Predicted No Effects Concentrations (PNEC) criterion of these products in waters for living organisms is proposed. This criterion refers to the concentration of a chemical below which no adverse effects of exposure in an ecosystem are measured. In addition, this criterion is quite variable depending on the organism analysed (algae, invertebrate and fish) and the toxic critical effects studied (growth inhibition, reproduction inhibition, half-maximal effective concentration, lethal concentration for 50% of the population or lowest effect concentration). Also, it is important to consider the possibility of the presence of several pharmaceutical compounds at the same time, establishing phenomena of synergism or antagonism in the organism toxicity (Trombini et al., 2016). For example, CBZ can be toxic from 0.1 or 100 mg L^{-1} and DCF from 0.0005 or 186 mg L^{-1} (Tran et al., 2014). Although PNEC are weak with regard to reflecting the toxicity of several pharmaceutical compounds present at the same time, these values are also considered very conservative. So, the PNEC criterion is selected to assess the GWF, considering the values found in Gheorghe et al. (2016) for the no observed effect concentration in *Daphnia magna*. Whereas, for the conventional pollutants the maximum values have been taken as those allowed by the Spanish legislation on water management (BOE, 2008; BOE, 2015). For $Cnat_k$, it is considered that all wastewater ends up in a surface water body. Consequently, $Cnat_k$ is zero for pharmaceutical pollutants, but setting a value for conventional pollutants is more complicated due to a lack of information. Liu et al. (2012) described a method linking natural concentrations to the population density of the study area. To this end, it was assumed that river basins with population densities equal to or less than 1 inhabitant per 10 km^2 are unaltered. No numerical modelling is needed in this study as there are already measurements of the concentrations in the unaltered water bodies in the Murcia Region, where the population density is lower. The measurements made in these unaltered surface water bodies showed that most TN, TP and BOD_5 concentrations were around zero (CHS, 2017), which allowed the establishment of null values for the natural concentrations ($Cnat_k$) of all three pollutants. In the calculation of the GWF, discharges into the sea have also been considered (and the $Cnat_k$ considered are the same as those of the fresh-water bodies). Thereby, discharges into the sea with large pollutant loads are not excluded from this analysis and the option of changing a discharge's destination (instead of a river, directly into the sea) cannot be proposed in order to reduce the value of the GWF. The data for the effluents (Q_j and $Ceff_{j,k}$) are summarised in Table 1, and the $Cmax_k$ values are presented in Table 2.

Table 1. Main characteristics of the influents and effluents of the WWTPs (Q_j, $Ceff_{j,k}$).

WWTPs(j)			Al*	CB*	Ca**	CC*	Ci*	LH*	MN*	ME**	PL*	SJ*	SP***	Y*
WWTP influents	Q_j (Hm^3 $year^{-1}$)[a]		2.45	7.83	0.62	1.65	2.09	17.4	5.37	42.5	0.48	2.53	2.69	1.68
	$Ceff_{j,k}$ pharmaceutical (μg L^{-1}), conventional pollutants (mg L^{-1})	CBZ[b]	26.5	4.99	N.D.	N.D.	21.8	17.4	N.D.	1.87	N.D.	0.56	N.D.	N.D.
		DCF[b]	5.78	N.D.	N.D.	N.D.	N.D.	2.01	N.D.	0.82	N.D.	N.D.	N.D.	N.D.
		KTP[b]	2.52	N.D.	N.D.	N.D.	N.D.	3.39	N.D.	0.54	N.D.	N.D.	N.D.	N.D.
		NPX[b]	1.36	0.09	2.63	N.D.	0.91	2.67	N.D.	0.36	1.81	N.D.	8.92	N.D.
		BOD_5[a]	676	420	533	408	564	597	786	262	407	152	190	493
		TN[a]	73	84	60	112	88	116	63	48	101	54	53	67
		TP[a]	11	7	12	9	11	8	8	7	6	9	5	13
WWTPs(j)			**Al***	**CB***	**Ca****	**CC***	**Ci***	**LH***	**MN***	**ME****	**PL***	**SJ***	**SP*****	**Y***
WWTP effluents	Q_j (Hm^3 $year^{-1}$)[a]		2.45	7.83	0.62	1.65	2.09	17.4	5.37	42.5	0.48	2.53	2.69	1.68
	$Ceff_{j,k}$ pharmaceutical (μg L^{-1}), conventional pollutants (mg L^{-1})	CBZ[b]	11.9	1.45	9.91	2.40	N.D.	10.4	N.D.	2.46	14.1	2.02	8.59	6.22
		DCF[b]	0.39	N.D.	N.D.	N.D.	N.D.	0.53	N.D.	0.39	N.D.	N.D.	N.D.	N.D.
		KTP[b]	0.67	N.D.	N.D.	0.15	N.D.	1.39	N.D.	0.34	N.D.	N.D.	N.D.	N.D.
		NPX[b]	0.28	1.01	N.D.	N.D.	N.D.	0.94	N.D.	0.23	3.70	N.D.	N.D.	N.D.
		BOD_5[a]	4	7	3	3	3	4	4	5	2	5	5	4
		TN[a]	12	31	6	5	9	56	11	9	6	6	7	5
		TP[a]	6	1	2	1	4	4	1	2	4	1	2	3

[a]Data obtained from ESAMUR (2017).

[b]Data obtained from Fernández-López et al. (2016): mean value of 4 replicates per sample. N.D.: Not detected.

* reuse in irrigation

** discharge into natural stream

*** discharge into sea

Table 2. $Cmax_k$ allowed in surface water bodies for the pharmaceutical and conventional pollutants considered.

Pharmaceutical pollutants	$Cmax_k$ (µg L^{-1})	Parameters of conventional pollutants	$Cmax_k$ (different units)
CBZ [1]	1.2	BOD_5 [2]	6 mg L^{-1} O_2
CBZ [1]	0.45	TP [2]	0.4 mg L^{-1} PO_4
KTP [1]	0.56	TN [3]	5 mg L^{-1} TN
NPX [1]	1.0		

[1] Gheorghe et al. (2016).
[2] BOE 2008.
[3] BOE 2015.

