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Transforming Agriculture: Innovations in Sustainable Wastewater Reuse – A review

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ABSTRACT

This scientific review delves into the crucial role of wastewater reuse in agriculture for sustainable water resource management, especially in the context of water scarcity. The paper examines innovative wastewater treatment methods like biofiltration, membrane bioreactors, and electrocoagulation, exploring their effectiveness and limitations. It emphasizes the significance of proper wastewater treatment in mitigating risks and maximizing benefits. Key considerations such as economic viability and social acceptance are highlighted, urging comprehensive cost-benefit analyses and active engagement with stakeholders. Drawing from case studies in Tshwane, Egypt, Valencia, and Sde Warburg, successful wastewater reuse practices underscore the importance of stringent water quality standards, public education, regulatory frameworks, and stakeholder involvement in achieving sustainable wastewater management. Despite global advancements, challenges persist in the adoption of these technologies in many African countries, necessitating collaborative efforts and targeted capacity-building for widespread implementation. Historical insights reveal the evolution of wastewater irrigation from European and American cities to its current global prevalence, impacting around 10% of the world's irrigated land with untreated or partially treated wastewater. Technological advancements, such as biofiltration relying on microbial activities, membrane bioreactors integrating biological treatment with filtration, and electrocoagulation as an electrochemical process, offer sustainable solutions. Case studies highlight the economic, environmental, and social benefits of successful wastewater reuse programs. However, the review acknowledges the risks associated with wastewater reuse, including environmental contamination and public health hazards. To strike a balance between risks and benefits, the paper advocates for proper wastewater treatment, robust regulatory frameworks, and responsible farming practices. It concludes by stressing the need for collaborative efforts, international partnerships, and targeted capacity-building initiatives to overcome barriers to the adoption of advanced wastewater treatment technologies in African countries, fostering water management, ensuring food security, and contributing to social and economic development amid global challenges.

Keywords: wastewater; agriculture; treatment technologies; biofiltration; membrane bioreactors; electrocoagulation; resource recovery

INTRODUCTION

Wastewater reuse in agriculture as claimed by Jaramillo & Restrepo (2017), specifically the utilization of treated wastewater for crop irrigation, represents a crucial strategy in the sustainable management of water resources. This practice has gained prominence as a pragmatic solution to address water scarcity issues arising from seasonal variations and the unpredictable availability of alternative water sources for agricultural irrigation throughout the hydrological cycle (Bhojwani et al., 2019).

In the 19th century, the adoption of soil irrigation with wastewater became widespread in rapidly growing European and American cities (Kretschmer et al., 2002). Ganoulis (2012) maintains that Cities like London, Paris, and Boston legally embraced this practice as a solution for the treatment and disposal of substantial wastewater volumes. Paris, in particular, stands out as the pioneer, irrigating peri-urban fields with wastewater on an extensive scale by 1872.

According to FAO, about 10% of the global irrigated land, covering approximately 20 million hectares across 50 countries, is exposed to untreated or partially treated wastewater (Winpenny et al., 2013). However, Jiménez and Asano (2008) present a more nuanced perspective by indicating that the extent of wastewater-irrigated areas varies significantly between countries and depends on whether the wastewater is treated or untreated. In terms of the volume of wastewater utilized in agriculture, Bixio and Wintgens (2017) highlight that the European continent alone recycles 963 million cubic meters per year of untreated wastewater. Meanwhile, in Latin America, an estimated 400 cubic meters per second of untreated wastewater is discharged and subsequently employed for the irrigation of diverse crops whereas in the African context, treated wastewater reuse is particularly substantial in the Middle East and North Africa standing at 15 % (Jones et al., 2021; Jones et al., 2019; Hanasaki et al., 2013; Kummu et al., 2016).

These findings underscore the global variability in the utilization of wastewater in agriculture and emphasize the need for a comprehensive understanding of both treated and untreated wastewater irrigation practices.

