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# Reusing Treated Waste-Water from a Circular Economy Perspective—The Case of the Real Acequia de Moncada in Valencia (Spain)

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**Abstract:** One of the most important challenges that agriculture faces is sustainable water management and its adaptation to climate change. This adaptation is more important in regions where recurrent draughts and overexploitation of water resources happen. However, historical irrigation systems, such as the Real Acequia de Moncada (RAM) in Valencia, have found innovative approaches to deal with this phenomenon. This paper analyzes the case of Massamagrell and Puçol, which reused the treated waste-water of the closest waste-water treatment plant (WWTP). The study focused from a circular economy perspective on the technological, agronomical, and social implications of this decision. Results show that there are clear benefits for both farmers and WWTP managers. On the one hand, additional nutrients and regularity in their water supply benefit farmers. On the other, WWTP managers can reuse the treated effluent in the system, contributing to the closure of the water cycle and avoiding pumping the treated water into the sea. However, more detailed information and coordination is needed among the different stakeholders. Questions regarding the illegal connection of waste pipes with the traditional irrigation or the payment of pumping costs for reuse have gone unanswered, and there is a need for better reflection from all stakeholders.

**Keywords:** recycle water; reuse; traditional irrigation; surface irrigation; water quality; East Spain

## 1. Introduction

The transition to a circular economy implies that the resources are conserved, and the generation of waste is reduced. There is a necessity to achieve a sustainable economy, applied to products, services, material waste, water, and energy. Recent works highlight the benefits of a circular economy [1–4]. The transition also entails costs for the necessary investments, for a regulation that sometimes does not facilitate the reuse of resources, and the need for a cultural change in society. The use of waste as a raw material for production is essential in the European Union (EU): the waste and by-products of products already used would enter a new production cycle as “secondary raw materials”, as the case presented in [5] where the Energy & Raw Materials Factory in the Netherlands has successfully reused resources such as cellulose, bioplastics, phosphate, alginate-like exopolymers, and biomass.

Nevertheless, closing the circle requires solutions in reducing the impact on the environment and favor the reuse of resources [6]. This new approach can benefit alternative business models interrelated with the circular economy applied to waste-water reuse. In Otoo and Drechsel [7], a review of 24 initiatives of business models related to circular economy for waste and agriculture were presented. However, most of them were also limited by user perceptions and government regulations to correctly being developed [8].

Although several international organisms, such as United Nations (UN), are analyzing the importance of water in Europe for sustainable development goals, in the 2030 Agenda [9,10], the European Directive 91/271/EEC, which has been in force since 1991, is the only reference to waste-water reuse at European level [11,12]. The regulation states that towns/villages with 2000 or more inhabitants must collect and treat waste-water. The treatment plants must treat the waste-water to minimum standards. These limits become stricter when the treated waste-water may potentially damage sensitive environments or human health. Most European countries meet the rules of this directive, where newer member states were obliged from 2018 onwards [13]. The directive does not explicitly include the agricultural reuse of waste-water, although Article 12 of European Directive 91/271/EEC states that “treated waste-water shall be reused whenever appropriate”.

After the enforcement of European Directive 91/271/EEC, several regulations were implemented in Spain to encourage waste-water reuse, both at national and a regional scale [14]. As stated in Steflova et al. [15], Spain is in the middle of this transformation, which requires a great effort to solve multi-level governance barriers. The use of waste-water for irrigated agriculture is recognized and included in Spanish legislation, restricting certain parameters in terms of water quality. The most significant regulations affecting waste-water reuse in Spain for agricultural purposes are the Spanish Royal Decree 1/2001 (revised version of the Water Act of 1985) and the Spanish Royal Decree 1620/2007, Regulation of Purified Water Reuse. The first defines the requisites and procedure to obtain a license for water reuse, an essential step within the process of reusing treated waste-water in agriculture. The decision can be made by the River Basin Authority, by which a compulsory report is made by the regional health authorities where the license is requested [14]. Moreover, the second one is the most important tool within the Spanish legislation with regard to waste-water reuse in agriculture, acting as a legal framework for the use of treated waste-water [13], defining the water quality criteria of treated waste-water for the use of different purposes.

Irrigation for agricultural purposes represents the greatest consumption of freshwater in the world, being in some case more than 90% of freshwater withdrawals [16,17]. Moreover, the increase of water consumption related to biogas production could increase the water usage by up to 20% in agriculture. Creating “new water” is an objective, which must have a holistic approach leading to an effective integrated water management strategy, as proposed in [8]. In this work, the attention is focused mainly in ensuring safety (biologically and environmentally), but also an adequate operational system.

There are several examples of waste-water reuse for agriculture all over the world. Some of them focus not only on operational or governance assessments, but also on safety and user perception of this new resource. This is the case carried out by Dare and Mohtar [18] where they analyzed the situation of the West Bank, Tunisia, and Qatar. In these cases, most of stakeholders considered waste-water reuse unsafe and insufficiently monitored and managed. Moreover, the Chilean case analyzed by Villamar et al. [19] also stated that treated waste-water does not ensure safety for food crops. Finally, the case of Murcia (Spain) was also studied by Gil-Meseguer et al. [20], where the authors analyzed the great effort carried out to adapt irrigation systems by means of new infrastructures and public policies. However, Valencia is somehow different, as its traditional irrigation system has always used waste-water (even untreated) for irrigation. In the study by Ortega et al. [21], a first approach is presented on how treated waste-water is presently used in this system. The most important conclusion is a positive acceptance of this new resource, which gives farmers more security and regularity for their weekly irrigation schedule. The quality of the water is also highly valued by the farmers, although it is less valued than river water. It is similar to the case in Germany analyzed by [22]. In this case,

they observed that when governance structures are aligned, they rule the reuse of waste-water more efficiently and they increase the value chain of waste-water treatment and crop production.

