Treated waste water reuse in agriculture: an Overview

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Abstract The reuse of treated wastewater in agriculture is a promising solution to the water scarcity challenge faced by many regions worldwide. This review paper provides an overview of the current state of knowledge on treated wastewater reuse in agriculture, highlighting its potential benefits and challenges. The paper begins by discussing the importance of treating wastewater before reuse and the potential it offers. The benefits of using treated wastewater in agriculture are discussed, including increased water availability, improved soil fertility and reduced fertilizer use. The risks associated with the use of treated wastewater, such as the accumulation of pollutants and the potential for pathogen transmission, are also discussed. The review paper then presents some examples of reuse projects for irrigation and their success criteria. The current regulations governing the use of treated wastewater in agriculture are examined, and their evolution presented. The paper concludes with a discussion of future research needed to address the remaining challenges surrounding the use of treated wastewater in agriculture. Overall, the review paper emphasizes the importance of careful management and regulation of treated wastewater reuse in agriculture to ensure safety and sustainability to meet the growing demand for water in agriculture.

1 Introduction

Water scarcity is a growing concern in many regions around the world, and it is projected to become even more severe with the ongoing climate change. Treated wastewater can provide an alternative source of water for various applications, including irrigation in agriculture. The use of treated wastewater in agriculture has gained significant attention as a sustainable solution to mitigate water scarcity while simultaneously reducing the discharge of polluted water into the environment. However, the reuse of treated wastewater in agriculture also raises concerns regarding potential health and environmental risks associated with the presence of contaminants in the water. Therefore, this review paper aims to summarize the current state of knowledge regarding the reuse of treated wastewater in agriculture, including its benefits, challenges, and potential risks, and to discuss the future research needs in this field. To conduct this review, we performed a comprehensive literature search in various academic databases such as Web of Science, Scopus, and PubMed. The search keywords included "treated wastewater", "agriculture", "irrigation" and "water reuse". The search resulted in a total of 40 articles. We screened the articles based on their titles and abstracts to select those relevant to the review's scope. After full-text reading, we included a total of 31 articles in the final review. We analyzed the included articles to extract information regarding the benefits, challenges, and potential risks associated with the reuse of treated wastewater in agriculture. In order to present a thorough summary of the state of knowledge on this subject, we combined the information from the chosen publications.

2 Treating wastewater: A necessity

In a context of recurrent droughts and decreasing water resources, the exploitation of non-conventional water resources has become a necessity. Treated wastewater is a valuable resource as it does not depend on the seasons or rainfall and therefore makes it possible to secure a continuous water resource throughout the year. The treatment of wastewater is all the more urgent given the danger it poses when it is discharged directly into freshwater sources or when it is used raw for irrigation of some crops. Every year approximately 70 million m^3 of untreated sewage are used for agriculture without sanitation to irrigate more than 7,000 hectares of various crops (fodder crops, vegetable crops, arable land cultivation, arboriculture, etc.). Reusing treated wastewater in agriculture offers a viable way to address the growing problems with water scarcity. Reducing the dependency on freshwater sources