While the use of wastewater in agriculture has historical roots dating back to ancient civilizations, its implementation has not always adhered to proper management practices or quality standards. The hazards that wastewater reuse posed to the environment and public health at this time made it a global concern. In order to preserve public health and enable the sensible use of wastewater and excreta in agriculture and aquaculture, the World Health Organization (WHO) drafted the document "Reuse of effluents: methods of wastewater treatment and health safeguards" in 1973. In the guidelines, parameters were established on the microbiological quality of wastewater for irrigation as part of the wastewater guidelines produced by the WHO in 2006. In these guidelines, the type of agricultural reuse was classified on the basis of the type of irrigated crop as shown in Table 1.

TABLE 1: FAO guidelines for the agricultural reuse of treated water.

Type of Agricultural Reuse	Type of Treatment	Quality Criterion
Agricultural reuse in crops that are consumed and not processed commercially.	Secondary Filtration—Disinfection	pH = 6.5–8.4 BOD < 10 mg/L <2 UNT <14 NMP E. coli/100 mL <1 Egg/L
Agricultural reuse in crops that are consumed and not processed commercially.	Secondary—Disinfection	pH = 6.5–8.4 BOD < 30 mg/L SS < 30 mg/L <200 NMP E. coli/100 mL
Agricultural reuse in crops that are not consumed.	Secondary—Disinfection	pH = 6.5–8.4 BOD < 30 mg/L SS < 30 mg/L <200 NMP E. coli/100 mL

Although research on wastewater treatment has been adequately progressed, the knowledge about wastewater treatment is inadequate, mainly because of limited data on wastewater quality guidelines for reuse and optimal combinations of conventional and advanced wastewater treatment processes. Moreover, the economic, environmental, and human and animal health impacts of wastewater treatment have to be thoroughly revisited and discussed. Kou et al., (2022) assert that the significance of advancements in treatment and reuse technologies lies in their potential to address critical global challenges such as water scarcity, environmental degradation, and public health risks. These innovations empower enhanced management of water resources, preservation of ecosystems, and facilitation of sustainable development across various sectors. This article therefore reviews sustainable solutions for wastewater reuse in agriculture. This practice is important, especially in the context of developing countries confronted with increased water shortages due to variability and climate change.

MATERIALS AND METHODS

This review employed a literature search across diverse databases, including Google Scholar, PubMed, Scopus, ScienceDirect, and ResearchGate, alongside other relevant platforms. The search focused on key terms such as "Wastewater," "Management," "Sustainability," "Water Quality," "Environmental Sustainability," and "Treatment Technologies." The inclusion criteria involved assessing article titles and abstracts, with emphasis on studies addressing wastewater reuse in agriculture, wastewater treatment technologies, case studies on wastewater reuse, and the health and environmental risks associated with wastewater usage. Additionally, management approaches for sustainable wastewater treatment systems were considered. The search results underwent detailed manual screening to ensure the relevance of the extracted information for inclusion in this review. This systematic approach aimed to provide a comprehensive and reliable foundation for the subsequent analysis and discussion in the review paper.

OVERVIEW OF WASTEWATER TREATMENT METHODS

• Biofiltration

In the domain of agricultural wastewater treatment, biofiltration stands out as a pivotal and environmentally sustainable method, as indicated by Buhmann et al. (2013). This approach relies on the activities of microorganisms, primarily bacteria, and fungi, which intricately break down both organic and inorganic pollutants within wastewater, as demonstrated by Barbusinki et al. (2017). Central to biofiltration's effectiveness is the development of a biofilm, a structured matrix where microorganisms adhere to a supportive medium, providing a stable environment for essential metabolic processes. Kilaite (2022) underscores the significance of aerobic conditions in biofiltration, ensuring an oxygen-rich environment crucial for microbial pollutant degradation.