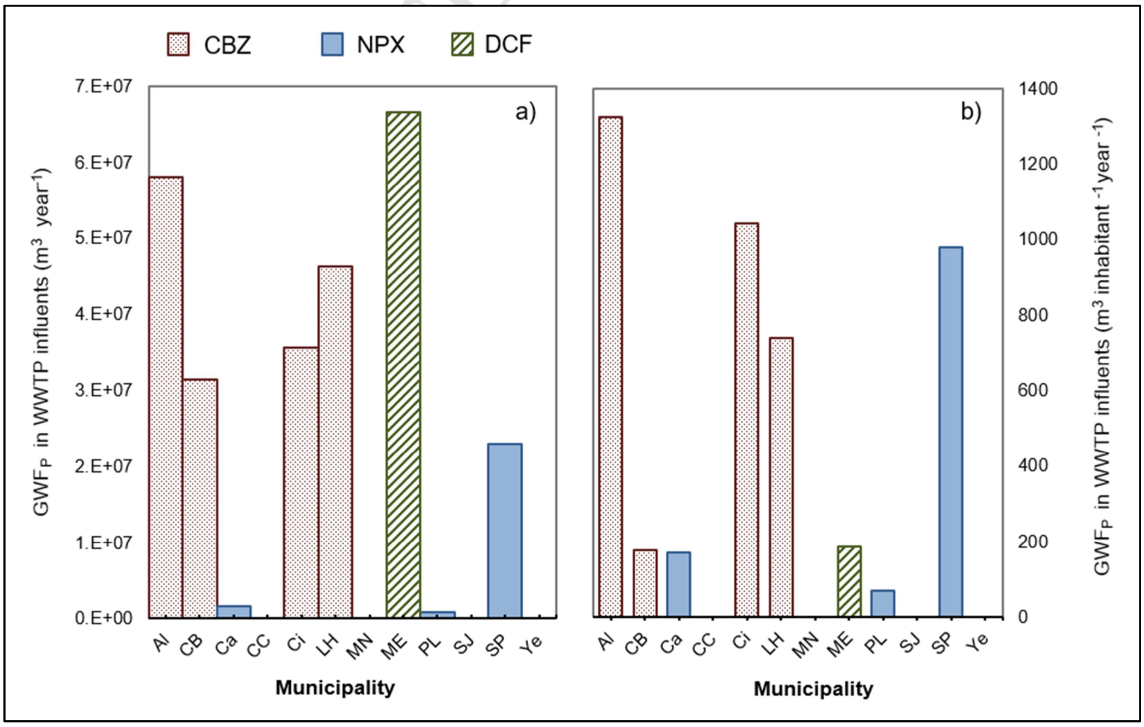
3. Results

The situation described in the Murcia Region is present in many other territories: an area with scarce water resources in which wastewater is reused for irrigation. But, unlike many other areas, the extensive network of existing treatment plants, many of them directly connected to irrigation communities, allows us to pose three scenarios in which different possible GWFs can be discussed depending on if the wastewater is treated and/or reused. First, GWFs are obtained with the concentrations in the wastewater before it reaches the treatment plants (influents), whose values would be analogous to those in areas where wastewater is not treated. Second, GWFs are assessed using the concentrations in the effluents of the WWTPs, which are representative of those territories where wastewater is treated but is not directly reused. Third, GWFs are accounted for considering also a direct reuse. This is conducted considering the particular characteristics of the Murcia Region. These results provide an idea or an order of magnitude of what the reuse of treated wastewater means for the GWF, since reuse diminishes the dispersion into the aquatic environment. Therefore, following these steps, the GWF results for pharmaceutical (GWF_P) and conventional (GWF_C) contaminants, calculated separately, are presented and compared. First, the values of the GWF_P and GWF_C are shown for the influents to the WWTPs. Second, the values for the effluents are given, evaluating the effect of the removal of pollutants by the WWTPs on the GWF_P and GWF_C. Finally, the GWF_P and GWF_C values of the effluents are presented considering their direct reuse in irrigation.

3.1. Grey Water Footprint generated by the main municipalities in Murcia Region (WWTPs influents)

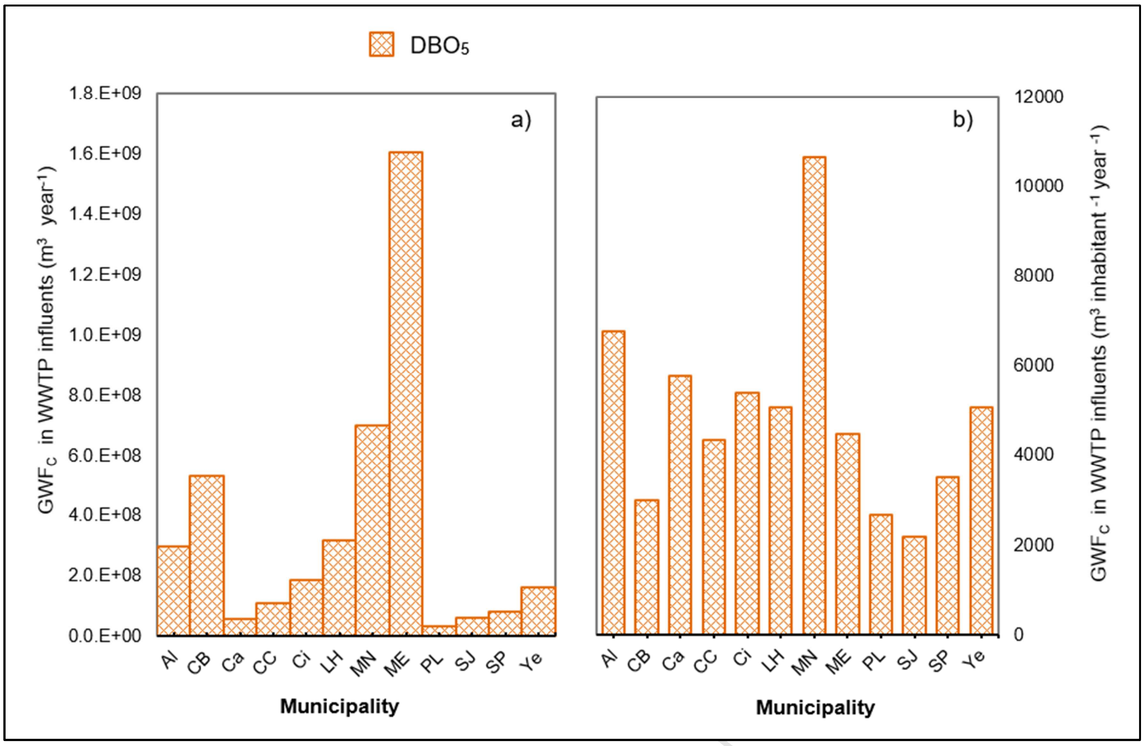
In this section, the GWF_P and GWF_C of the WWTPs influents are presented; these represent the values that would be generated by the populations in 12 municipalities if there were no purification processes (Figure 2a). In this case, the GWF_P has a significant value of $263 \cdot 10^6$ m^3 $year^{-1}$. The municipalities that contribute most to this value are Murcia Este ($66.5 \cdot 10^6$ m^3 $year^{-1}$), Alcantarilla ($58.0 \cdot 10^6$ m^3 $year^{-1}$) and La Hoya ($46.2 \cdot 10^6$ m^3 $year^{-1}$). The results indicate that the critical contaminant is not the same for all municipalities. Overall, CBZ is responsible for 65% of the GWF_P, while DCF and NPX have less weight in this global value: 25% and 10%, respectively. Meanwhile, KTP is not the critical pollutant in any municipality, since the volume of fresh water required to dilute this pollutant in each influent is not capable of diluting the other pollutants to their established water quality standards. It should be noted that four of the studied municipalities do not generate a GWF_P due to the low concentrations of these pharmaceutical pollutants in the analysed wastewaters (three are below the detection limits established by the methodology employed in Fernández-López et al. (2016)). The maximum value of the GWF_P per inhabitant is for Alcantarilla (1,322 m^3 $inhabitant^{-1}$ $year^{-1}$), followed by Cieza (1,041 m^3 $inhabitant^{-1}$ $year^{-1}$) and San Pedro (980 m^3 $inhabitant^{-1}$ $year^{-1}$), with a wide range of variation (Figure 2b). So, although Murcia Este is the municipality that contributes most to the GWF_P for the whole area, its inhabitants do not contribute the most individually, ranking fifth. On average, each inhabitant generates a GWF_P of 301 m^3 $year^{-1}$.

