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Review

Urban Wastewater as a Source of Reclaimed Water for Irrigation: Barriers and Future Possibilities

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Abstract: Water resources are under pressure worldwide, resulting in scarcity and deterioration of freshwater quality. According to European directives, we could reduce the pressure on water resources in urban areas by increasing the reuse of treated wastewater, reducing the impact on water bodies, and promoting water recycling through multiple uses of urban wastewater. Besides the need to address water supply challenges, wastewater treatment systems show environmental stewardship and innovative practices. Using reclaimed water for agricultural irrigation is gaining interest because of the drought conditions experienced in Europe over the past few years. Furthermore, using treated wastewater for agricultural irrigation may help to restore nutrients (N and P) to natural biogeochemical cycles. This review highlights the importance of water reuse, current legislation, and existing technologies to implement in wastewater treatment systems to meet the minimum requirements to produce reclaimed water to reuse in agricultural irrigation.

Keywords: water scarcity; water recycling; wastewater treatment plants; nutrients; phosphorus

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1. Introduction

Global freshwater use has increased six times since 1900 because of world population growth and the economic shift towards resource-intensive consumption habits [1]. In 2014, about 4 trillion m^3 of global freshwater was used for agriculture, industry and domestic uses [1]. However, to maintain sustainable levels of this vital resource, the rate of freshwater abstraction must be lower than the rate of natural replenishment. For instance, the renewable freshwater resources (river flows and groundwater from rainfall) of the European Union (EU) declined by 17% from 1962 to 2018 [1].

As the demands for water increase, water stress and scarcity are now concerns for various parts of the world, not only in the EU. Several social and health risks, lower agricultural yields, compromised industrial production, droughts, and fires are some consequences if this resource is unavailable [2]. Reducing water waste and using it more efficiently is mandatory to adapt to climate change and ensure the security and sustainability of domestic, industrial, and agricultural supply. The water used for agriculture accounts for approximately 70% of the world's freshwater, but this share varies significantly from country to country. In 2017, The EU used 32% of their withdrawn freshwater in agriculture. Denmark, Poland, and Sweden used just 16, 10, and 3% of their withdrawn freshwater for agriculture. Portugal, Cyprus, and Spain displayed values above the average for the EU (79, 59, and 65%, respectively) [1]. This significant dependency on freshwater resources reinforces the need to reuse water.

From the perspective of water reuse, it is possible to recover water from various sources and treat and reuse it for beneficial purposes and environmental restoration. This strategy can provide alternative sources to the existing water supply and improve water security and sustainability. Water sources eligible for reuse include urban wastewater, industrial wastewater, cooling water, stormwater, agricultural runoff, and natural resources [3,4].

According to the European Commission, treating wastewater at urban wastewater treatment plants (WWTP) is a viable option to appease the increasing demand for water resources. This approach is in line with the Circular Economy Action Plan and the new EU Climate Adaptation Strategy. Reusing water will also help achieve Sustainable Development Goal 6, which aims to ensure the availability and sustainable management of water and sanitation worldwide [5]. However, the costs associated with wastewater reuse systems and the lack of common environmental and health safety legislation are limiting factors for the full implementation of this strategy [6,7]. Although increasing reclaimed water production is a significant financial and technical challenge for WWTP, various treatment options are available to achieve any level of reclaimed water quality.

Irrigation for agriculture and landscaping (e.g., parks and golf courses) are the two primary uses of treated wastewater. Within the European Green Deal, urban wastewater reuse in agriculture can also contribute to the Farm to Fork Strategy. Considering the aim of reducing the environmental footprint of the EU food system, this strategy provides an alternative and more reliable water source for irrigation. The Farm to Fork Strategy establishes the urgent need to enhance organic farming and reduce the overuse of fertilizers [3,8]. From this perspective, reusing urban wastewater for irrigation can help to reintroduce nutrients (mostly nitrogen (N) and phosphorus (P)) to the soil, reducing the requirement for mineral fertilizers [7]. However, monitoring nutrients in wastewater will prevent their surplus application to soil and the contamination of freshwater systems. Indeed, the plants do not absorb all the nutrients used in agriculture, and the EU Commission seeks to reduce nutrient losses by at least 50%, maintaining soil fertility [8]. The possible presence of microorganisms, potentially toxic metals, and microplastics in wastewater provides a potential health risk that will also require control [9,10].

The reuse of treated wastewater for agricultural irrigation is a market-driven practice because of the lack of water resources in some European countries. As a result, the production of reclaimed water should meet the minimum quality standards, and its reuse as irrigation water should consider the application methods and the sensitivity and needs of each crop, not only of water but also of nutrients, to avoid environmental contamination issues.

This review aims to discuss the steps involved in obtaining water for reuse from urban wastewater, especially for agricultural irrigation. Therefore, the present work hopefully fills some gaps existing in the literature and systematically analyzes the following aspects:

(i) the current legislation in force regarding the reuse of wastewater in agriculture.
(ii) the technologies available to produce treated water from wastewater, focusing on the removal of contaminants and nutrients (mainly phosphorus).
(iii) the health, environmental, and agronomic risks of using treated wastewater for agricultural irrigation.