Moreover, various foodborne pathogenic microorganisms such as *Escherichia coli* 0157:H7, *Listeria monocytogenes*, or *Salmonella* have been linked to cases of infection and isolated from many different varieties of fresh fruit and vegetables. These products can become contaminated with bacterial pathogens in the field through contact with soil or irrigation water. Currently, microbial criteria are used to assess the safety of food and the detection and enumeration of indicator organisms such as aerobic mesophilic or coliform microorganisms, because they are regularly isolated from vegetables in sufficient numbers that can be counted, in contrast to most pathogens. Fecal coliforms have long been used as an indicator of fecal contamination in water and food and *E. coli* is generally considered the most reliable, since its presence directly relates to fecal contamination with its implied threat of the presence of enteric disease agents [23–25].

On the other hand, Pedrero et al. [26] studied the viability of using nitrogen (N), phosphorous (P), and potassium (K) in the treated waste-water for the irrigation of mandarin trees. The research showed that the content of N, P, and K can provide 24% and 15% of the annual crop needing N and P as well as completely meet the K requirements. Nevertheless, an excess of these elements in irrigation effluents might pose a risk to plants, and therefore it requires special attention and the parameters must be carefully monitored [13]. The type of crop grown and the type of irrigation used also determine the amount of N required. Out of the entire N forms present in the soil, only  $\text{NH}_4^+$  and  $\text{NO}_3^-$  fractions (ammonium and nitrate respectively) are important from the point of view of plant use. In particular,  $\text{NO}_3^-$  is the only form of N which is taken up by plants. The predominant N compound in waste-water is  $\text{NH}_4^+$ , but since this form is oxidized in soils,  $\text{NO}_3^-$  will be the predominant element available for plants after irrigation [13]. On the contrary, as stated by Feigin et al. [27] (pp. 34–116), an excessive concentration of nitrogen affects both crop growth and yield. A reduction of crop yield is observed for tomato plants and orange trees when irrigating with waste-water containing high concentrations of N, obtaining non-uniform ripening and longer fruiting results. Furthermore, quantities of phosphorous (P) are normally not excessive in the treated waste-water, but when these values are high it can result in nutrient imbalances causing Cu, Fe, or Zn deficiencies [13], considering that P is listed in the EU list of critical raw materials [28]. Other possible contaminants, such as trace metals and different ions, are also of great interest and must be taken into account, as states [29].

The proposed study intends to identify the potential benefits and risks of agricultural waste-water reuse. The goal is to recommend to local and regional authorities how to improve, control, and regulate the reuse of waste-water in peri-urban or rural areas highly connected to large cities.

This work is a case study of waste-water reuse in the Valencian traditional irrigation system of Real Acequia de Moncada (RAM) framed in a circular economy perspective. In the study, quantitative fieldwork was paired with qualitative interviews from different stakeholders.

## 2. Materials and Methods

The research data is collected by quantitative as well as qualitative measurements. The irrigation volumes at field level are measured for the rotational use of surface and treated waste-water in the area of Massamagrell and Puçol (500 ha) concerning two fields of orange trees (respectively with groundcover and 70% canopy and without groundcover and 20% canopy), kaki, onion, and tomato. The data is used to quantify the water balance at field and scheme level for various crops by irrigating either with two water resources: exclusively treated waste-water (waste-water case) or diluted with river water in the irrigation main channel on an estimated proportion of 1:3 approximately (mixed water case). The flow data is gathered by using three different methods, namely: an acoustic flow meter (OTT type C2), RBC flume (furrow section onion field) and by measuring the advance time with water levels in the field.

The nutrient levels, pH and salt concentrations are analyzed in the laboratory by collecting water samples of different water sources (respectively treated waste-water, mixed water–river and

waste-water- and groundwater) in the irrigation system. The MERCK Rqflex test kit is used to measure the nitrate concentration. Furthermore, the UviLine 9400 is used to measure the concentration of nitrite and phosphorus. The potassium concentration is measured with a Flame Photometer, which is designed to measure sodium and potassium. The pH is measured by using a device of CRISON, which is calibrated with standard fluids (pH 4, 7, and 9). The Electrical Conductivity (EC in dS/m) is measured directly in the field by using a conductivity meter type digimeter L21 aqualytic autotemperature. The conductivity meter is calibrated with a standard solution before the measurements.

Furthermore, the water quality data of the WWTP at Pobla de Farnals provided by the public company of waste-water treatments (EPSAR) is compared with the collected data. The quality data of this WWTP provides insight in the total nitrogen (sum of nitrate, nitrite, ammonia and organically bonded nitrogen) of the effluent water from the WWTP.

The detection of bacterial indicators in the water suggests the presence of pathogenic organisms that are sources of waterborne diseases. Indicator microorganisms survive better and longer than pathogens, with uniform and stable properties, and may be easily detected using standard laboratory techniques. These indicator organisms include total coliforms, species that may inhabit the intestines of warm-blooded animals and occur naturally in soil, vegetation, and water. Their presence in water indicates the possible presence of pathogens. *E. coli*, one species of the coliform group, is always found in feces and is, therefore, a more direct indicator of fecal contamination and the possible presence of enteric pathogens. Some authors questioned the usefulness of coliforms as indicators and *E. coli* is preferred because it is specific and most reliably reflects the fecal origin. The two methods commonly used to detect coliforms in water include the multiple fermentation tube technique and the membrane filter technique [23,30].

The membrane filter-colony method usually yields colony counts a little lower than those by the plate count method, but has the added advantage of permitting a count on samples very low in numbers of bacteria. Chromogenic coliform agar (CCA) for the enumeration of *E. coli* and coliform bacteria was used to both methods [31]. The water samples were analyzed for the enumeration of *Escherichia coli* and coliform bacteria following the UNE-EN-ISO-9308-1:2014/Amd 1:2016 by the membrane filtration methods and by the surface plating technique following the UNE-EN-ISO 4833-2:2013. Bacterial counts of coliform bacteria and *E. coli* were expressed as Colony Forming Units per 100 mL (CFU/100 mL). The investigation of Salmonella in samples was carried out following the UNE-EN/ISO 6579-1:2017 detection method.