Figure 2. GWF_P generated by the populations of the 12 main municipalities in Murcia Region, considering pharmaceutical pollutants (GWF_P due to critical pollutants in the WWTPs influents): a) m^3 $year^{-1}$; b) m^3 $inhabitant^{-1}$ $year^{-1}$.



Comparing the GWF_P values with those obtained for conventional pollutants (GWF_C), it can be observed that the former are lower in all the influents studied. So, the volume of fresh water needed to dilute the conventional pollutants is also able to dilute the pharmaceutical ones, and the GWF_C would be the GWF generated by these municipalities. The GWF_C reaches a value of $4{,}124 \cdot 10^6$ m^3 $year^{-1}$ as a whole for all the municipalities studied, organic matter (BOD_5) being the critical conventional pollutant. The municipalities that contribute most to the GWP_C are Murcia Este ($1{,}063.2 \cdot 10^6$ m^3 $year^{-1}$), Molina Norte ($696.2 \cdot 10^6$ m^3 $year^{-1}$) and Cabezo Beaza ($528.5 \cdot 10^6$ m^3 $year^{-1}$), which are also the ones with the greatest populations (Figure 3a and Table 1). The analysis by inhabitants indicates that the GWF_C varies between 10,642 m^3 $inhabitant^{-1}$ $year^{-1}$, in Molina Norte, and 2,171 m^3 $inhabitant^{-1}$ $year^{-1}$, in Calasparra. On average, each inhabitant generates a GWF_C of about 4,718 m^3 $year^{-1}$ (Figure 3b).

Figure 3. GWF_P generated by the populations of the 12 main municipalities in Murcia Region, considering conventional pollutants (GWF_C due to critical pollutants in the WWTPs influents): a) m^3 $year^{-1}$; b) m^3 $inhabitant^{-1}$ $year^{-1}$.

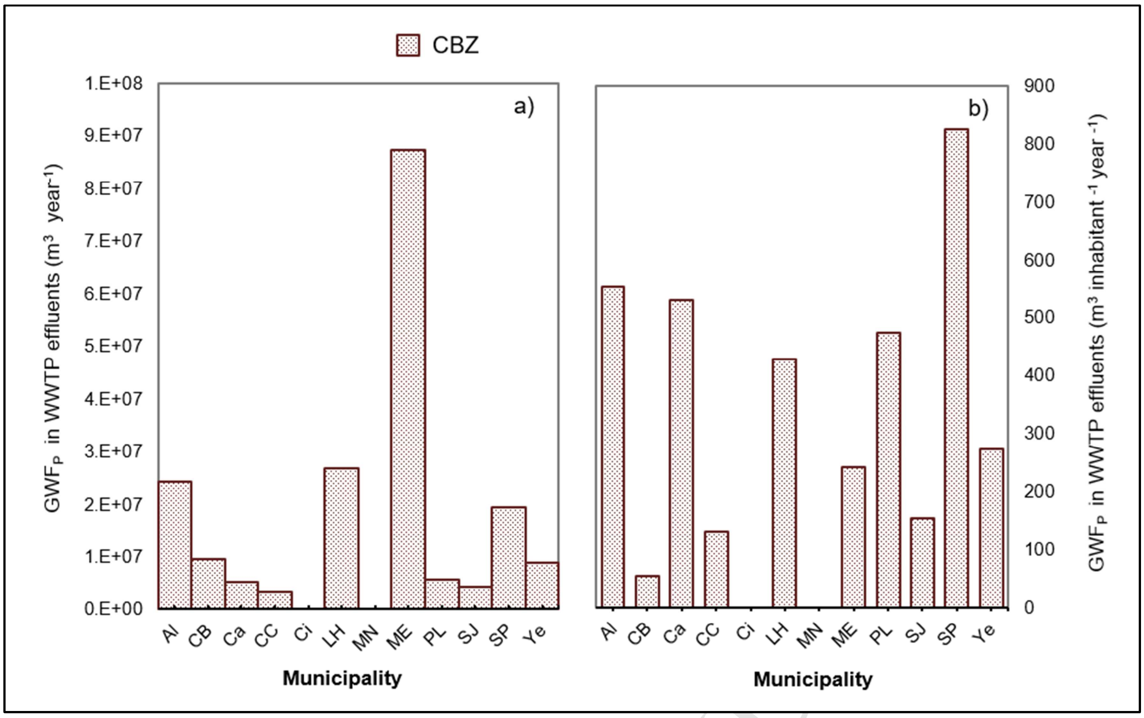


3.2. Grey Water Footprint of treated effluents (WWTPs effluents)

In this section, we present the GWF values of the effluents from the WWTPs of the 12 municipalities studied. As in the previous section, the results for the pharmaceutical pollutants are shown first, followed by those of the conventional ones. Subsequently, the results are compared and analysed together.