2. Urban Wastewater Reuse in Agriculture

2.1. Motivations and Regulatory Barriers

Wastewater management plays a central role in the circular economy plan, and its reuse has two major driving forces: (i) minimizing freshwater scarcity and optimizing resource use; and (ii) ensuring the protection of the environment and public health. Indeed, treated wastewater reuse can improve agricultural production, decrease energy consumption associated with the production/treatment/distribution of water, and reduce environmental problems by reducing the nutrient loads in receiving waters [11,12]. However, the reuse of urban wastewater presents several challenges related to the existence of adequate regulations, sociocultural acceptance, and financial and technical aspects of wastewater treatment (discussed in the next chapter).

The need to reduce the health and environmental risks of water reuse practices led to the development of guidelines and regulations for the safe use of reclaimed water. The World Health Organization (WHO), the Food and Agriculture Organization (FAO), and several countries defined regulations to reuse treated wastewater a while ago. The EU released only on 25 May 2020 the Regulation (EU) 2020/741, which provides minimum requirements for water quality and monitoring and provisions for risk management for the safe use of reclaimed water in integrated water management. The legislation summarized in Tables 1, 2, and 3 focuses primarily on physicochemical parameters (e.g., total suspended solids and turbidity) and microbiological quality criteria (e.g., *Escherichia coli* (*E. coli*) and fecal coliforms). The regulations defined water reuse categories to facilitate the comparison of existing regulations and guidelines.

Microbiological contamination is the most relevant parameter for all organizations/countries. For crops consumed raw, with direct contact with reclaimed water, the *E. coli* enumeration should be less than 5 CFU/100 mL (in Cyprus, the most restrictive) or 10 CFU/100 mL (European Union and Portugal). Other categories and regulations for water reuse have more permissive values. The biochemical oxygen demand (BOD), as an organic matter indicator, and the total suspended solids (TSS), are the more commonly legislated physicochemical parameters, with values of 10–40 mg O_2/L and 10–60 mg/L, respectively, depending on the water category for almost all regulations, except in Jordan.

From the national regulations presented (Tables 1, 2, and 3), only Portugal, Cyprus, Jordan, New Jersey, and North Carolina consider the control of total N (TN) and total P (TP). On the one hand, these macronutrients in reclaimed water can improve crops' yields while reducing the use of mineral fertilizers and the environmental impact [13]. However, excessive N and P concentrations in water lead to incomplete crop assimilation, causing environmental losses, and as a result, environmental problems (e.g., eutrophication) [14]. Portuguese legislation limits P not only to 5 mg/L in agricultural applications, but also to 2 mg/L for water use in landscaping irrigation [15]. Italy appears to be more stringent than other countries, limiting P to 2 mg/L for reclaimed water reuse, regardless of application. To avoid complications and because wastewater has high and variable P concentrations, the removal of this element should be considered to meet regulatory limits. This strategy can contribute to the EU's efforts to improve P recycling, as it is a non-renewable resource [14]. FAO provides guidelines for interpreting water quality for irrigation that consider parameters other than those listed in Tables 1, 2, and 3. These guidelines consider that nitrate in reclaimed water with concentrations lower than 5 mg/L allows its use without restrictions, whereas concentrations >30 mg/L limit the use of the reclaimed water. According to a report provided by WHO, several countries from the Eastern Mediterranean Region (Kuwait, Oman, Saudi Arabia) established limits for P and N in the treated wastewater for reuse. Kuwait defines that the maximum values allowed are 30 mg PO_4^{3-}/L, 15 mg NH_3/L, and a total Kjeldahl nitrogen limit of 35 mg/L; and Saudi Arabia limits the concentrations of NO_3 and NH_3 to 2 and 5 mg/L, respectively [16].

Table 1. Reclaimed water quality guidelines for agricultural reuse for EU, WHO, FAO, EPA, Portugal and Spain.

	EU (2020)				**WHO (2016) FAO (1992)**		**EPA (2012)**		**Portugal (2019)**					**Spain (2007)**		
Category / Parameter	**A**	**B**	**C**	**D**	**A**	**B**	**A**	**B**	**A**	**B**	**C**	**D**	**E**	**A**	**B**	**C**
E. coli (CFU/100 mL)	10	100	1000	10,000	1000	-	-	-	10	100	1000	10,000	10,000	100	1000	10,000
Fecal coliforms (CFU/100 mL)	-	-	-	-	-	-	0	200	-	-	-	-	-	-	-	-
BOD_5 (mg/L)	10	25	25	25	-	-	10	30	10	25	25	25	40	-	-	-
TSS (mg/L)	10	35	35	35	-	-	-	30	10	35	35	35	60	20	35	35
Turbidity (NTU)	5	-	-	-	-	-	2	-	5	-	-	-	-	10	-	-
Intestinal nematodes (eggs/L)	1	1	1	1	1	1	-	-	-	-	1	1	-	1 (in 10 L)	1 (in 10 L)	1 (in 10 L)
TN (mg/L)	-	-	-	-	-	-	-	-	15	15	15	5	15	-	-	-
TP (mg/L)	-	-	-	-	-	-	-	-	5	5	5	5	5	-	-	-