while increasing the sustainability and dependability of the irrigation water source for crop production can be achieved through the use of treated wastewater.
In Morocco, many regions have been suffering from cases of direct and indirect use of untreated wastewater. In Meknes, increasing discharges have seriously damaged the aquatic environment, mainly in the Bouishak river. Investigations of the physical and microbiological parameters of Bouishak river between July 2005 and June 2006 showed that this discharge seriously affected the water quality of this surface water. In fact, the physicochemical and bacteriological parameters measured gradually evolved from upstream to downstream, and were condensed near the agricultural areas. In addition, bacteriological surveys revealed high levels of fecal contamination in the Bouishak waters, exceeding the standards set by the World Health Organization for unrestricted irrigation of raw vegetables [1]. The irrigation by these waters is an indirect reuse that threatens the health of farmers and consumers. Thus, Morocco has banned the use of untreated sewage to irrigate vegetable crops. However, this prohibition is not always respected [2, 3].
Beyond the environmental and safety necessity to treat wastewater before discharge, more countries became aware of the great potential gained by treating and reusing wastewater. It is mainly used for purposes that do not need water of very high quality (contrary to drinking water) such as industrial use (power plant cooling, processing, construction, aggregate washing, dust control, etc.) and agricultural and urban irrigation [4]. Japan has been dedicating it’s treated wastewater to meeting its urban water requirements [5, 6]. The country has developed a “comprehensive strategy for treated wastewater reuse in which 7% of wastewater is reused in agriculture” [7]. In China, wastewater irrigation was initiated in 1957 and is now common, particularly in suburban areas near large and medium-sized cities in the northwest [6]. In southern Europe, treated wastewater is primarily reused for agricultural purposes (44% of the projects). It is also utilized for environmental or urban purposes (37% of the projects) [8, 6]. In Australia, the utilization of recycled water is increasing, and it currently comprises 4% of the total volume consumed [9].
Treated wastewater reuse can also be helpful environmentally when it comes to groundwater recharge or replenishment of dry watercourses to guarantee a livable ecosystem for aquatic species (fauna and flora), as well as ensure the discharge of less polluted water and therefore reduce the pollution of rivers and oceans [10, 11, 6]. Other benefits of reuse are a better treatment-energy nexus as it’s less expensive than other non-conventional water resources, for example desalinization [12], also, compared to dams, reusing treated wastewater has fewer impacts [13, 6].
Deciding on each specific use of the treated wastewater depends on the level of treatment applied [14]. The “primary treatment stands for a 30–40% reduction of organic load and pathogens. The secondary treatment stands for 95% and tertiary treatment stands for almost a 99% reduction of organic load with no significant pathogens after disinfection. The last two levels also include disinfection” [15, 6].

3 Reuse in agriculture

Because of agriculture’s high water consumption (70% of water resources) [16, 17], irrigation and food production is the first candidate for treated wastewater reuse. Treating and reusing wastewater in agriculture is launched not only because of difficult climate conditions but also because it can bring natural fertilizers to the soil [17, 18]. The amount of fertigation (mainly nitrogen and phosphorus) provided depends on the origin of the wastewater and the level of treatment undergone [19-23, 6]. The choice of the level of treatment is influenced by the crops destined to be irrigated by the treated wastewater. “According to [24], primary treatment can be used for the controlled irrigation of forestland and parks, as long as all the safety precaution measures are taken. Secondary treatment is appropriate for trees such as olive trees, vineyards, etc. as long as it does not come into contact with the crops. Lastly, tertiary treatment is appropriate for all types of crops consumed by human beings” [6]. The level of treatment should be advanced as much as the water comes in contact with the crops and the produces. Many countries have already launched the process on a large scale [6]. Israel is a pioneer in the use of treated wastewater for irrigation, with over 85% of its agricultural land being irrigated with recycled wastewater. The country has developed advanced technologies for treating wastewater to meet high-quality standards for agricultural use. The success of Israel's treated wastewater reuse program has led to increased agricultural productivity and reduced water stress on the country's limited freshwater resources [25].
In Morocco, an example of wastewater treatment projects is the M’zar treatment plant of Agadir for irrigation which has a capacity of 10,000 m3/day (category A, WHO standards). This capacity could satisfy the needs for irrigation water for the entire Agadir area (Morocco). Despite that success, studies showed an increase in salinity and leaching to the groundwater [26]. These projects came a long way from the beginnings of treated wastewater reuse. Mexico has been reusing these waters for more than 80 years now and has faced many challenges [17]. The most important failures were related to “operational and maintenance problems which related to a lack of understanding of the system, security and hygiene issues, and to a poorly equipped laboratory with untrained personnel” [17]. Besides problems related to the management of wastewater treatment plants, governments realized that this water usage needed to be regulated to ensure safety and conformity throughout the world.