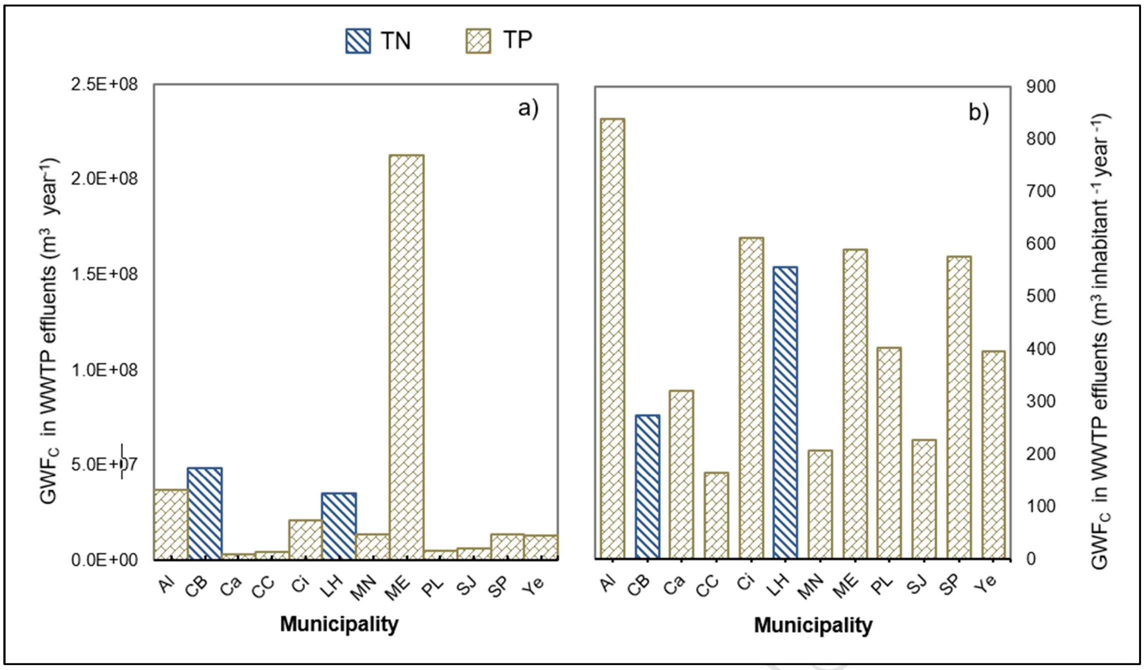
In this scenario the GWF_P diminishes to $194{\cdot}10^6$ m^3 $year^{-1}$, a 26% decrease, due to the action of the WWTPs. The analysis by municipalities indicates that the Murcia Este effluent has the highest GWF_P ($87.2{\cdot}10^6$ m^3 $year^{-1}$), followed by La Hoya ($26.8{\cdot}10^6$ m^3 $year^{-1}$) and Alcantarilla ($24.3{\cdot}10^6$ m^3 $year^{-1}$). The removal rates of each pharmaceutical pollutant are different in each WWTP, and the pollutant that provides the value of the GWF_P in each WWTP effluent has changed; now, CBZ is the only critical pollutant (Figure 4a). It is noteworthy that, although the GWF_P decreases as a whole, in some municipalities it rises slightly, as is the case of Murcia Este, Calasparra, Caravaca de la Cruz, Puerto Lumbreras, San Javier and Yecla. This increase is due to the fact that some pharmaceuticals are not detectable in WWTPs influents (due to encapsulation in faeces, transformation into other compounds and retransformation after the treatment in the mother substance…), but they are detected in effluents. This is why a low value of GWF_P appears now for three municipalities (Caravaca de Cruz, San Javier and Yecla) that previously had no value and that together only account for 8% of the GWF_P in this scenario. When the GWF_P is expressed per inhabitant, its value and dispersion with respect to untreated wastewater are appreciably reduced. The maximum value, found in San Pedro, is 823 m^3 $inhabitant^{-1}$ $year^{-1}$. In average terms, a general decrease exists, from 301 to 222 m^3 $inhabitant^{-1}$ $year^{-1}$ (Figure 4b).

Figure 4. GWF_P generated by treated wastewater, considering pharmaceutical pollutants (GWF_P due to critical pollutant in the WWTPs effluents): a) m^3 $year^{-1}$; b) m^3 $inhabitant^{-1}$ $year^{-1}$.



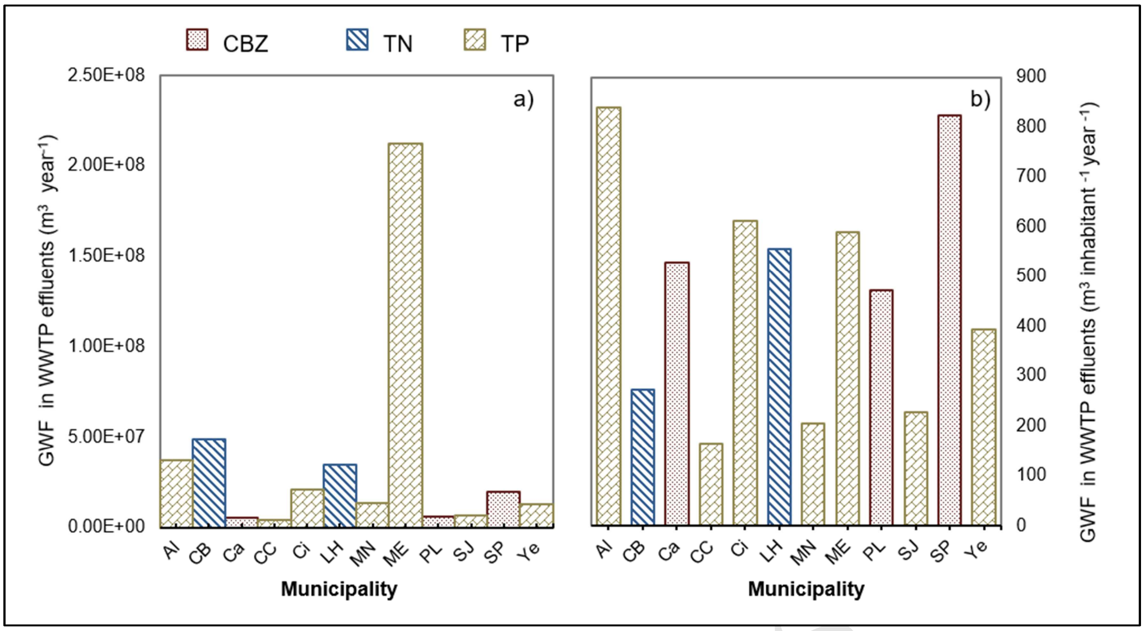
In the case of the conventional pollutants, the GWF_C decreases by 90%, which demonstrates the effectiveness of the WWTPs in eliminating this kind of pollutant. The value of the GWF_C for all WWTPs as a whole is reduced to $411 \cdot 10^6$ m^3 $year^{-1}$. Murcia Este continues to contribute the most to this value of GWF_C, being responsible for more than half (52%). The reduction of the GWF_C, was greatest for Molina Norte (98%) and smallest for San Pedro (83%) (Figure 5a). In the effluents, BOD_5 ceases to be the critical pollutant; now, TP is responsible for 80% of the GWF_C and TN for 20%. Per inhabitant, the values vary between 164 m^3 $year^{-1}$ (Caravaca de la Cruz) and 839 m^3 $year^{-1}$ (Alcantarilla), the average being 470 m^3 $year^{-1}$ (Figure 5b).