CFU—colony-forming units; BOD_5—biochemical oxygen demand for 5 days; TSS—total suspended solids; NTU—nephelometric turbidity units; TN—total nitrogen; TP—total phosphorus. Categories: EU [7]: A—crops consumed raw; edible parts in direct contact with the reclaimed water; B—crops consumed raw; edible parts produced above ground, processed food crops, and non-food crops—all irrigation methods; C—crops consumed raw; edible parts produced above ground, processed food crops and non-food crops—drip irrigation or other methods without direct contact with the edible part; D—industrial, energy, and seeded crops. WHO and FAO [16,17]: A—crops consumed raw, sports fields, public parks; B—cereal crops, industrial crops, fodder crops, pasture, and trees. EPA [11]: A—surface or spay irrigation of food crops for human consumption consumed raw; B—surface irrigation of food crops for human consumption after processing; irrigation of food not consumed by humans (e.g., pasture land). Portugal [15]: A—crops consumed raw; edible parts in direct contact with the reclaimed water; public and private parks (without access restrictions); B—crops consumed raw; edible parts produced above ground without direct contact with the reclaimed water, processed food crops, and food for non-human consumption (e.g., including crops for animal consumption, except swine) with access restrictions for urban and agriculture use; C—same as B, but for agriculture use only; D—production of seeds, including seeds for industrial use or energy production (with access restrictions); E—production of seeds; fodder crops. Spain [18]: A—crops consumed raw; edible parts in direct contact with the reclaimed water; B—edible parts in direct contact with the reclaimed water, but crops consumed after processing; use in pasture lands for animals that produce milk or meat for human consumption; aquaculture; C—fruit crops, ornamental flowers, greenhouses, and industrial crops without direct contact with the reclaimed water.

Table 2. Reclaimed water quality guidelines for agricultural reuse for Cyprus, France, Jordan, and Greece.

	Cyprus					**France (2010)**			**Jordan (2002)**			**Greece (2011)**	
Parameter / **Category**	**A**	**B**	**C**	**D**	**E**	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**
E. coli (CFU/100 mL)	5	5 */15 **	50 */100 **	200 */1000 **	1000 */5000 **	250	10,000	100,000	100	1000	-	200	5 */50 **
Fecal coliforms (CFU/100 mL)	-	-	-	-	-	-	-	-	-	-	-	-	-
BOD_5 (mg/L)	10	10*	10 */15 **	20 */30 **	20 */30 **	60(COD)	-	-	30	200	300	25	10 *
TSS (mg/L)	10	10*	10 */15 **	30 */45 **	30 */45 **	15	-	-	50	150	150	10	10 *
Turbidity (NTU)	-	-	-	-	-	-	-	-	10	-	-	-	2
Intestinal nematodes (eggs/L)	0	-	-	-	-	-	-	-	1	1	1	-	-
TN (mg/L)	15	-	-	-	-	-	-	-	45	70	70	-	-
TP (mg/L)	10	-	-	-	-	-	-	-	30 ***	30 ***	30 ***	-	-

CFU—colony-forming units; BOD_5—biochemical oxygen demand for 5 days; TSS—total suspended solids; NTU—nephelometric turbidity units; TN—total nitrogen; TP—total phosphorus; * 80% of the samples; ** maximum acceptable value for Cyprus, and 95% of the samples for Greece; *** values of PO_4^{3-}. Categories: Cyprus [19]: A—the quality of reclaimed water of WWTP with >/2000 pe; all crops; B—WWTP with ≤/2000 pe; all crops and green areas but no vegetables with leaves, bulbs, and condyles eaten raw; C—WWTP with ≤2000 pe; green areas and cooked vegetables (potatoes, beetroots); D—green areas with restricted use by the public; E—fodder crops. France [20]: A—crops consumed raw; B—public parks, gardens, sports lawns, and forests with public access; C—crops consumed after cooking, forage crops, vineyards, orchards. Jordan [16]: A—cooked vegetables, parking areas, playground, and sides of roads inside cities; B—plenteous trees and green areas, side of roads outside cities; C—field crops, industrial crops and forestry. Greece [21]: A—areas without public access, feed crops, industrial crops, meadows, trees (excluding fruit)—provided that the harvest is not in contact with the soil, seed crops, and crops producing products that are processed further before consumption.

Table 3. Reclaimed water quality guidelines for agricultural reuse for Italy, Arizona, Florida, New Jersey, and North Carolina.

	Italy (1999)	**Arizona**			**Florida**		**New Jersey**		**North Carolina**		
Parameter / **Category**	**-**	**A**	**B**	**C**	**A**	**B**	**A**	**B**	**A**	**B**	**C**
E. coli (CFU/100 mL)	100	-	-	-	-		-	-	25 (dm)	25 (mm)	25 (dm)
Fecal coliforms (CFU/100 mL)	-	23	200 */800 **	1000 **/4000 **	25 ***	800 (avg:200)	14	200	14 (mm)	3 (mm)	14 (mm)
BOD_5 (mg/L)	20	-	-	-	60	60	-		15 (dm)	15 (dm)	15 (dm)
TSS (mg/L)	10	-	-	-	5	60	5	30	10 (dm)	10 (dm)	10 (dm)
Turbidity (NTU)	-	5	-	-	2—2.5	-	2	-	10	5	10
Intestinal nematodes (eggs/L)	-	-	-	-	-	-	-	-	-	-	-
TN (mg/L)	15	10	10	10	-	-	NH_3-N + NO_3-N: <10	NH_3-N + NO_3-N: <10	NH_3-N: 6 (dm)	NH_3-N: 2 (dm)	NH_3-N: 6 (dm)
TP (mg/L)	2	-	-	-	-	-	-	-	-	-	-