4 The legislations

When it comes to legislation for using treated wastewater in agriculture, there is a great discrepancy between countries. Some chose to follow the WHO guidelines for example, Australia, Egypt, India, Iran, Israel and Jordan. Other countries may have adopted similar guidelines or have their own regulations in place that are inspired by the WHO guidelines. Published in 1989, the WHO Health Guidelines for the Use of Wastewater in Agriculture and Aquaculture suggest varying water quality based on the discharge endpoint, such as for restricted or unrestricted agricultural irrigation. [27, 17]. The most recent guidelines were published in 2006 and provide updated recommendations based on scientific evidence and best practices for the safe use of treated wastewater in agriculture. The 2006 guidelines recognize that treated wastewater can be a valuable resource for irrigation in areas where water is scarce, but they also emphasize the importance of protecting public health and the environment. The guidelines provide a comprehensive framework for assessing and managing the risks associated with the use of treated wastewater in agriculture. Some of the key changes in the 2006 guidelines include updated recommendations for treatment processes, monitoring and testing of wastewater quality, and guidelines for the safe use of treated wastewater in agriculture. The guidelines also include specific recommendations for different types of crops and irrigation methods. It's worth noting that while the WHO guidelines provide a useful framework for assessing and managing risks associated with the use of treated wastewater in agriculture, they are not legally binding and individual countries may have their own regulations and guidelines for the use of treated wastewater in agriculture and might choose different approaches to enforce them. The requirements for irrigation with treated wastewater are different compared to other uses of treated wastewater, such as industrial processes or direct potable reuse. To use this unconventional water in irrigation, it’s essential for it to meet certain quality standards to ensure that it does not contain harmful substances that could contaminate crops or soil. The WHO guidelines recommend specific standards for parameters such as pathogens, chemical contaminants, and physical characteristics. These guidelines have been challenged by many studies that have tested them in experimental settings and compared them with their own countries’ regulations. For example, [28] conducted an experiment in a pilot plant at a municipal wastewater treatment plant in West Bari, Southern Italy. The effluents received different types of treatment, including secondary, clarified, and clarified-filtered treatment. The aim of the experiment was to investigate the effectiveness of three disinfectants in achieving microbial guidelines for the unrestricted reuse of wastewater in agriculture set by the World Health Organization (1,000 CFU/100mL for Faecal Coliforms) and the corresponding Italian standard (2 CFU/100mL). The results showed that all three disinfectants easily achieved the WHO guideline, but only UV treatment was effective in meeting the Italian standard, with an operation and maintenance cost between 17.5-35 Euro/1000m. The results show how some countries’ regulations can be very rigid and complicate the use and reliance on this unconventional resource. The new guidelines, based on scientific results and research recommendations, for safe wastewater use is critical, especially since many countries, particularly those in the Mediterranean region, are already experiencing the effects of climate change, such as droughts. On another hand, wastewater treatment for irrigation should be compatible with local climate conditions and affordable. Therefore, countries should be free to choose methods that are suitable for their climatic conditions and can be combined with a series of barriers to achieve the health-based standards for the quality of the treated water used for irrigation [29]. In some cases, regional regulations have taken precedence over global frameworks. In Europe, the Spanish Royal Decree 1620/2007 was a significant step forward in regulating water reuse. It outlines the responsibilities of public administrations, concession holders and end-users, sets permitted uses and quality criteria, establishes the minimum frequency of sampling, benchmark analytical methods, and conformity criteria. However, [30] and [31] found that many water reuse regulations in several EU countries were not developed in line with the transversal principles of the EU, such as the precautionary principle. In another study, [32] surveyed farmers on their knowledge of laws and regulations related to safe wastewater reuse in agriculture, with only half of them responding positively [6].