Figure 5. GWF_C generated by treated wastewater, considering conventional pollutants (GWF_C due to critical pollutants in the WWTPs effluents): a) m^3 $year^{-1}$; b) m^3 $inhabitant^{-1}$ $year^{-1}$.



Although the global value of the GWF_C is double that of the GWF_P ($411 \cdot 10^6$ m^3 year^{-1} versus $194 \cdot 10^6$ m^3 year^{-1}), there are three WWTPs where the value of the GWF_P is greater than that of the GWF_C: San Pedro, Puerto Lumbreras and Calasparra. This is because CBZ appears or its concentration increases in the effluents of these WWTPs, exacerbating the value of the GWF_P, while the GWF_C values are significantly reduced. So, the fresh water volume required to dilute the CBZ in these three WWTPs is capable of diluting all the pollutants analysed in this treated wastewater (DCF, NPX, KTP, TP, TN and BOD_5), even the conventional pollutants. Therefore, the final value of the GWF of the treated effluents is due to both conventional (TP and TN) and pharmaceutical pollutants (CBZ) (see Figure 6a), reaching the value of $420 \cdot 10^6$ m^3 year^{-1} (a little higher than the $411 \cdot 10^6$ m^3 year^{-1} obtained with only conventional pollutants). Similarly, the value per capita rises slightly, to 480 m^3 inhabitant^{-1} year^{-1} (Figure 6b).

Figure 6. GWF generated by treated wastewater of WWTPs effluents, considering conventional and pharmaceutical pollutants (GWF_P and GWF_C of the critical pollutants in the WWTPs effluents evaluated jointly): a) m^3 year^{-1}; b) m^3 inhabitant^{-1} year^{-1}.



3.3. Grey Water Footprint in the Murcia Region

In the Murcia Region, as has been pointed out previously, almost all the wastewaters are treated. These treated volumes are discharged into natural streams, infiltrate into aquifers, are sent into the sea or are directly reused. For the latter case there are legal concessions for the reuse by irrigation communities (CHS, 2016). Among the 12 WWTPs studied, nine send their effluents to direct reuse in irrigation, preventing the majority of their pollutants from reaching water bodies (assuming that their degradation, accumulation in soil or accumulation in crops do not generate a GWF). For that reason, as the pollutant load that would reach the water bodies is small, these nine effluents were not considered for the calculation of the GWF of the Murcia Region, and only the effluents of the three WWTPs that discharge directly into a water body (including the one that releases into the sea) were taken into account: Calasparra, Murcia Este and San Pedro. Consequently, evaluating the GWF jointly for pharmaceutical and conventional pollutants, the three treatment plants that discharge into the environment generate a GWF of $237{\cdot}10^6$ m^3 $year^{-1}$. This supposes a reduction of 43.6% with respect to the value previously obtained after wastewater treatment ($420 \cdot 10^6$ m^3 $year^{-1}$). The critical pollutant in Calasparra and San Pedro is CBZ, representing 10% of the total GWF, while in Murcia-Este it is TP (Figure 6a), representing the remaining 90%. If the GWF taking into account the WWTPs and reuse ($237 \cdot 10^6$ m^3 $year^{-1}$) is extrapolated to the entire Murcia Region, the GWF increases to $339 \cdot 10^6$ m^3 $year^{-1}$ (GWF_P and GWF_C), which represents a value of 271 m^3 $inhabitant^{-1}$ $year^{-1}$.

4. Discussion

Regarding the three scenarios evaluated, the first reveals how, in areas where no purification processes are employed, the GWF can reach values of around 4,718 m^3 $inhabitant^{-1}$ $year^{-1}$ (Figure 3b), due to conventional pollutants (organic matter). This value indicates the fresh water per capita that would be necessary to reduce the pollutants in the wastewater effluents to acceptable levels. So, in areas with water stress (Falkenmark et al., 1989), in which the fresh water available is less than 1,000 m^3 $inhabitant^{-1}$ $year^{-1}$, it would not be possible to dilute these pollutants. This indicates that in these territories there is no practical option other than to reuse wastewater directly, with the consequent health problems that this can involve. The second scenario (representative of areas where treated wastewaters are not directly reused) demonstrates that the WWTPs are very effective at eliminating conventional pollutants (especially organic matter), reducing the GWF_C by around 90%. The pharmaceuticals are removed partially, reducing the GWF_P to a lesser extent, around 26%. Therefore, in this case, it is likely that the GWF no longer depends on just the organic matter, since the WWTPs are very efficient at removing this contaminant; other, partially-eliminated pollutants would become critical (for example, nitrate, phosphates) and some emerging pollutants could also be critical (such as CBZ). Consequently, part of the GWF of an area with WWTPs may be due to non-conventional pollutants, such as pharmaceuticals. Despite the significant reduction of the GWF effected by the WWTPs, the treated wastewater discharged into natural streams continues to generate an important GWF that reaches values around 480 m^3 $inhabitant^{-1}$ $year^{-1}$ (Figure 6b). Although this is not as serious as in areas without WWTPs, above all in areas with plentiful water resources, it is not a negligible value. For example, and as a comparison, the United Nations (UN, 2010) proposes a value between 50 and 100 litres of fresh water per inhabitant and day for domestic use, to ensure that basic needs are met and health is assured. This represents 18.3-36.5 m^3 $inhabitant^{-1}$ $year^{-1}$. So, domestic pollution, even if there is an efficient system of purification, requires a much-greater volume of fresh water, to ensure the assimilation of the rest of the pollutants by the environment, than domestic water consumption itself. The third scenario reveals that, in territories with WWTPs, the option of reusing their effluents can reduce the GWF significantly, although this reduction depends on the reuse rates of each territory; for the case of the present study it implies a decrease from 480 to 271 m^3 $inhabitant^{-1}$ $year^{-1}$ on average. This example value, while still high, could be inferior if the WWTP technology improved or the direct reuse ratio increased.