The expert's perception is gathered by semi-structured interviews to 10 people representing 6 different stakeholders in the Valencia area: 3 researchers, 1 president of an irrigation community, 1 technician of IC, 1 lawyer of IC, 3 technicians of WWTP and 1 technician from a non-governmental organization (NGO). Moreover, the farmer's perception is described by collecting data through semi-structured interviews around Massamagrell (16 farmers, two irrigators and the guard) and Puçol (5 farmers). The area of Puçol is chosen because it is the last irrigation community downstream and it only receives surface water from the river Turia mixed with treated waste-water for irrigation. The "regador" or irrigator can be hired to water the field for the farmer, which is not seen as an official job. The guard is responsible for the functioning of irrigation for the different irrigation water users' associations (WUAs) when the river water arrives in his section. The social background shows that 20 out of the 21 farmers are older than 50, after which age most people are retired and/or cultivate the field part-time as farmer. From which eight farmers cultivate fruit trees, six farmers cultivate vegetables, six farmers cultivate a combination of fruit trees/vegetables and one farmer has a fallow field. The area of Massamagrell has only five professional farmers.

### 3. Results

#### 3.1. Circular Economy of the Waste-Water Cycle

Circular Economy (CE) stands for a counter-reaction of the predominant economic model of “take, make and dispose” [32]. Recent research has reviewed this concept and analyzed the transition and impacts of CE on environmental and economic systems [33]. For Waste-water, several loops can be closed, and water can be used for irrigation, energy production or industrial use [8]. In the particular case of Valencia, 5 different potential uses were selected from interviews to stakeholders; (i) Phosphorus recovery, (ii) Reuse in irrigation, (iii) Agricultural valorization of the sludge, (iv) Energy co-generation and co-digestion, and (v) seaweed cultivation. Among them, only reuse in agriculture for irrigation is a widespread practice in Spain and in particular in Valencia [21]. In our case, a Strengths, Weaknesses, Opportunities and Threats analysis (SWOT) was generated through the interviews with the stakeholders for the reuse in irrigation of the waste-water treated in a WWTP in the Valencia case scenario (Table 1).

**Table 1.** SWOT matrix obtained from experts’ interviews on the treated waste-water reuse.

STRENGTHS	WEAKNESSES
<ul style="list-style-type: none"> <li>• The installed capacity in the already built WWTP is sufficient to treat the influent’s flow.</li> <li>• Very demanding quality standards can be achieved for agricultural processes</li> <li>• The WWTP can guarantee a flow of water for irrigation in areas of scarcity.</li> <li>• Savings in fertilizers can be seen as benefits.</li> </ul>	<ul style="list-style-type: none"> <li>• The standard values required for agriculture demand high water quality measures.</li> <li>• It may not be effective in eliminating emerging contaminants (medications, estrogens, etc.).</li> <li>• Reuse requires hydraulic networks, which may have an environmental and energetic impact.</li> <li>• Sometimes, it is necessary to mix with other resources to guarantee sufficient flow.</li> </ul>
OPPORTUNITIES	THREATS
<ul style="list-style-type: none"> <li>• The seasonality of the water demand of the crops requires a guarantee of water in summer.</li> <li>• There is a high flow discharged into the sea and it could be reused for agriculture and environment.</li> <li>• There is a demand for fresh fruit and vegetables that benefits from WWTP irrigation.</li> <li>• Farmers do not have a negative attitude to watering with treated waste-water.</li> </ul>	<ul style="list-style-type: none"> <li>• Budget cuts penalize water reuse options.</li> <li>• Investment and operating costs are high.</li> <li>• Reuse options for irrigation require expensive hydraulic works.</li> <li>• There may be over-fertilization on fields irrigated by treated waste-water.</li> </ul>

The high-quality criteria to allow the usage of water from a WWTP is an important issue extracted from all experts’ interviews. Even some experts showed concerns about it, other see a strength due to the increase of high-tech WWTPs in Valencia (similar to [8,34]). Another interesting result is the positive attitude of farmers towards the use of treated waste-water in Valencia, unlike the case study by Dare and Mohtar [13] where farmers are unsure about the safety of the resource. Finally, it is interesting to remark the importance of reducing fertilizer inputs in the plots, which can lead to a successful experience as in the case described in Italy by [35].

#### 3.2. Description of the Real Acequia de Moncada (RAM) and Their Irrigation Network

One of the most famous farmer-managed irrigation systems is that of l’Horta (garden) of Valencia in Spain. In this area water management has conditioned the development of the existing landscape since ancient times, and as a result a complex system of channels dating back to Muslim times is still used for gravity irrigation. Its main water source is the Turia River. In addition, they also use collective wells, in some areas, and more recently waste-water [21].

In the area, farmers come together in irrigation WUA. Farmers belonging to the irrigated area of an irrigation WUA share a collective water right. The larger irrigation WUA in the system is known as the RAM. The RAM covers approximately 5200 ha and includes more than 10,000 farmers. This system



is a peri-urban agricultural area highly connected to several cities and towns (total population around 2 million people), where there is an important potential for water reuse. The most dominant crops are citrus (orange) and a wide array of garden vegetables (onion, artichoke, tomatoes, cabbage, salad, etc.), and persimmon (kaki), which has been growing in importance in recent years. Water is distributed by gravity across the system, the main channel has a length of 33 km, and secondary channels divide the irrigated area in sub-sectors for water distribution, at plot level farmers use surface irrigation. The irrigation WUA has a governing board, elected by farmers, and water guards, workers of the WUA, in charge of following up irrigation and diverting water to different channels and sectors. The RAM system is divided in several sub-areas from head to tail. Massamagrell and Puçol are in the tail of the system and has an agriculture area of 500 ha irrigated by the RAM with a current population within the irrigation area of 15,752.

Average water used in the RAM system derived from the Turia River between 2000 and 2012 was approximately 75 Mm<sup>3</sup>/year. However, there is an important variability as water use ranging from 40 Mm<sup>3</sup>/year (during drought periods when important water restrictions are applied) up to 120 Mm<sup>3</sup>/year (in exceptionally wet years when irrigation channels are also used as drainage channels to prevent flooding in neighboring areas, and therefore water is not exclusively used for irrigation).