Having laws and legislation adapted to each type of use of treated wastewater and each context is one thing, but enforcing these laws and convincing farmers and consumers of the opportunity offered by this reuse is another. Authorities often face challenges from communities living near proposed wastewater treatment systems, both conventional and non-conventional. While most people recognize the importance of treating wastewater, they often object to having the treatment systems located near their community due to issues like bad smells or insects. These problems can usually be attributed to poor operation and maintenance of the treatment system. Therefore, ensuring that personnel are trained to operate and maintain an efficient treatment system can help avoid these issues [17].

5 The consumers’ side

According to the literature, it has been widely acknowledged that the main obstacles to achieving more effective water management are primarily socio-institutional rather than technical. These challenges include institutional fragmentation, limited long-term strategic planning, insufficient project demonstration, and inadequate community participation [33]. Specifically, individuals may view the benefits of using recycled water as distant and abstract, as they may not perceive the long-term benefits such as improved water availability for future generations to be worth the perceived short-term health risks [6]. The "yuck factor" is commonly cited as the reason for public resistance to water reuse projects, where people feel disgusted by the idea of consuming or using products produced with wastewater. Social research has highlighted the importance of addressing this psychological repugnance in order to successfully implement water reuse schemes. Public perception of water reuse is influenced by factors such as water quality, farmers' ability to manage risks, societal concerns, and economic benefits [6]. To promote the use of reclaimed water among farmers and gain public acceptance for water reuse, the cost of recycled water plays a crucial role. Therefore, many water reuse projects provide direct or indirect subsidies, whereby suppliers offer recycled water at concessional rates. For instance, in Spain, public administrations can finance up to 70% of the operation costs associated with transporting water from the WWTP to irrigate fields, as well as 10% of the overall cost of installing the irrigation system [35]. For instance, a study by [37] found a positive correlation between the provision of information and public acceptance of recycled and desalinated water based on a sample of 1000 Australian participants. In another study conducted in the Jordan Valley, over 70% of respondents expressed their willingness to learn more about water treatment and reuse [38]. These studies demonstrate that the public's acceptance of water reuse is more likely when the benefits of water conservation and environmental protection are clearly communicated, and when there is a high level of awareness of water supply issues in the community [39]. [40] proposed an innovative approach to promote public acceptance of water reuse programs, which was later revisited by [41]. The strategy suggests showcasing recycled water in a positive light by associating it with enjoyable activities that the public supports. As the authors suggest, “this may include creating an attractive setting for the reclaimed water, inviting the public to explore and appreciate it, and engaging in activities such as picnicking, fishing, or swimming around it (p. 670)”. For instance, in Italy, the managers of the Milano Nosedo wastewater treatment plant, the largest plant in the region treating around 150 million m3/year of wastewater, organize open days to showcase the plant's operations and promote public acceptance among farmers and the general public in a large agricultural region that grows corn, rice, grass, and grain. Besides raising awareness among the public and changing their perception, the usage of tools allowing a better management of treated wastewater would be beneficial in integrating this water resource in agriculture, thus alleviating the pressure on fresh water [41]. Even though the reuse of treated wastewater in irrigation and food production is a viable solution for a multitude of water management problems, it can harbor many risks and should be carefully managed and closely monitored to avoid any health hazards.