Focusing now on direct reuse, it has been indicated previously that the treated effluents do not generate a GWF if they are used directly in irrigation. The conventional pollutants studied (organic matter, nitrate, and phosphates) would not generate an impact on the water environment since they are degraded in the soil or consumed by the crops. In fact, nitrate and phosphates are necessary for crops, so if their concentrations in the soil are lower than the needs of the crops (as is usual) fertilisers are added to increase them. Similarly, pharmaceutical pollutants in treated wastewaters tend to accumulate in soil and crops (Carter et al., 2014), preventing many of them from reaching the aquatic environment. However, even if we assume that no pharmaceuticals reach any body of water, they may have negative impacts on crops. In this sense, the accumulation of pharmaceutical compounds in edible agricultural products has been confirmed (Prosser and Sibley, 2015; Carter et al., 2014). So, regarding reuse, pharmaceutical pollutants are more harmful than conventional ones. Therefore, the concept of the GWF can be adapted or extrapolated to the field of reuse in general. In this sense and in irrigation reuse, the GWF can be used to determine the volume of water with which it is necessary to dilute a certain effluent so that it can be used safely. But it is important to highlight that, previous to this, maximum concentrations for certain types of crops must be established for each pollutant, due to the possibility of bioaccumulation or effects on crop survival. For this case, assuming that the maximum concentrations employed for the PNEC criterion were similar to those that could be established in future legislation, the GWF due to pharmaceutical contaminants (GWF_P) in WWTP effluents that are reused in irrigation would not be zero.

Consequently, the GWF could be composed of two different values: one would be due to treated wastewater that goes to natural streamflows (3 WWTPs: $237 \cdot 10^6$ m^3 year^{-1}) and another would arise when treated wastewater is reused in irrigation, due to pharmaceutical pollutants (9 WWTPs: $82.4 \cdot 10^6$ m^3

year^{-1}). So, in this scenario, the GWF would increase slightly, from 237·10^{6} m^{3} year^{-1} to 319·10^{6} m^{3} year^{-1}. Extrapolating these values to the Murcia Region produces a change from 338·10^{6} m^{3} year^{-1} to 456·10^{6} m^{3} year^{-1}, an increase of 118·10^{6} m^{3} year^{-1} due to the pharmaceutical pollutants in the treated wastewater that is reused. Although this increase is not very high, and the concept of the GWF is being slightly altered, it shows the order of magnitude of the quantity of uncontaminated fresh water with which it is necessary to mix the pollutant load to reduce its concentration to the quality standards established. So, if the treated wastewater has a volume of 38.6·10^{6} m^{3} year^{-1}, to achieve the designated dilution it is necessary to mix this volume with an additional volume of fresh water of 79.4·10^{6} m^{3} year^{-1} (to reach the indicated volume of 118·10^{6} m^{3} year^{-1}). So, for this particular case, and according to the previously-established criteria, it would be necessary, on average, to mix one volume of treated wastewater with two volumes of fresh water from another source without pharmaceutical pollutants (transfer, underground, surface or desalinised water). Although the load of contaminants is not eliminated, the dilution at least reduces their concentrations and thus the risk and concern related to the use of this water for irrigation. Regarding the case of the Murcia Region, the levels of dilution that are currently being used are higher than those indicated here, being of the order of two or 10 (fresh water) to one (treated wastewater). Therefore, according to this study, the pharmaceutical compounds studied here should not pose a risk in the food chain when the treated wastewater is used in this way in irrigation.

5. Conclusions

In this work, GWF accounting for pharmaceutical pollutants (GWF_P) was carried out in the Murcia Region. In the influents of the WWTPs, among the four pharmaceutical compounds studied, CBZ, DCF and NPX were the critical pollutants, whereas KTP was not found to be responsible for the GWF_P. Nevertheless, the GWF_P was low when compared to the GWF produced by conventional pollutants (GWF_C). The great differences between the GWF_P and GWF_C suggest that, although water quality standards can vary between different legislations, conventional pollutants will also be critical in other geographic areas without WWTPs.

The WWTPs have been shown to be very efficient for the conventional pollutants, while the pharmaceuticals are removed partially. The effect of the removal of the contaminants is transferred directly to both values, GWF_P and GWF_C. Nevertheless, the results indicate that achieving a GWF_P or GWF_C equal to zero is not a simple task since all the WWTPs studied have tertiary treatment. To do this, the purification rates of the WWTPs should be increased to values close to 100% - a fourth treatment step, such as osmosis, activated carbon or ozone filtration, being necessary. However, this aim could be achieved through reuse, thus saving important economic resources and encouraging a circular economy. The only drawback is that the pollutant concentrations of the effluents must be decreased to acceptable ranges for this secondary use. Otherwise, as can be observed in the example presented here, pharmaceutical pollutants could be a limiting factor. In these cases, an alternative that avoids increasing the purification costs and allows water reuse to continue is the mixture of waters from different origins. This is a habitual practice in zones of water scarcity but with connectivity of waters. To this end, the GWF concept is an indicator that can be used to determine the volume of fresh water that needs to be added to an effluent to reduce its levels of pollutants to a specific concentration. So, the GWF, in addition to raising awareness of the effects of pollution on the environment, also shows the dilution of treated wastewater that is necessary to allow its safe reuse in another economic activity.

Acknowledgements

This work was supported by the Entidad de Saneamiento y Depuración de la Region de Murcia (ESAMUR), through the projects [CFL-ESAMUR 16/17], [CFL-ESAMUR 13/14] and [IMA-ESAMUR 18/19], and by the Research Project 19342/PI/14, funded by “Fundación Séneca - Agencia de Ciencia y Tecnología de la Región de Murcia” in the framework of PCTIRM 2011–2014. The authors would like to thank Jesús Artero and Dr. Agustín Lahora from ESAMUR, for providing help with data collection, as well as other information needed for this study, and Dr. David Walker for the correction of the English.

References:

Aparicio, J., Candela, L., Alfranca, O., García-Aróstegui, J.L., 2017. Economic evaluation of small desalination plants from brackish aquifers. Application to Campo de Cartagena (SE Spain). Desalination 411, 38-44.

Arriaga, S., de Jonge, N., Nielsen, M.L., Andersen, H.R., Borregaard, V., Jewel, K., Ternes, T.A., Nielsen, J.L., 2016. Evaluation of a membrane bioreactor system as post-treatment in waste water treatment for better removal of micropollutants. Water Research 107, 37-46.