Biswas (2021) emphasizes several mechanisms (Figure 1) employed by biofiltration for proficient pollutant removal from agricultural wastewater. Adsorption allows pollutants to attach to the support medium's surface, facilitating interaction with microorganisms. Biodegradation plays a central role, involving microbial metabolism of organic compounds through intricate biochemical reactions (Hasan & Muhammad, 2020). Additionally, absorption and sorption mechanisms come into play, where microorganisms absorb or absorb inorganic pollutants, reducing their concentration in the wastewater. These diverse methods confirm biofiltration's adaptability and resilience, making it a versatile technology for agricultural wastewater treatment, as highlighted by Piras et al. (2020). This underscores its relevance within sustainable agricultural practices, aligning with the findings depicted in Figure 2 (Piemont et al., 2016).

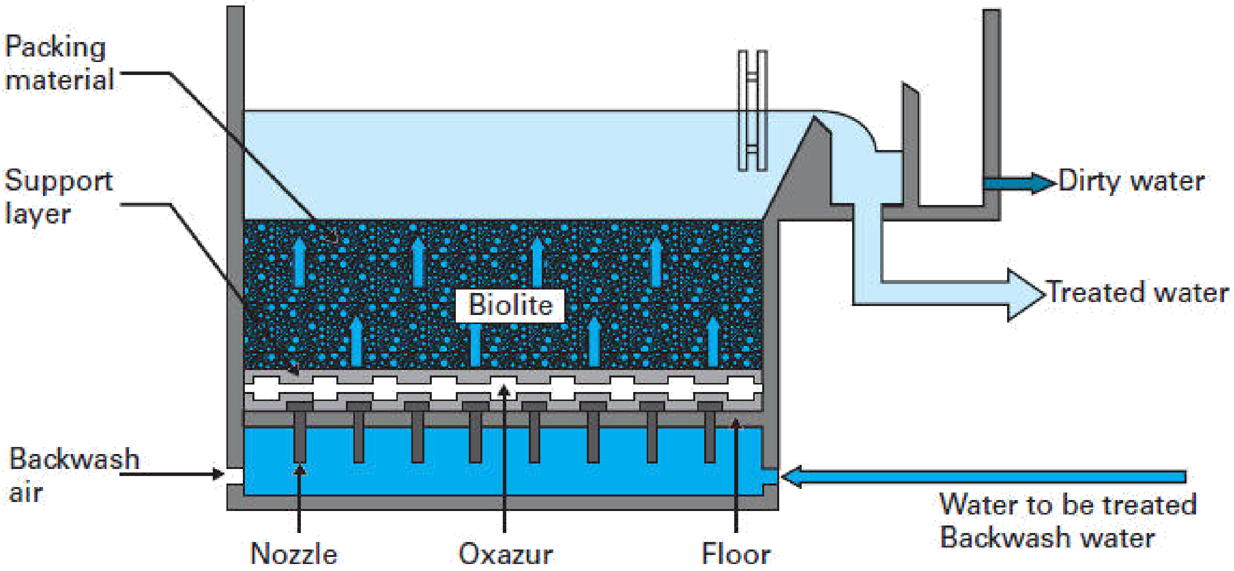

FIGURE 1: Biofiltration system (Piemont et al., 2016).

Biofiltration finds diverse applications in agricultural wastewater treatment. It is instrumental in removing excess nutrients like nitrogen and phosphorus from agricultural runoff, mitigating water pollution and eutrophication (Quyen, 2020). Biofiltration also excels in degrading pesticides, herbicides, and organic matter commonly present in agricultural wastewater. Furthermore, it contributes to the reduction of pathogenic microorganisms and heavy metals, safeguarding water quality and ecological balance. Biofiltration systems can be tailored to target specific pollutants and treatment goals, making them a valuable tool in promoting sustainable agriculture and protecting water resources from contamination (Francesco et al., 2020).