CFU—colony-forming units; BOD5—biochemical oxygen demand for 5 days; TSS—total suspended solids; NTU—nephelometric turbidity units; TN—total nitrogen; TP—total phosphorus; * value detected in the last 4 of 7 samples; ** maximum value, *** 75% of the samples below detection; avg—average; dm—daily maximum; mm—month mean. Categories: Italy [21,22]: no category—irrigation of crops for the production of food for human and animal consumption and non-food crops, and irrigation of green or recreation and sports areas. Arizona [11]: A—food crops; B—non-food crops and processed food crops with secondary treatment and disinfection; C—non-food crops and processed food crops with secondary treatment and with or without disinfection. Florida [11]: A—food crops; B—non-food crops and processed food crops. New Jersey [11]: A—food crops; B—non-food crops and processed food crops. North Carolina [11]: A—food crops with filtration or equivalent; B—food crops with filtration and dual UV/chlorination (or equivalent); C—non-food crops and processed food crops.

Apart from the parameters presented, there are already some regulations that suggest maximum values allowed for potentially toxic metals in reclaimed water (e.g., Portugal), independently of the category. Other parameters, such as pH, electrical conductivity, and sodium adsorption ratio (SAR), are important variables to be considered when using wastewater for irrigation, since they may influence crop growth or soil structure [23]. SAR is a measure of the ratio of the sodium ions to the calcium and magnesium ions in water (in meq/L), as expressed in Equation (1) [24]. The maximum limits of these parameters should attend to the crop type and the soil characteristics, and the irrigation plan and systems may have to be adapted.

$$SAR = \frac{[Na^{+}]}{\sqrt{0.5\ ([Ca^{2+}] + [Mg^{2+}])}} \quad (1)$$

2.2. Socio-Economic Barriers

Despite the lack of uniform legislation, reclaimed water production requires additional investment costs for WWTP to upgrade systems to meet reuse requirements. Aside from equipment, there are also transportation and storage costs. Incentives and reclaimed water market value should offset these additional costs [23].

The sociocultural aspects are also significant barriers to implementing a wastewater reuse strategy. Indeed, public perception influences the decision-making process. Reuse of wastewater can encounter strong public resistance because of diverse factors, such as the availability of alternative water sources, levels of education, associated health risks, and religious concerns, among others. The appearance of reclaimed water, such as its color and odor, is critical to public acceptance. Educational programs, branding, and information dissemination, mainly discussing the benefits and concerns of reclaimed water, can create an awareness of the importance of wastewater reuse [12,25].

2.3. Health and Environmental Hazards

The primary parameters to be monitored in reclaimed water are pathogenic microorganisms, particulate matter, organic matter, potentially toxic metals, nutrients, and contaminants of emerging concern (CEC). Indeed, despite the multiple benefits of irrigating the soil with wastewater, there is a risk to human health by contaminating food or exposing people to pathogenic microorganisms, potentially toxic metals, and other pollutants. Untreated wastewater contains a variety of microorganisms that can survive for long periods on the soil or crop surface, and as a result, reach humans or animals [26]. Thus, identifying hazards in reclaimed water should be based on the specific wastewater reuse system, the characteristics of the wastewater, and any applicable legal requirements existing in the location of the WWTP. The European Commission suggests a list of microbiological pathogens for assessing health risks, which may be relevant depending on the local context. Table 4 provides some examples of microbial hazards commonly found in wastewater and their impacts on human health [27]. Certain pollutants that are potentially present in wastewater also require control to avoid health problems, such as benzene, dichloromethane, and potentially toxic metals (e.g., cadmium and lead).

Table 4. Microorganisms present in wastewater and their effects on human health [27].

Pathogen	Examples	Examples of Diseases for Humans	Reference Pathogen (Indicator)
Bacteria	*Salmonella*	Gastroenteritis (diarrhea, vomiting, fever)	*E. coli*
	Vibrio cholera	Cholera	
	Pathogenic E. coli	Gastroenteritis and septicemia	
Protozoa	*Entamoeba*	Amebiasis	*Cryptosporidium*
	Giardia	Gastroenteritis	
	Cryptosporidium	Diarrhea, fever	
Helminths	*Ascaris*	Ascariasis	Intestinal nematodes (Helminth eggs)
	Ancylostoma	Ancylostomiasis	
	Necator	Necatoriasis	
Viruses	*Enteroviruses*	Gastroenteritis, heart anomalies	*Rotavirus*
	Adenovirus	Respiratory disease, eye infection	
	Rotavirus	Gastroenteritis	
	SARS-CoV-2 virus [28,29]	Respiratory disease	

Aside from human health concerns, there are also some environmental hazards in wastewater that could harm soil, freshwater resources, and crops. Table 5 presents some of the key environmental hazards to be controlled and some existing guidelines that apply regardless of the reclaimed water category. The values for these parameters should consider soil type and acidity, climate conditions, and crop type and tolerance. Relevant legislation and standards may direct the maximum allowable concentrations of these specific hazards.