BOE., 2008. Orden ARM/2656/2008, de 10 de septiembre, por la que se aprueba la instrucción de planificación hidrológica. Ministerio de Medio Ambiente y Medio Rural y Marino. Boletín Oficial del Estado. nº 71. Madrid. Pp. 12820-12821.

BOE., 2015. Real Decreto 817/2015, de 11 de septiembre, por el que se establecen los criterios de seguimiento y evaluación del estado de las aguas superficiales y las normas de calidad ambiental. Ministerio de Agricultura, Alimentación y Medio Ambiente. Boletín Oficial del Estado. nº 219. Madrid. Pp. 80582-80677.

Camacho-Muñoz, D., Martín, J., Santos, J. L., Aparicio, I., & Alonso, E., 2009. An affordable method for the simultaneous determination of the most studied pharmaceutical compounds as wastewater and surface water pollutants. Journal of separation science 32(18), 3064-3073.

Carter, L. J., Harris, E., Williams, M., Ryan, J. J., Kookana, R. S., & Boxall, A. B. (2014). Fate and uptake of pharmaceuticals in soil–plant systems. Journal of agricultural and food chemistry, 62(4), 816-825.

Cazcarro, I., Duarte, R., Sanchez-Choliz, J. 2016. Downscaling the grey water footprints of production and consumption. Journal of cleaner Production 132, 171-183.

Cerdá, A., 2016. Aproximación al dimensionamiento del sistema agroalimentario de la Región de Murcia. Catédra UCAM-Santander. 40 Pp.

CHS, 2016. Plan Hidrológico de la Cuenca del Segura. Confederación Hidrográfica del Segura. Memoria. Ministerio de Medio Ambiente, Madrid.

CHS, 2017. Monitoring and analysis: surface water quality (in Spanish). Available in: http://www.chsegura.es/chs/cuenca/redesdecontrol/calidadenaguassuperficiales/ (accessed on 31 May 2017).

Cuthbert, R., Taggart, M. A., Prakash, V., Saini, M., Swarup, D., Upreti, S., ... & Green, R. E., 2011. Effectiveness of action in India to reduce exposure of Gyps vultures to the toxic veterinary drug diclofenac. PLoS One 6(5), e19069.

Díaz-Garduño, B., Pintado-Herrera, M. G., Biel-Maeso, M., Rueda-Marquez, J. J., Lara-Martin, P. A., 2017. Environmental risk assessment of effluents as a whole emerging contaminant: Efficiency of alternative tertiary treatments for wastewater depuration. Water Research 119, 136-149.

ESAMUR, 2017. Entidad de Saneamiento y Depuración de Aguas Residuales de la Región de Murcia. http://www.esamur.com(accessed on 17 January 2017).

European Union., 2000. Directive 2000/60/EC of the European Parliament and of the Council Establishing a Framework for Community Action in the Field of Water Policy. Official journal of the European Communities. L327. Volume 43. Pp. 1-72.

European Union., 2008. Directive 2008/105/EC of the European Parliament and of the Council on environmental quality standards in the field of water policy, amending and subsequently repealing Council Directives 82/176/EEC, 83/513/EEC, 84/156/EEC, 84/491/EEC, 86/280/EEC and amending Directive 2000/60/EC of the European Parliament and of the Council. Official journal of the European Communities. L348. Volume 51. Pp. 84-97.

European Union., 2013. Directive 2013/39/EU of the European Parliament of the Council Amending Directives 2000/60/EC and 2008/105/EC as Regards Priority Substances in the field of Water Policy. Official Journal of the European Communities. L226. Volume 56. Pp. 1-17.

European Union., 2015. Commission Implementing Decision 2015/495/EC of 20 March 2015 establishing a watch list of substances for Union-wide monitoring in the field of water policy pursuant to Directive 2008/105/EC.

Falkenmark, M., Lundqvist, J., Widstrand, C., 1989. Macro-scale water scarcity requires micro-scale approaches – aspects of vulnerability in semi-arid development. Natural Resources Forum 13(4), 258-267.

Fernández-López, C., Guillén-Navarro, J.M., Padilla, J.J., Parsons, J.R., 2016. Comparison of the removal efficiencies of selected pharmaceuticals in wastewater treatment plants in the region of Murcia, Spain. Ecological engineering 95, 811-816.

Fowdar, H.S., Hatt, B.E., Breen, P., Cook, P.L.M., Deletic, A., 2017. Designing living walls for greywater treatment. Water Research 110: 218-232.

Gheorghe, S., Petre, J., Lucaciu, I., Stoica, C., & Nita-Lazar, M., 2016. Risk screening of pharmaceutical compounds in Romanian aquatic environment. Environmental monitoring and assessment. 188(6), 379.

Gil, R., Bojaca, C.R., Schrevens, E., 2017. Uncertainty of the Agricultural Grey Water Footprint Based on High Resolution Primary Data. Water Resources Management 31(11): 3389-3400.

Gil-Olcina, A., 2009. Clima e hipótesis de cambio climático en la región geográfica del sureste ibérico. Investigaciones Geográficas (Esp), (49).

Grindlay, A.L., Zamorano, M., Rodríguez, M.I., Molero, E., Urrea, M.A., 2011. Implementation of the European Water Framework Directive: integration of hydrological and regional planning at the Segura River Basin, Southeast Spain. Land Use Policy 28(1), 242-256.

Güler, E., Kaya, C., Kabay, N., Arda, M., 2015. Boron removal from seawater: State-of-the-art review. Desalination 356, 85-93.

Hoekstra, A.Y., Chapagain, A.K., Aldaya, M.M. Mekonnen, M.M., 2011. The Water Footprint assessment manual. Ed. Earthscan, Available in: http://www.waterfootprint.org/downloads/TheWaterFootprintAssessmentManual.pdf.

INE, 2017. Instituto Nacional de Estadística. Censo Agrario 2014. Available in: http://www.ine.es (accessed on 15 May 2017).

Jiao, W.J., Min, Q.W., Cheng, S.K., Li, W.H., 2013. The waste absorption foot-print (WAF): a methodological note on footprint calculations. Ecological Indicators 34,356–360.

Kroll, S.A., Ringler, N.H., De las Heras, J., Gomez-Alday, J.J., Moratalla, A., Briggs, R.D., 2013. Analysis of anthropogenic pressures in the Segura Watershed (SE Spain), with a focus on inter-basin transfer. Ecohydrology 6(5), 878–888.