In addition to water resources from the Turia River, there is also access to groundwater for irrigation in some areas. Farmers came together in the past to share the cost of drilling wells and established Groundwater WUAs. To use groundwater, farmers pay a price per irrigation hour set to recover the operation and maintenance costs of groundwater use. Groundwater is usually used when no river water is available. Therefore, it has become a crucial resource during times of drought, as it allows more frequent irrigation when there is scarcity, securing the plantation of more demanding crops.

The population in the RAM always used the irrigation channels as a sewage system for waste-water. For this reason, reused untreated waste-water was done on a small scale without any treatment, comprising only urban waste-water of surrounding villages and the sparsely distributed houses in the rural area. This situation was critical after the 60 s when massive industrialization and use of chemical products in the houses produced quality problems in all the traditional irrigation systems in Valencia. During the 2004–2008 drought period, in a context of acute water shortage, the Water Authority (the Confederacion Hidrográfica del Júcar), promoted water reuse for irrigation as a measure to supplement river water and release pressure over existing water demand. Public funds, at that time, were devoted to building conveyance infrastructure from the Waste-Water Treatment Plants (WWTPs), to a point of discharge in the channel network. In that context, farmers accepted these additional water resources, introducing the use of treated waste-water in certain areas. However, although public authorities have been devoting efforts to disconnect the sewage and irrigation systems, some connections, mainly of sparsely distributed houses in the rural area or old houses inside the rural towns, still exist and seem to be a source of pathogens in irrigation water.

In the RAM, treated waste-water is used from the WWTP of Pobla de Farnals. The water is pumped from the WWTP to the main channel (Figure 1). As discussed later in the results, pumping costs are not currently paid by farmers, but by the local administration. Although treated waste-water was initially intended to be used as a supplement to river water (mixed with river water), when water is limited to irrigate once every two weeks (draught measures), waste-water is used directly by introducing differences and inequity on the irrigation schedule in some areas.

Before the treated waste-water is pumped into the main irrigation canal or to the sea, the quality of the water should meet the effluent regulations, which are described in Directive 91/271/EEC for urban waste-water treatment. The objective of the regulation is to protect the environment from the adverse effects of urban waste-water discharges as well as discharges from industrial sectors.

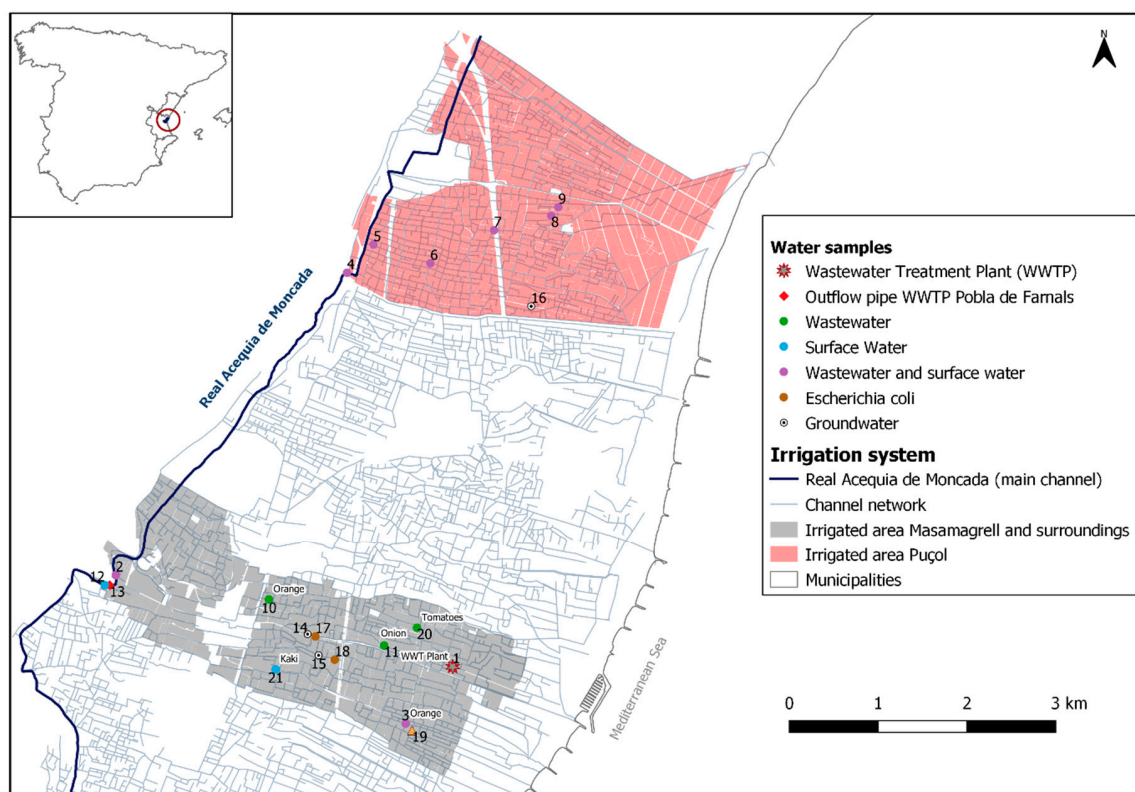


Figure 1. Studied area with measurement points.

The waste-water treatment plant of Pobla de Farnals treats waste-water in three process steps (pre-, secondary and tertiary treatment) for nine municipalities. The daily effluent water flow in 2014 was 24.691 m<sup>3</sup>/day (annually 9.01 hm<sup>3</sup>), from which a certain volume is pumped towards the main canal of the RAM three days per week, from Wednesday until Saturday and a certain volume is pumped towards the sea. This WWTP is designed to treat an effluent water flow of 30.000 m<sup>3</sup>/day (annually 10.95 hm<sup>3</sup>). In accordance to the Water Authority, the WWTP carries out chemical and biological analysis of the water at the exit to accomplish with the European regulation. The results are shown in Table 2, where the values are always below the maximum requirements except for total nitrogen.

Table 2. Water quality data (average and standard deviation) provided by WWTP of Pobla de Farnals taken at the outlet compared to the National and European directives.