Phosphorus and nitrogen are also environmental parameters requiring control, as highlighted in Tables 1, 2, and 3. The main benefit of using reclaimed water for agricultural purposes is that it provides macronutrients (such as N, P, and K) to crops. The concentrations of these elements vary according to the type of wastewater and the water management policies employed [30]. However, some regulations (Tables 1, 2, and 3) already recommend maximum concentrations of TN and TP in reclaimed water of 15 and 5 mg/L, respectively (Portuguese case). Indeed, most nutrients, including P, are stored in nutrient polls, which are immediately available to the plants or can become overtime. Depending on the nutrients, different soils have different adsorption capacities and retaining abilities [31]. Considering P, if its concentration is excessive, runoff from agricultural soils can occur, causing environmental problems such as eutrophication or contamination of groundwater. The TP input concentration in the WWTP is in the 5–10 mg P/L range [14]. According to the literature, at some points of the WWTP (e.g., biological systems with anaerobic digestion), the TP in the mixture (both solid and liquid phases of wastewater) reaches values between 600 and 1000 mg P/L. However, most of the P is in the solid phase, and only 2–20 mg P/L is in a dissolved form (liquid phase) as orthophosphates ($P\text{-}PO_4$) [32–36]. In treated water (before discharge into the environment), some studies reported concentrations of orthophosphates of 1.6–3.3 mg P/L [37] and 5–8 mg P/L [38]. Phosphorus is one parameter to control when reusing water from different points in the WWTP. Although most legislation (Tables 1, 2, and 3) does not regulate TP as a quality parameter for wastewater reuse, its recovery is critical to avoid environmental problems and relieve pressure on nature resources (phosphate rock is a Critical Raw Material to the EU). Phosphorus recovery to meet legal limits will also provide raw material to produce alternative fertilizers, for example. It is important to ensure reasonable dosages of these macronutrients through more frequent and less intensive irrigation.

Another source of concern is the increase in both salinity and sodium content in soil caused by crop irrigation with reclaimed water. Indeed, high soil salinity and sodium levels can degrade soil structure, reduce soil permeability, and reduce crop yields because of toxic and osmotic effects [22,26]. Salinity is normally measured by the electrical conductivity (EC) of water or the concentration of total dissolved solids (TDS). The increase in soil salinity will increase the osmotic pressure of the soil, reducing the ability of the crop to absorb water and nutrients. FAO (1992) provides different degrees of restriction on using reclaimed water for irrigation based on salinity guidelines. For example, an EC of 0.7 dS/m or TDS of 450 mg/L will indicate no restriction on use, whereas EC values of 0.7–3.0 dS/m and TDS of 450–2000 mg/L may affect crops. Jordan limits TDS to 1500 mg/L, and Italy requires EC values to be below 3 dS/m. Portugal reports that EC values (as a restriction for salinity) can vary depending on the sensitivity of the crop.

Excess sodium can cause soil physical problems and reduce soil porosity and permeability if its concentration rises to above 15% of the cation exchange capacity of the soil [25,26]. According to FAO (1992) guidelines, the SAR should be less than nine, preferably less than three, to avoid problems of sodium toxicity when using reclaimed water in soil. Jordan also limits the SAR to nine, and Portugal emphasizes the importance of first determining the type of crop. There is a relationship between salinity and SAR because of its importance as a water quality factor influencing the infiltration rate (the ability of soil to absorb irrigation water) [39]. For a given SAR value, an increase in total salt concentration increases soil permeability, whereas for the total salt concentration, an increase in SAR will decrease soil permeability. These two parameters must work together. For example, the FAO recommends that reclaimed water with SAR values between 0 and 3 should have EC values greater than 0.7 dS/m to avoid any restriction on use or any environmental issues. If the SAR values rise to 3–6, the EC values must be greater than 1.2 dS/m [17].

Urban wastewater may contain other potentially toxic elements that are present in trace amounts and can cause specific toxicity problems if not removed during treatment stages. As a result, some regulations set maximum values for these elements in the reclaimed water, regardless of the category, as shown in Table 5. The presence of CEC is another factor that is currently relevant in the water reuse industry. CEC are classified into several categories, including nanomaterials, disinfection by-products, pesticides, and others. The incomplete removal of these contaminants in the WWTP may increase their concentration in the receiving medium, especially in susceptible environments, e.g., groundwater, but also in soil, surface water, and sediments [40]. Advanced treatment processes capable of removing CEC from reclaimed water are required to avoid health and environmental issues.

Table 5. Maximum recommended concentrations for some parameters, independently of the reclaimed water category.