MEMBRANE BIOREACTORS

Membrane bioreactors (MBRs) as shown in Figure 2 are an innovative wastewater treatment technology that integrates biological treatment with membrane filtration (Mofijur et al., 2023). The process begins in a biological reactor, similar to conventional activated sludge treatment, where microorganisms metabolize organic matter and contaminants in the wastewater. However, Abuabdus &Ahamad (2020) claim that the pivotal advancement in MBRs occurs during the subsequent membrane filtration phase. In contrast to conventional settling tanks used to separate solids from treated water, MBRs utilize microfiltration (MF) or ultrafiltration (UF) membranes. These membranes, with pore sizes typically ranging from 0.1 to 0.4 micrometers, act as effective physical barriers. Clean water, known as permeate, passes through these membranes, while contaminants, including suspended solids, bacteria, viruses, and other particles, are retained and subsequently removed (Mahmood, 2022).

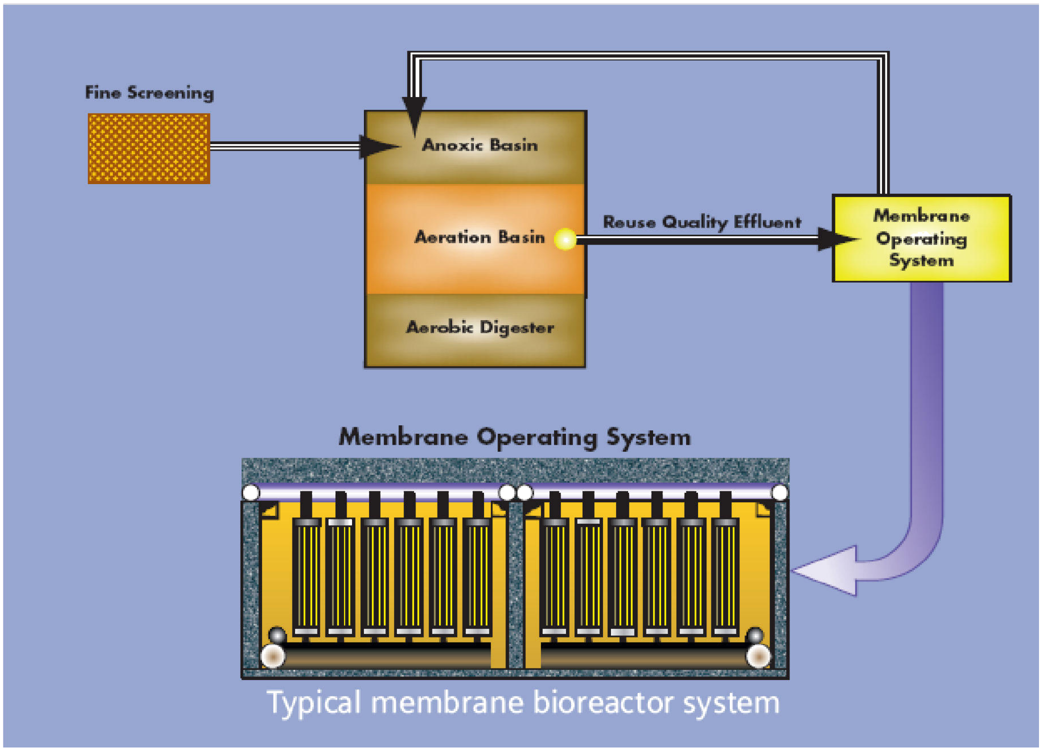

FIGURE 2: Typical membrane bioreactor system (Source: USA Environmental Protection Agency 2015).

Membrane bioreactors (MBRs) offer several compelling advantages in the realm of wastewater treatment (Tian & Filed, 2022). First and foremost, MBRs are known for their ability to consistently produce high-quality effluent. The membranes used in MBRs effectively remove suspended solids, pathogens, and a wide array of contaminants, ensuring that the treated water meets stringent water quality standards (Table 2), which makes MBRs highly suitable for various applications, including treating wastewater for water reuse, where the demand for exceptionally clean water is imperative.