Date	Year 2014–2015	The Royal Decree 1620/2007	The European Directive 91/271/EEC (>100,000 p.e.)
pH (Ud)	8.00 ± 0.16	-	-
EC (dS/m)	2.35 ± 0.35	3.00	-
Turbidity (NTU)	6.57 ± 4.00	10.00 <sup>1</sup>	-
SS (mg/L)	6.62 ± 3.23	20.00 <sup>1</sup> –35.00 <sup>2</sup>	35.00
BOD5 (mg/L)	14.86 ± 8.19	-	25.00
COD (mg/L)	47.84 ± 18.65	-	125.00
N (mg/L)	44.70 ± 10.26	-	10.00
P (mg/L)	1.50 ± 0.76	-	1.00

Note: <sup>1</sup> Irrigation of crops for human consumption using application methods that do not prevent or have direct contact of treated waste-water with edible parts of the crop; <sup>2</sup> Localized irrigation whereby reclaimed water is not allowed to contact fruit for human consumption.

### 3.3. Water Quality Analysis for the Waste-Water Reuse

#### 3.3.1. Chemical Water Quality (Nutrient Concentrations and pH)

As explained above, farmers in this area can use different water resources depending on the date and their access and belonging to WUAs and Groundwater WUAs. For this reason, we can distinguish three different irrigation resources around Massamagrell and Puçol: mixed water from river and waste-water (mixed), exclusively treated waste-water (waste-water) and groundwater. Results for each case can be seen in Table 3.

**Table 3.** Water quality data for the field measurements in the three different water resources.

Source	pH	Conductivity dS	Nitrate mg/L	Nitrite mg/L	Phosphorus mg/L	Potassium mg/L
Mixed	8.23 ± 0.33	1.34 ± 0.09	21.44 ± 2.54	1.54 ± 1.71	0.57 ± 0.47	6.61 ± 2.84
Waste-water	7.92 ± 0.13	2.48 ± 0.27	18.50 ± 3.54	3.20 ± 3.52	1.12 ± 0.61	25.14 ± 6.14
Groundwater	7.03 ± 0.05	1.89 ± 0.31	53.33 ± 15.92	1.90 ± 2.69	0.20 ± 0.14	5.63 ± 1.64

The results show a different behavior depending on the water resources. First, the mixed water case shows that average concentrations are 21.44, 0.57 and 6.61 mg/L for nitrate, phosphorus, and potassium, respectively. However, for the exclusive waste-water scenario, the average values change onto 18.50, 1.12 and 25.14 mg/L for each compound. This change is due to the dilution with the river water, which can also be observed in the other chemical parameters such as the pH and conductivity. The effluent water of the treated waste-water has an average pH of 7.92 and the mixed water a value of 8.23, which is within the range of normal pH of 6.5 and 8.4 [36]. The effect of alkaline water (pH for the river water is 9.5) is that it can contain high concentrations of bicarbonate (pH ≥ 8.0) and carbonates (pH ≥ 9.0), which can cause calcium to precipitate from the soil. The effect is a reduction in the soil's exchangeable calcium, which can increase the soil salinity.

A deeper analysis of the nutrient concentration in the treated waste-water shows that the waste-water presents an average concentration of 25.14 mg/L in the level of potassium oxide (K<sub>2</sub>O), since it is not obligatory to remove K<sub>2</sub>O from the waste-water. The average of phosphorus measured from the waste-water is 1.12 mg/L, which does not exceed the norm of 1.0–2.0 mg/L P (Directive 91/271/EEC). The sum of nitrate (NO<sub>3</sub><sup>-</sup>) and nitrite (NO<sub>2</sub><sup>-</sup>) from the waste-water is equal to 21.70, without measuring the ammonia and organically bonded nitrogen that forms the total nitrogen concentration. The total amount of nitrogen averaged for 2014–2015 measured by the WWTP at Poble de Farnals is 45.0 mg/L N (Table 2). This would exceed the norm, which fixes the maximum value on 10.0–15.0 mg/L N (Directive 91/271/EEC).

The measurements of the shallow groundwater resulted in an excess of nitrate concentration (norm > 50.0 mg/L). These requirements are applicable for sensitive areas, which are subject to eutrophication (European Union, 1991), of which the area of Valencia was designated as a so-called "Nitrate Vulnerable Zone" (NVZ) 2000–2003 by the Nitrates Directive (1991) [6]. In the NVZ areas, farmers need to implement several measures on a compulsory basis to reduce leaking of nitrogen in the environment.

In summary, the use of waste-water for irrigation can lead to a different management where the nutrient concentrations of the treated waste-water for irrigation can benefit the crop yields with the result of savings in fertilizers. The Nitrogen-Phosphorus-Potassium complex used for the cultivation of orange is 15/15/30, which indicates the use of 15% nitrogen (N), 15% phosphorous (P) and 30% potassium (K). The calculated benefits of the nutrient concentrations are shown in Table 4. The total volume of water applied to a field is multiplied with the nutrient concentration and then converting it to kilogram gives an indication of the amount of nutrients applied to a hectare per irrigation.



**Table 4.** Calculated benefit of total nitrogen (N), phosphorous oxide (P<sub>2</sub>O<sub>5</sub>) and potassium oxide (K<sub>2</sub>O) in the treated waste-water (WW) and surface water mixed with treated waste-water (Mixed).