Parameter	Recommended Maximum Concentration						Example of Effects on Environmental Receptor [27]
	WHO and FAO [16,17]	Portugal [15]	Jordan [16]	Italy [41]	Greece [41]	Spain [42]	
pH	6.5–8.0	-	6.0–9.0	6.0–9.5	-	-	
Salinity	EC: 0.7–3.0 dS/m TDS: 450–2000 mg/L	*	TDS: 1500 mg/L	EC: 3.0 dS/m	EC<10 dS/m	EC: 3.0 dS/m	Soil damage (salinization);Crop stress; Crop uptake of cadmium; Increase in water salinity
SAR	3–9	*	9.0	-	-	6.0	Crop toxicity
Boron (mg/L)	0.7–3.0	*	-	1.0	2.0	0.5	Crop toxicity due to soil accumulation
Chloride (mg/L)	4–10 (in meq/L)	-	400	250	-	-	Crop toxicity (e.g., via leaves or roots uptake);Toxicity to aquatic biota
Trace elements or potentially toxic elements (mg/L)							
Al	5	5	5	1.0	5.0	-	Crop toxicity due to soil accumulation
Be	0.1	0.1	0.1		0.10	-	
Co	0.05	0.05	0.05	0.05	0.05	-	
F^-	1.0	2.0	1.5	1.5	1.0	-	
Fe	5.0	2.0	5.0	2.0	3.0	-	
Li	2.5	2.5	2.5	-	2.5	-	
Mn	0.2	0.2	0.2	0.2	0.2	-	
Mo	0.01	0.01	0.01	-	0.01	-	
Se	0.02	0.02	0.05	0.01	0.02	0.02	
V	0.1	0.1	0.1	0.1	0.10	-	
Zn	2.0	-	5.0	0.5	2.0	-	
Cd	0.01	-	0.01	0.005	0.01	-	
Cr	0.1	-	0.1	0.1	0.1	-	
Cu	0.20	-	0.2	1.0	0.2	-	

* Variable with the sensitivity of the crop; SAR—sodium absorption capacity; EC—electrical conductivity; TDS—total dissolved solids; meq—milliequivalent.

3. Production of Reclaimed Water for Reuse

3.1. Treatment Technologies

There are various technologies available for producing reclaimed water. These technologies are based on biological, chemical, mechanical, and natural processes. However, each technology has its own set of advantages and disadvantages, which helps to determine the selection of the best solution for each water reuse application. Table 6 summarizes the levels of treatment and examples of technologies appropriate for each type of wastewater reuse.

Table 6. Treatment technologies to produce reclaimed water, according to each level of treatment, and examples of applications [11,43].

	Levels of Treatment in WWTP		
	Primary	**Secondary**	**Tertiary/Advanced**
Technologies	Screening Sand removal Primary sedimentation Flotation	Biological processes (e.g., activated sludge, anaerobic treatment) Secondary sedimentation	Chemical coagulation Disinfection (e.g., chlorination, ozonation, photo-driven processes) Microfiltration; nanofiltration; ultrafiltration Adsorption Ion exchange Reverse osmosis Electrodialysis
End-use of reclaimed water	No uses recommended	Surface irrigation of orchards and vineyards Non-food crop irrigation Restricted landscape irrigation	Food crop irrigation Vehicle washing Irrigation of recreation fields Industrial applications Indirect potable reuse
Human exposure	Higher risk for human exposure	Medium risk for human exposure	Low risk for human exposure
Cost	Low	Medium	High

High-quality reclaimed water can be obtained by combining various treatment technologies, and the choice of each technology or level of treatment is determined by the raw wastewater's characteristics and by the specifications for its end-use.

3.2. Selection of Treatment Technologies Based on Target Pollutants

Each target pollutant relates to a specific treatment technology (Table 7). *E. coli* is an indicator bacteria and a common parameter regulated in the legislation for reclaimed water reuse. For *E. coli*, there are at least five treatment technologies that provide good indicative log reductions (a measure used to express the related number of microorganisms eliminated by disinfection): membrane filtration (ultrafiltration, nanofiltration, and reverse osmosis), ozonation, UV disinfection, advanced oxidation processes (AOP) (based on hydroxyl radicals), chlorination [11,22,40], and photo-driven processes [44]. According to the guidelines of the US EPA (2012), the AOP may provide the best log reduction (>6 log) [11]. Membrane filtration can also reduce *E. coli* in by 4-6 log. Apart from the commonly used methods for the removal of microorganisms (UV disinfection, for example), there is one important advantage of membrane filtration, which is the combination of this process with biological wastewater treatment (e.g., activated sludge process). The membrane bioreactor has a high potential to remove not only pathogenic microorganisms [45,46], but also remaining solids [47] and CEC [48,49]. However, this is a complex process with great sensitivity and high equipment and operational costs [50].

Table 7. Advantages, disadvantages, and potential to remove target pollutants of different technologies [14,25,40,50].