Kümmerer, K., 2011. Emerging Contaminants versus Micro-pollutants. Clean-Soil Air Water 39(10), 889-890.

Lapuente, E., 2012. Full cost in desalination. A case study of the Segura River Basin. Desalination 300, 40–45.

Liu, C., Kroeze, C., Hoekstra, A.Y., Gerbens-Leenes, P.W., 2012. Past and future trends in grey water footprints of anthropogenic nitrogen and phosphorus inputs to major world rivers. Ecological Indicators 18, 42–49.

Mandaric, L., Celic, M., Marcé, R., Petrovic, M., 2015. Introduction on Emerging Contaminants in Rivers and Their Environmental Risk. In Emerging Contaminants in River Ecosystems: Occurrence and Effects Under Multiple Stress Conditions. Springer International Publishing 46, Pp. 3-25.

Martínez-Alcalá, I., Guillén-Navarro, J.M., Fernández-López, C., 2017. Pharmaceutical biological degradation, sorption and mass balance determination in a conventional activated-sludge wastewater treatment plant from Murcia, Spain. Chemical Engineering Journal 316, 332-340.

Martínez-Paz, J.M. and Perni, A., 2011. Environmental cost of groundwater: a contingent valuation approach. Journal of Environmental Research 5(3), 603–612.

Martínez-Paz, J.M., Perni, A., Ruiz-Campuzano, P., Pellicer-Martínez, F., 2016. Economic valuation of irrigation systems supply failures in the Segura basin (Valoración económica de los fallos de suministro en los regadíos de la cuenca del Segura). Revista Española de Estudios Agrosociales y Pesqueros 244, Pp. 35-67.

Mekonnen, M.M. and Hoekstra, A.Y., 2015. Global gray water footprint and water pollution levels related to anthropogenic nitrogen loads to fresh water. Environmental Science & Technology 49 (21), 12860-12868.

Morera, S., Corominas, L.I., Poch, M., Aldaya, M.M., Comas, J., 2016. Water footprint assessment in wastewater treatment plants. Journal of Cleaner Production, 112: 4741-4748.

NORMAN, 2017. Norman network. www.norman-network.net (accessed on 31 May 2017).

Paudel, K., Amano, T., Acharya, R., Chaudhary, A., Baral, H. S., Bhusal, K. P., ... & Galligan, T. H., 2016. Population trends in Himalayan Griffon in Upper Mustang, Nepal, before and after the ban on diclofenac. Bird Conservation International 26 (3), 286-292.

Pellicer-Martínez, F. and Martínez-Paz, J.M., 2016. The Water Footprint as an indicator of environmental sustainability in water use at the river basin level. Science of the Total Environment 571, 561-574.

[b]Pellicer-Martínez, F. and Martínez-Paz, J.M., 2016. Grey water footprint assessment at the river basin level: Accounting method and case study in the Segura River Basin, Spain. Ecological Indicators 60, 1173-1183.

Pellicer-Martínez, F. and Martínez-Paz, J.M., 2018. Probabilistic evaluation of the water footprint of a river basin: Accounting method and case study in the Segura River Basin, Spain. Science of the Total Environment 627, 28-38.

Petrie, B., Barden, R., Kasprzyk-Hordern, B., 2015. A review on emerging contaminants in wastewaters and the environment: current knowledge, understudied areas and recommendations for future monitoring. Water Research 72, 3-27.

Prosser, R.S. and Sibley, P.K., 2015. Human health risk assessment of pharmaceuticals and personal care products in plant tissue due to biosolids and manure amendments, and wastewater irrigation. Environment International 75, 223-233.

Qiang, L., Cheng, J., Yi, J., Rotchell, J. M., Zhu, X., Zhou, J., 2016. Environmental concentration of carbamazepine accelerates fish embryonic development and disturbs larvae behavior. Ecotoxicology 25(7), 1426-1437.

Quinteiro, P., Ridoutt, B.G., Arroja, L., Dias, A.C., 2018. Identification of methodological challenges remaining in the assessment of a water scarcity footprint: a review. International Journal of Life Cycle Assessment 23(1): 164-180.

Ródenas, M.A., Albacete, M., 2014. The River Segura: reclaimed water, recovered river. Journal of Water Reuse and Desalination 4(1), 50-57.

Rozas, O., Vidal, C., Baeza, C., Jardim, W., Rossner, A., Mansilla, H., 2016. Organic micropollutants (OMPs) in natural waters: Oxidation by UV/H_2O_2 treatment and toxicity assessment. Water Research 98, 109-118.

Satterthwaite, D., 2016. Missing the Millennium Development Goal targets for water and sanitation in urban areas. Environment & Urbanization 28(1), 99-118.

Tran, N.H., Urase, T., Ta, T.T., 2014. A preliminary study on the occurrence of pharmaceutically active compounds in hospital wastewater and surface water in Hanoi, Vietnam. CLEAN–Soil, Air, Water, 42(3), 267-275.

Trombini, C., Hampel, M., Blasco, J., 2016. Evaluation of acute effects of four pharmaceuticals and their mixtures on the copecod Tisbe battagliai. Chemosphere, 155, 319-328.

UN (United Nations), 2010. Resolution on Human Right to Water and Sanitation, UN General Assembly Research A/64/292; United Nations: New York, NY, USA.

Wang, L. Wu, X., 2014. Careful considerations when reporting and evaluating the grey water footprint of products. Ecological Indicators 41, 131-132.

Wang, W.L., Wu, Q.Y., Huang, N., Wang, T., Hu, H.Y., 2016. Synergistic effect between UV and chlorine (UV/chlorine) on the degradation of carbamazepine: Influence factors and radical species. Water Research 98, 190-198.

Wu, B., Zeng, W., Chen, H., Zhao, Y., 2016. Grey water footprint combined with ecological network analysis for assessing regional water quality metabolism. Journal of Cleaner Production 112, 3138-3151.

Zhang, Y.J., Zhu, H., Szewzyk, U., Geissen, S.U., 2015. Removal of pharmaceuticals in aerated biofilters with manganese feeding. Water Research 72, 218-226.

Pharmaceutical grey water footprint: accounting, influence of wastewater treatment plants and implications of the reuse.

Highlights:

- Pharmaceutical Grey Water Footprint (GWF) was accounted in Murcia Region.
- GWF by conventional pollutants (organic matter, nitrates, and phosphates) was also accounted.
- WWTPs were very efficient in reducing the GWF of both types of contaminants.
- Reuse treated wastewater help to decrease conventional pollutants GWF.