Crop	Volume Applied		Nutrient Benefit (kg/Hectare/Irrigation Application)						
			Total N		P <sub>2</sub> O <sub>5</sub>		K <sub>2</sub> O		
Field	Liters	Mm	Area (m <sup>2</sup> )	WW	Mixed	WW	Mixed	WW	Mixed
Orange field <sup>1</sup>	817,920	284	2880	127.8	65.0	6.5	3.7	98.8	22.4
Orange field <sup>2</sup>	105,399	49	2151	22.1	11.2	1.1	0.6	17.1	3.9
Kaki	1,692,000	235	7200	105.8	53.8	5.4	3.1	81.8	18.6
Tomato	68,750	55	1250	24.8	12.6	1.3	0.7	19.1	4.3
Onion	124,660	23	5420	10.4	5.3	0.5	0.3	8.0	1.8

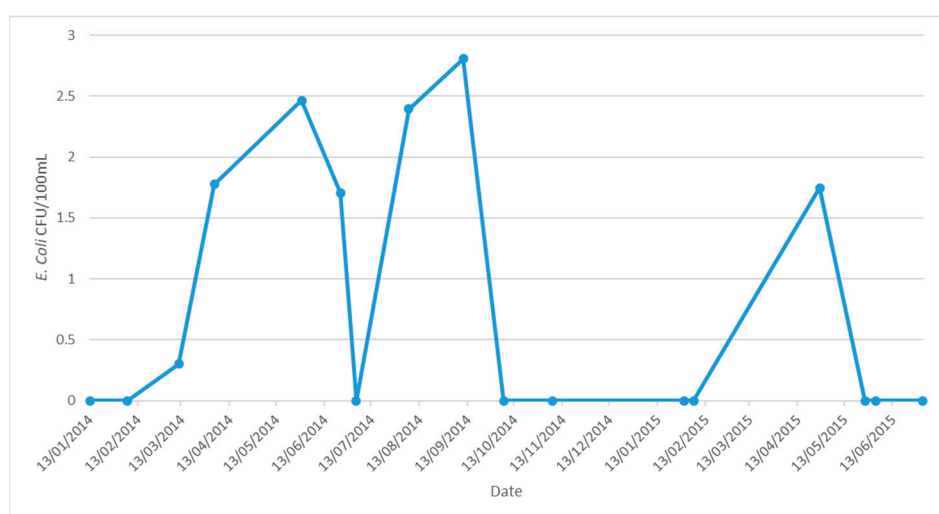
Note: <sup>1</sup> Groundcover and 70% canopy; <sup>2</sup> Without groundcover and 20% canopy.

Furthermore, the salinity of the waste-water from the WWTP of Pobla de Farnals is not treated because the EC remains under the norm of 3.0 dS/m. The industrial water (30% of the total influent) that is used for cooling purposes mainly causes the salinity level of the effluent water. The average EC value of the effluent water is of 2.55 dS/m for the treated waste-water measured in the irrigation channel and 1.34 dS/m when mixed with surface water (Table 3). It is important to be aware of the effect of the industrial water since it can cause soil salinity and reduce the yield of different crops.

### 3.3.2. Microbiological Water Quality (*E.coli*)

In the present study, the total coliform count was reported to be ranging from 1.74 to  $3.53 \times 10^6$  CFU/100 mL by filtration and plate count, respectively. *E. coli* count was  $3.9 \times 10^4$  CFU of *E. coli* in 100 mL by filtration and  $2.75 \times 10^5$  CFU of *E. coli* in 100 mL by plate count. These fluctuations in the number of *E. coli* in one logarithmic unit may be attributed to the false-negatives by inhibition by the high concentration of non-*E. coli* colonies or by the filter type, or by false-positive by the selectivity for *E. coli* seems to be worse in comparison with coliform bacteria, due to the fact that the CCA medium is not intended to be selective for *E. coli* alone [31,37]. Our results of the irrigation water exceed on more than 1–2 Log CFU/100 mL the maximum value established by the RD 1620/2007.

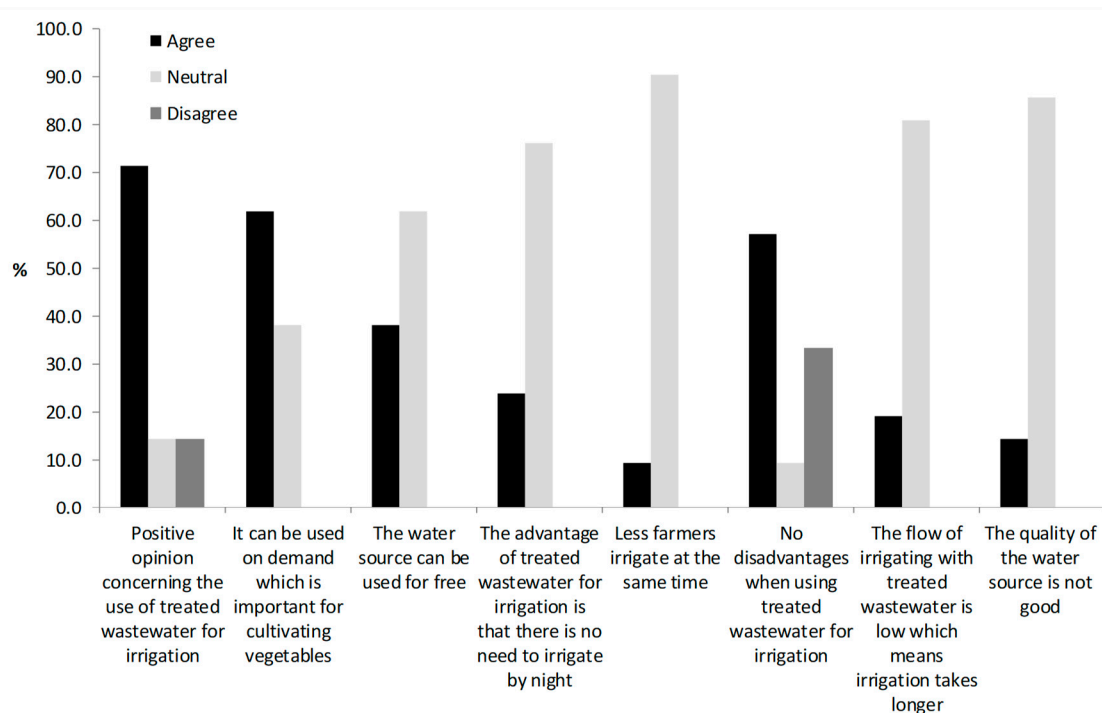
On the other hand, the WWTP performs regular analysis of *E. coli* at the outlet pipe. The results are shown in Figure 2. The increase of the bacteria CFU in our measurements (10 km away from the connection with the RAM's principal channel) is about 4 log CFU. It can be explained by the connection of old houses in the town of Massamagrell or the spread country houses located near the fields, which can pollute the irrigation water with untreated spills.