Technology	Advantages (A)/Disadvantages (D)	Removal of Target Pollutants: Pathogenic Microorganisms	Nutrients	Potentially Toxic Metals	Remain Solids	CEC
UV disinfection	(A) Fast, efficient, and cost-effective process	+++	0	0	0	+
Chlorination	(D) Formation of harmful by-products	+++	+	0	0	+
Ozonation		++	+	0	+	+++
Nutrients biological removal	(A) Requires less or no chemical addition (D) Complex process; Large space requirements	+	+++ (N and P)	0	++	0
Ion exchange	(A) Selective and reverse process (D) Formation of organic contaminants from the resin	+	++	++	0	++
Chemical precipitation	(A) Simple operation; Less probability of releasing potentially toxic metals (D) High chemical requirements	0	+++ (P)	+++	++	0
Adsorption	(A) Simple operation and design (D) High requirements for adsorbents	+	++	++	0	++
Constructed wetlands	(A) Low energy input; Cost-effective (D) Performance depending on season; Large area footprint	+	0	++	++	++
Nanofiltration/ Reverse osmosis	(A) Need for less space; Physical barrier against particle material; No by-product formation	+++	+++ (N and P)	+++	+	+++
Microfiltration/ ultrafiltration	(D) High energy is required for nanofiltration and reverse osmosis; High investment	++	+	0	+++	0
Membrane bioreactors	(A) Higher mixed liquor-suspended solids concentration, allowing smaller reactors (D) Complex process; High equipment and operation costs	++	++	0	+++	+

+ low contaminant removal; ++ medium contaminant removal; +++ high contaminant removal; 0—no/negligible contaminant removal; CEC—contaminants of emerging concern.

Constructed wetlands are another technology widely used for preparing reclaimed water, especially because of their high capability to treat most of the pollutants (nutrients, potentially toxic metals, solids, and CEC) [51–54]. However, combining this process with others is crucial to remove pathogenic microorganisms.

With a focus on P removal, if required, several technologies are available, including biological removal, ion exchange, chemical precipitation, and adsorption. The most used nutrient removal strategy by biological uptake is the method known as enhanced biological phosphorus removal (EBPR). Although this method recovers organic P, it may require additional treatments before use. At the industrial scale, EBPR is used to concentrate the P in the system before the use of another technology [55,56]. Some studies indicate the possibility of using EBPR followed by the chemical precipitation of P as struvite [57]. One of the most studied strategies for recovering P, and as a result, preparing water for reuse, is chemical precipitation. Indeed, chemical precipitation allows the production of fertilizer by-products such as struvite and/or hydroxyapatite [58–61]. This strategy reduces P concentration to ensure proper use of reclaimed water and provides new products to reintroduce P in soils only when desired. Adsorption processes are an alternative to chemical precipitation. Some studies are already investigating low-cost adsorbents to reuse the loaded adsorbent as a fertilizer. Although activated carbon adsorption is one of the most widely recommended advanced treatments for producing high-quality reclaimed water, the costs of the processes (e.g., adsorbent preparation) are a disadvantage, and the use of alternative adsorbents can contribute to the circular economy [36,50,62–64]. However, these technologies are adequate for removing nutrients (particularly P) but are ineffective at removing pathogenic microorganisms, potentially toxic metals, and CEC (Table 7).

According to Table 7, membrane filtration and reverse osmosis are technologies that promote the removal of most target pollutants while producing high-quality reclaimed water. A previous study used a microfiltration-reverse osmosis system in a pilot plant to evaluate the removal of 28 pharmaceuticals and 20 pesticides from reclaimed water. The combined treatment allowed the removal of target micropollutants to levels below 1 ng/L or quantifiable limits [65]. However, membrane technologies have high economic costs and maintenance costs, especially because of membrane fouling when using high fluxes. Applying low fluxes reduces operating costs while increasing investment costs because more membrane units are required [50].

4. Irrigation with Reclaimed Water: Practical Applications

Selecting an appropriate reclaimed water irrigation system is important to ensure uniform application and high efficiency. The wastewater quality, type of soil and crop, the operator's ability to use various methods, and the potential risks to the environment and human health determine the type of irrigation chosen. The irrigation methods can be grouped into five categories: (i) flood irrigation, (ii) furrow irrigation, (iii) sprinkler irrigation, (iv) subsurface irrigation, and (v) localized irrigation [17,66]. One example of localized irrigation is drip irrigation, where the application of reclaimed water is directly on the plant's roots. Drip irrigation prevents diseases from spreading through direct contact with contaminated leaves (e.g., black spots and powdery mildew) or by drifting aerosols, reducing health problems for the operators and the community [67]. As shown in Table 8, the literature has explored this technique widely through studies that use reclaimed water for irrigation of agricultural soils.

Several studies have already been conducted on the use of reclaimed water for agricultural soil irrigation. Table 8 highlights some studies that used treated wastewater for improving crop growth while preserving soil and final product quality. According to the study developed by Bedbabis et al. [68], using reclaimed water raises the pH and the contents organic matter, major nutrients, salts, and potentially toxic metals (Mn, Zn, and Fe) in the soil. However, metal levels did not exceed Tunisian limits. The ripening of olives was faster as soil salinity increased (as expected because of wastewater's properties).

A 10-year study conducted by Jahany and Rezapour [69] found some negative effects of using reclaimed water in the soil. Soil salinity–sodicity indices, such as electrical conductivity, SAR, and potentially toxic metals were affected by reclaimed water. The concentration of Cd in the soils irrigated with reclaimed water was double the threshold defined by Kabata-Pendias (2010) [70]. This pattern, repeated for all soil sites, indicated that potentially toxic metals enriched these soils when irrigated with reclaimed water. As shown in Table 5, these parameters all have a negative impact on soil quality. It is important to note, however, that studies from the literature show that potentially toxic metals have not been a limiting factor. In contrast, soil fertility indices such as total N, available P, and organic matter increased with reclaimed water irrigation.