Despite the many benefits of membrane bioreactors, it is crucial to think about their downsides. One major issue is the high cost, both for setting up the system and for running it. The initial investment can be really expensive because of the costs of the membrane parts and the necessary equipment (Radjenovic, 2017). Also, the day-to-day costs, including the energy needed to keep the biological processes going and the money spent on cleaning the membranes, can add up. This high cost makes it hard for some groups, like certain organizations or communities, to use membrane bioreactors. So, it's important to carefully evaluate and plan for these financial challenges when deciding to use membrane bioreactors.

TABLE 2: Agricultural wastewater quality parameters before and after treatment.

Parameter	Influent Average	Effluent		
		Average	Max Month	Min Month
Flow (mg/d)	0.35	--	0.44	0.26
BOD (mg/L)	145	1	1	1
TSS (mg/L)	248	1	1	1
Ammonia-N (mg/L)	14.8	0.21	0.72	0.10
P (mg/L)	0.88	0.28	0.55	0.12
Fecal coliforms (#/100 mL)	--	14.2	20	0
Turbidity (NTU)	--	0.30	1.31	0.01

***Data Source**:* (USA Environmental Protection Agency, 2007).

- **Electrocoagulation**

Electrocoagulation is an electrochemical water treatment process widely employed to treat agricultural wastewater. In this method, two metal electrodes, typically made of materials like aluminum or iron, are submerged in the wastewater and connected to an electrical power source (Bazrafshan et al., 2015).

As an electric current passes through the water, the metal electrodes dissolve, releasing ions into the wastewater. According to Rakhmania et al. (2022), these ions play a pivotal role in destabilizing and coagulating contaminants, leading to the formation of larger flocs. These agglomerated particles are then more easily separated from the water through processes such as sedimentation or flotation.

According to Bener et al. (2019), electrocoagulation as shown in Figure 3 demonstrates remarkable effectiveness in treating agricultural wastewater. Its versatility in managing diverse contaminants, such as heavy metals and nutrients, its efficient removal of pathogens and suspended solids, and its potential for minimizing chemical usage establish it as a sustainable option for agricultural effluent treatment.

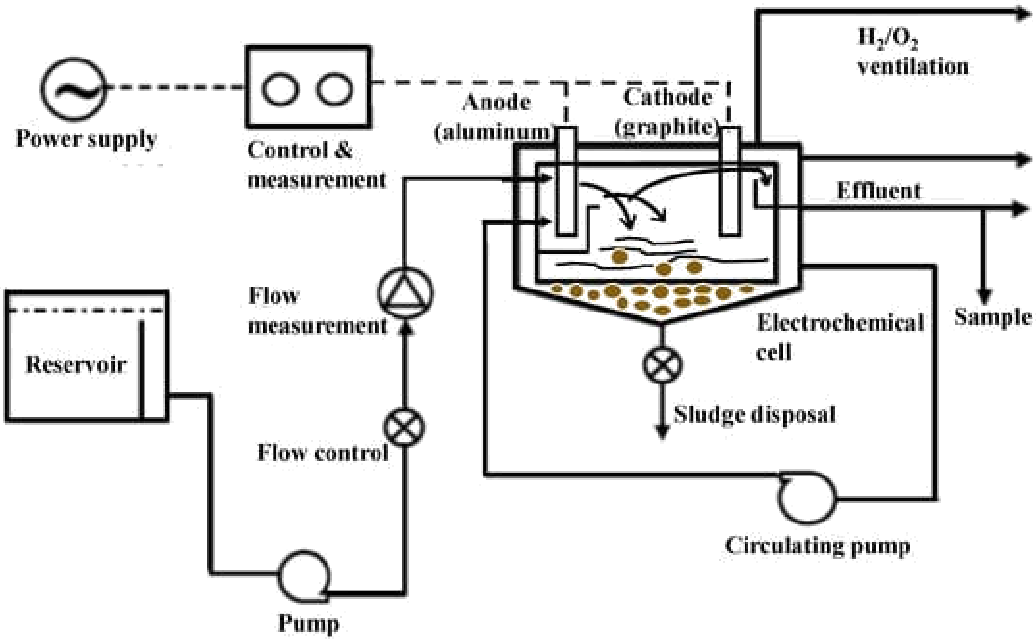

FIGURE 3: Schematics of electro-coagulation (Chien-Hung et al., 2020).