**Figure 2.** Data of *E. coli* (CFU/100mL) at the outlet pipe of the WWTP.

Domestic washing of fresh vegetables prior to its consumption constitutes a fundamental stage to guarantee the consumers safety. Washing by a shower with tap water or hypochlorite dips (4 ppm of chlorine or two drops of commercial suitable bleach) with a contact time of 5 min is enough to sanitize fruit and vegetables and allows for a reduction of 1 Log CFU/g from initial contamination [24,25].

### 3.4. Farmer's Perception on Waste-Water Reuse

The results are shown in Figure 3. Most of the interviewed farmers (71.4%) agree with the use of treated waste-water for irrigation and mention no disadvantages (57.1%). Although the farmers are positive, most of them are not informed about the quality of the treated waste-water (86.0%). The farmers that are against the use of treated waste-water (14.3%) mention the high concentration of salts in the water source as well as the right to have access to river water for irrigation, since they pay for it. The guard confirmed that the salinity concentration is a problem for farmers that prefer to irrigate with treated waste-water because of its higher availability. In the first year, the farmers can sell the oranges but, in the second year, the leaves of the trees turn yellow and it was not possible to sell their yields. For the vegetables, the soil salinity produces no problems; the tomatoes and melons grow well. It also creates the feeling of inequity since the farmers in Puçol are not able to use the treated waste-water directly for irrigation due to the non-availability of this water source. The available volume, which results in a low water flow when the treated waste-water is used directly for irrigation, is seen as a disadvantage (19.0%). When the fields are irrigated directly with treated waste-water, it takes more than twice as long compared to the irrigation with surface water, which also depends on the field characteristics.



**Figure 3.** Farmers' perception about the advantage and disadvantage of using treated waste-water for irrigation.

The introduction of treated waste-water increased the access to irrigation water in periods of water scarcity, where the RAM receives irrigation water from the river once every two weeks as a drought measure. The treated waste-water is currently a free water source. The surface water arrives on different days of the week in each area of the RAM (normally Thursday or Friday for Massamagrell and Puçol) and the time of arrival fluctuates. The available new water source (since 2013) enables farmers to irrigate on demand, which has the advantage that night irrigation is not needed, and they do not

have to wait for the irrigation water of the river Turia (23.8%). This was observed during the fieldwork where some farmers irrigate directly with treated waste-water, while the next day the surface water arrived in the area of Massamagrell and Puçol, which also led to fewer farmers irrigating with surface water since the introduction of treated waste-water for irrigation. Farmers mention the importance of the treated waste-water when crops need to be irrigated every week such as horticulture crops (6.9%). Before the treated waste-water was available, the farmers had to use collective groundwater wells. These groundwater wells cost around 7-8 euro per 30 minutes for the operation and maintenance of the pumps, which is costly compared to 215 euro/hectare/year for the right to irrigate with surface water.

#### 4. Discussion

The use of treated waste-water from the WWTP is initiated and authorized to use for irrigation by the Water Authority. Although the system has used waste-water since its origin because of the use of the irrigation channels such as the sewage system, the severe drought from 2004 to 2008 changed the paradigm of the use of this resource due to the water scarcity and the availability of the treated waste-water obtained in the new WWTPs built in the area. The introduction of this new water source for irrigation is legally intended to be used combined with surface water but is also used directly due to benefits such as an increase of irrigation frequency. Public policies can increase the reuse of waste-water up to 92.7% as in Murcia [20]. Although the south of Valencia shares this environment, the situation in the traditional huerta of Valencia where surface irrigation is still the most common technique is quite different. Farmers accept this water source if they do not have to pay for the treated waste-water (like pumping costs) and it does not affect their water rights from the river Turia. In the current situation, EPSAR is paying for all the costs involved in treating the waste-water, which is financed by the taxes for sanitation. On the other hand, the farmers have a very long history of water reuse, since in the past, there was no collecting system for the waste-water and therefore it went untreated directly to the irrigation canals. Therefore, farmers in this area easily accept the treated waste-water for irrigation. In times of water scarcity, when the water turn is once every two weeks, the treated waste-water can save the crop yield and reduce irrigation costs since expensive groundwater pumps are unnecessary. The farmers have a positive attitude towards the use of treated waste-water for irrigation which is also observed by the RAM lawyer as well as the director of the WWTP but only when the treated waste-water is a free source. The WWTP creates electricity from biogas, which accounts for 65% of the total electricity costs involved in the total treatment process, but the remaining 35% electricity taken from the public electricity network is still costly. Since the water source is used as a valuable benefit, it would be normal to pay an additional fee. On the contrary, one can say that the waste-water discharge can be taxed on the principle of “polluter pays” which will be proportional to the level of contamination [13]. This is also the case in the Valencia region where EPSAR is paying to treat the waste-water, which in return is financed by the taxes for sanitation. On the other hand, farmers and RAM institution own historical rights over the river water, which are used for negotiating who pays the bill. They argued that they should not pay the pumping costs because they are providing an ecosystem service using this water and reducing their use of river water, which can be diverted for other uses, normally human and industrial consumption.