6 The risks

According to the World Health Organization [29], the main hindrance for the use of wastewater in agriculture is the presence of parasitic helminths, due to their low infective dose and extended survival in the environment. Consequently, before any project involving wastewater reuse in agriculture, special attention must be paid to the parasitological aspect of wastewater [29]. A study focused on raw wastewater from Oujda found that the helminth egg load in wastewater from various collectors in the city poses a clear potential risk to both human and livestock populations. Therefore, treating wastewater is necessary in case of its reuse in agriculture [41]. The presence of chemical particles is another concern. In fact, the primary objective of treating wastewater for irrigation purposes is to eliminate pathogens through primary and secondary treatment, followed by granular media filtration and/or disinfection. However, even after treatment, the effluent may still contain various chemicals that can harm plants and groundwater quality, and ultimately pose a threat to human and animal health. This is particularly concerning in arid regions where drip irrigation can cause chemical concentrations in drainage water or deep-percolation to be much higher than in the original wastewater. The chemicals of concern include salts, pesticide residues, nitrogen (mainly as nitrates in drainage water), disinfection by-products, pharmaceutically active chemicals, and other chemicals and precursors of disinfection by-products, such as humic substances and dissolved organic matter [4]. Among the potential agronomic adverse effects of irrigation with these waters, salinity is the most important factor. Natural waters contain some amount of salt, which is expressed as total dissolved solids (TDS). The TDS content of surface water typically ranges from a few tens to a few hundred mg/L [4]. The typical salt content in wastewater can vary greatly depending on the source of the wastewater and the treatment processes it has undergone. In general, the salt content in domestic wastewater (i.e. wastewater generated from households) is relatively low and ranges from 500 to 1500 mg/L. However, industrial wastewater may have much higher salt content depending on the nature of the industry and the processes involved. For example, wastewater from industries such as food processing, chemical manufacturing, and metal plating can have much higher salt content, ranging from 2000 to 10,000 mg/L or even higher. It's worth noting that high levels of salt in wastewater can cause problems in the treatment process and can also contribute to environmental issues such as soil salinization and damage to aquatic ecosystems. Therefore, it's important to monitor and control the salt content in wastewater as part of effective wastewater management. Even though the use of treated wastewater is encouraged because of the diminution in fertilizers use, it can still raise concerns about nitrogen contamination in the soil and underlying groundwater.

Nitrogen compounds tend to convert to nitrate in the soil, and while crops absorb significant amounts of nitrogen, nitrates can still leach into the groundwater. Additionally, if farmers cannot control the fertilization while using wastewater, excess nitrogen can negatively affect crop quality and yield, delay harvest, and cause nitrate toxicity in humans and animals [4]. The health risk associated with human exposure is also to be taken into consideration. This exposure is influenced mainly by the irrigation technique used. The highest risks occur with spray or sprinkler irrigation. Flood and furrow irrigation expose field workers to the highest risks. Furrow irrigation may also fail to protect crops from direct exposure to wastewater. Drip irrigation techniques, such as drip, trickle, and subsurface irrigation, offer the most effective health protection by reducing workers' exposure to wastewater [17]. The need for children protection, as being more sensitive than adults, is also evident [17], especially in Morocco where farmers' children are often involved in the farm work. So, they must be aware of the importance of providing protection, especially for partially treated wastewater.

7 Conclusion and recommendations

Treated wastewater reuse in agriculture presents a promising solution to the increasing water scarcity challenges faced by many regions around the world. The use of treated wastewater can provide a reliable and sustainable source of irrigation water for crop production while reducing the reliance on freshwater sources. Health protection measures should be implemented alongside crop restriction, irrigation technique optimization and human exposure control. It is also crucial to established a network of laboratories throughout the country to monitor treatment plant effluents for compliance with national microbiological standards. To avoid the public's rejection because of bad smells, wastewater treatment plants' malfunction should be avoided and maintenance and operation should be kept up to date. Thus, it's necessary to implement training programs and closely monitor these treatment plants. Costs are also subject to discussion as it can discourage consumers. It is generally accepted that the discharger should bear the cost of treatment, but until that can be achieved, the discharger and the user must share the burden of treatment. All of this needs to be accomplished within existing technological and financial constraints [17]. Overall, the success of treated wastewater reuse programs in agriculture depends on various factors, including the quality of the treated wastewater, the type of crops and farming practices, the regulatory framework, and public perception and acceptance of recycled wastewater. While some programs have been successful, others have faced challenges and require ongoing management and monitoring to ensure safe and sustainable use of treated wastewater in agriculture. To ensure the latter, the treated wastewater must go through appropriate treatment processes to ensure that it meets the required quality standards. It is also primordial to ensure the irrigation method used be appropriate for the specific crop and soil type, as well as the quality of the treated wastewater.

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