Except for the study of Urbano et al. [71], the other studies in Table 8 used conventional irrigation and a commercial fertilizer to supplement the growth process. However, Urbano et al. [71] tried to apply a fertigation technique with reclaimed water. Fertigation involves the application of a fertilizer solution (in this case, reclaimed water) with drip irrigation. This technique facilitates the supply of both water and nutrients directly to the root zone while reducing the need for commercial fertilizers [30]. However, the wastewater requires analysis to provide the correct amount of nutrients to the crop and supplementation with additional nutrients if necessary. As concluded by Urbano et al. [71], even with the complement of conventional fertilization, the use of reclaimed water as fertigation was not enough to provide the right doses of micronutrients (e.g., Cu, Fe, and Zn) to the lettuce.

Table 8. Example of studies using reclaimed water for irrigation of agricultural soils.

Crop	Treatments of Reclaimed Water	Irrigation Type and Conditions	Conclusions	Ref.
Olive orchards	No information	Drip irrigation Water supply: 5000 m^3/ha year 10 years treatment	90% increase in crop productivity compared with irrigation with draw-well water Increased fruit fresh weight, but no significant effect on oil content Increased major nutrients, salts, and potentially toxic metals (e.g., Mn, Zn, and Fe) Reduced chlorophyll content and increased β-carotene content.	[68]
Rice	Secondary treatment with activated sludge system; filtration; UV treatment unit	T1: Groundwater; T2: Untreated domestic wastewater; T3: Reclaimed water Irrigation water level: 1–10 cm	Average crop growth in T2 and T3 increased approximately 7% than in T1 Concentrations of Cu and Zn were slightly higher in T3 than in T1, but with no adverse effects observed.	[72]
Lettuce and leeks	Lagoon-based secondary treated	Surface drip irrigation T1: Tap water; T2: Raw domestic wastewater; T3: Reclaimed water; T4: Reclaimed water with a spiked with fourteen organic contaminants Water supply: 0.5 L/2 days in spring/fall and 1 L/2 days in summer	The accumulation of fourteen organic contaminants in soil and crops was very limited when using reclaimed water, even after five successive lettuce crops Longer growing period did not imply higher contaminants accumulation	[73]
Only soil restoration	Lagoon-based secondary treatment	T1: Reclaimed water; T2: Freshwater (control) Water supply: 6000 m^3/ha.year 10 years treatment	T1 increased the average values of electrical conductivity up to 147% compared	[69]

Lettuce	Grease tap, septic tank, microalgae tank, anaerobic sludge digestor, two wetlands	Drip irrigation T1: drinking water with conventional fertilization; T2: reclaimed water with partial conventional fertilization Water supply: field capacity; 4 L/h	to control (values below 4 dS/m) and sodium absorption ratio up to 76% (values below the limits of FAO) Values of Cd were twice higher than its maximum allowable limit T1 offers nutrients to the crop only during fertigation (20–30 days growth); T2 offers nutrients to the crop during the entire cultivation cycle Deficiency in lettuce levels for B, Cu, Fe, Mn, and Zn for T1 and T2 The concentration of Cu, Fe, and Zn in the soil was not affected by T2 The presence of *E. coli* was not detected during the experiment	[71]

Using reclaimed water as a source of both water and nutrients is critical in water-stressed areas. According to the EU reports, the reuse of treated urban is approximately 1 billion cubic meters each year. However, it only accounts for 2.5% of treated urban wastewater, which is less than 0.5% of annual EU freshwater withdrawals. Cyprus, Malta, and Israel reuse over 90, 60, and 80% of treated wastewater, respectively. However, Greece, Italy, and Spain only reuse between 5 and 12% of their wastewater [30,74,75]. Fito and Hulle (2021) [76] reported that Chile irrigates over 100 thousand hectares with treated wastewater, whereas the United States of America irrigates less than 50 thousand hectares.

With caution, irrigation—and possibly fertigation—seems to be a valuable option with which to reduce the impacts of hydrological drought and the dependency on freshwater and mineral resources.

5. Conclusions and Future Perspectives

Although using urban wastewater to produce reclaimed water for agricultural irrigation is not a consensual practice, it represents a valuable resource to consider in the future. There are already regulations and guidelines in place, from European institutions and other organizations, considering the use of reclaimed water in agricultural soil for food production. Of the existing advanced technologies to treat wastewater, the most reliable are nanofiltration and reverse osmosis, which allow the removal of almost all target pollutants. However, these technologies have several disadvantages, such as high maintenance costs because of membrane fouling. It is necessary to consider the ultimate purpose of reclaimed water when selecting a technology, and more than one technology is likely to be used to meet all requirements.

In the near future, implementing these new technologies will become mandatory in the WWTP. However, more financial support and social awareness will be required to promote reclaimed water production, as these are the two main barriers to reusing this type of water for irrigation. Fertigation techniques using reclaimed water may represent a way to reduce the use of commercial fertilizers. It will also minimize the P and N resource depletion, from the circular economy perspective. The preparation of water for reuse will also be a source of recovered P and N for other applications.

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