The *E. coli* concentrations measured from the irrigation network do not comply with the norm of The Royal Decree 1620/2007, even though all the *E. coli* concentrations analyzed by the WWTP after the tertiary treatment do. In the current situation, farmers have no problems in selling their products by using treated waste-water for irrigation, since it is not regulated. In the law, the end-users (in this case the farmers) are responsible for the water source, but if necessary, farmers can hold the RAM irrigation community accountable. Every two weeks, the RAM lawyer discusses the water quality and quantity data with the responsible person in the WWTP. Some farmers are concerned about the water quality of the waste-water for irrigation but when the water quality criteria after the tertiary treatment do not meet the requirements then the pumping towards the irrigation canal system is stopped immediately. Once the treated waste-water enters the irrigation network, the WWTP Poble de

Farnals is not responsible anymore because other sources of pollution can occur. A possible source of pollution can be the sewage network of the houses because in the past these were connected to the irrigation channels. The high-quality criteria to allow the usage of water from a WWTP are an important issue for the different stakeholders (similar to [8,34]). Although some interviewees showed concerns about the treated waste-water in terms of high salinity, most farmers remained neutral on this subject. Most farmers are positive concerning the use of treated waste-water for irrigation, unlike the case study by Dare and Mohtar [13] where farmers are unsure about the safety of the resource. The difference between the cases analyzed by Dare and Mohtar [18] and the case of the RAM is that even in both cases, farmers are worried about salinity and pathogens, general performance of WWTPs in Tunisia, Qatar, and the West Bank are worse than in the Spanish case, with problems in tertiary treatments and higher values of EC in the effluent. This explains the different attitude of farmers in each case.

Regarding the source of pathogen contamination, as stated by different interviewees, the contamination appears due to sparsely distributed houses in the rural area and old houses inside the rural towns, whose sewage discharges are still connected to the irrigation channels. Although public authorities have been devoting efforts to disconnect the sewage and irrigation systems, these connections still exist. Presently, it is very difficult to control these discharges because irrigation channels are extremely ramified and they flow underground with many derivations, they experience changes due to new urbanization while old branches remain connected to the irrigation system. In some cases, the RAM ignores the path under the cities of the channel, which made this task extremely difficult.

The nutrient concentrations can be seen as a threat as well as an opportunity because the farmers are not aware of the nutrient benefits that come with this water source for irrigation, which could lead to over-fertilization in the NVZ area concerning the concentration of total nitrogen. The Royal Decree 1620/2007 only states criteria for environmental use when an aquifer is recharged by localized percolation through the ground or by direct injection with a total nitrogen level of 10 mg/L. To minimize over-fertilization the farmers need to be frequently informed about the nutrient concentration, so that fertilizers can be saved as stated by the stakeholders in the SWOT analysis. The importance of reducing fertilizer inputs in the plots can be successful, as has been observed in Italy [35]. Furthermore, the stakeholders mention that high water quality measures are demanded for agriculture. The influent water comes from different villages (70%) as well as industries (30%), where each water flow has a different water quality. The norm of salinity is currently set at 3.0 dS/m with a yearly average of 2.48 dS/m after tertiary treatment. The high salinity is mainly caused by the industries that use the water for cooling purposes. The result is an increase of soil salinity, which can lead to a yield reduction, as mentioned by several farmers. The main concern extracted from the interviews is the lack of information about nutrient contents in water, both for mixed and undiluted water from the WWTP.

In conclusion, as summarized in the SWOT analysis, the reuse of waste-water provides means for achieving enough quantity and good quality standards for irrigation purposes. Moreover, it can help manage scarcity and reduce inputs of water and fertilizers in semi-arid regions, as also confirmed by [38]. However, to use these potential benefits in the future, tertiary treatments for salt reduction may be seen to reduce the negative effects of waste-water salinity. Moreover, more detailed information exchange and coordination is needed among farmers, public administration and WWTP's technicians. Questions regarding the illegal connection in towns of waste pipes with the traditional irrigation or the payment of pumping costs for reuse are still not answered and need a better reflection from all stakeholders. Until now, this resource has been used only as a complementary source to river and groundwater, except in some areas during the severe drought of 2004–2008 [21]. However, in the following years, the use of recycled waste-water must increase, more indeed in these times of uncertainty and climate change, as is also expressed in [20]. The case of the RAM in Valencia, a traditional irrigation system functioning since 11th century, is a good example of adaptation and revalorization of a water resource with a circular economy perspective, which helps farmers grow safer crops and with more water requirements, such as tomatoes or melons, while at the same time being financially viable.

## 5. Conclusions

The paper provides an example of a case study on one coastal, arid region, which is transitioning from informal and traditional water reuse (with potential contamination issues) to reuse for agriculture within a regulated and industrialized urban and coastal metropolitan area with a total population of approximately 2 million.

Even historically the farmers have regularly reused waste-water when there was no sewerage, and the sewage went untreated into the irrigation channels; after the extreme draught of 2004–2008, the paradigm of using treated waste-water has changed and it has been used as a complementary resource to alleviate pressures on surface water bodies that supply agricultural demands. The most important benefit of reusing waste-water is the alternative supply of water and nutrients from a circular economy perspective during the summer, when the crop water requirements are higher, and water is scarce. However, the main risk is the possible accumulation of salt and pathogens, which cannot be correctly managed by the farmers, mainly because the lack of information and formation. On the other hand, groundwater is also a complementary resource used in the irrigation network with also high levels of nutrients, which could also be taken into account by the farmers for reducing external supplies of N and P. However, it is important to monitor the potential diffuse pollution from the reused waste-water with high levels of salt.

Moreover, some recommendations arise from the results of this paper. First, WWTPs must reduce the salt contents in waste-water effluents to obtain a more suitable resource for surface irrigation. It could be interesting to introduce in the WWTPs themselves, and N and P recovery methods for direct application in agriculture. Moreover, the public administration must eliminate illegal waste pipe connection to irrigation channels in rural areas, such as the case of the RAM irrigation system.

Finally, pumping costs from the WWTPs are a big and central element in this case. On the one hand, it is an important cost for WWTPs because the irrigation intake is normally upstream of the location of the WWTP. However, farmers are not willing to pay these costs as they argue that they own historical rights to the river water. Currently, barriers such as mistrust and lack of communication between farmers and public authorities are hindering this transition to a more formal and regulated waste-water reuse. On the one hand, farmers fear losing their historical water rights and incurring future waste-water pumping costs. On the other hand, public authorities do not have a clear and well-defined policy on waste-water reuse for agriculture, and there are no appointed spokespersons to negotiate with the farmers, nor any training or information programs regarding irrigation waste-water reuse.

In this case, communication and transparency are very low and our recommendation is to analyze in depth the ecosystem services provided by agricultural uses when using treated waste-water, as a complementary and supplementary resource, and their impact on reducing water stress on surface water bodies.

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