WATER STRESS IN AFRICAN NATIONS: TAPPING INTO WATER REUSE AS A SOLUTION

African countries are grappling with a growing problem of water stress, where there's a rising demand for water but limited availability (United Nations, 2019). Factors like fast population growth, unpredictable climate patterns, and ineffective water management worsen this situation, putting a heavy burden on water resources (Asante & Biney, 2018). To tackle this challenge, an encouraging solution is to explore ways to reuse water. African nations can ease the strain on regular water sources by using sustainable technologies to treat wastewater and safely reuse it (Qadir et al., 2010). Even though people usually see wastewater as a problem, when it's treated properly, it can become a valuable resource, especially for things like agricultural irrigation (World Health Organization, 2006). This not only saves fresh water but also helps prevent environmental pollution. The discussion covers the technological, economic, and social aspects of adopting water reuse, stressing the importance of having comprehensive policies, involving communities, and investing in infrastructure. This is crucial for unlocking the potential of water reuse as a practical and sustainable solution to the water stress challenges faced by African nations. By taking this approach, African countries can improve their ability to handle water challenges, ensure food security, and boost overall social and economic development.

RESOURCE RECOVERY INNOVATIONS AND CASE STUDIES OF WASTEWATER REUSE

Resource recovery innovations and emerging technologies in agricultural wastewater use are transforming the landscape of sustainable water management in Africa and Europe (UNESCO, 2021). Constructed wetlands, exemplified by the Czech Republic's implementation, utilize natural treatment systems with wetland vegetation to absorb and filter contaminants (Vymazal, 2011). Solar-powered drip irrigation, notably successful in Kenya, combines solar energy with drip irrigation to enhance water efficiency in Sub-Saharan Africa (Akhtar et al., 2012). Decentralized water reuse systems, piloted in South Africa, offer localized treatment, reducing dependence on centralized facilities and minimizing water transport needs (Winpenny et al., 2017). Spain's adoption of smart farming technologies, including IoT sensors, enables real-time monitoring of water quality and crop needs, optimizing water use in agriculture (Pérez-Martin et al., 2019). In Nigeria, biogas generation from agricultural waste through anaerobic digestion promotes sustainable resource recovery, providing both energy and nutrient-rich byproducts (Ogunkunle et al., 2019). Algae-based water treatment systems in the Netherlands (Lam et al., 2018) and rainwater harvesting practices in both Africa and Europe, such as Morocco's initiatives (Boujrouf et al., 2016), contribute to improved water quality and reduced dependence on traditional water sources. Precision agriculture incorporating drones, as seen in France, facilitates aerial surveys and data collection, optimizing irrigation and resource management (Lelong et al., 2008). These examples illustrate the diverse and practical applications of innovative technologies, showcasing their potential to address agricultural wastewater challenges and foster sustainable water practices in various regions.

- **Tshwane, South Africa**

Tshwane, South Africa's "Roodeplaat Water Reclamation Plant," exemplifies a successful largescale wastewater reuse program, treating municipal wastewater to high standards and supplying it to the local agricultural sector for irrigation, reducing reliance on freshwater sources. Naidoo et al. (2017) documented its success in addressing water scarcity and supporting local agriculture. While Tshwane's approach serves as a promising model for effective wastewater reuse, challenges like substantial initial investment may hinder adoption in other African and developing countries. To overcome these challenges, strategic approaches involve seeking international collaborations and financial support, implementing phased plans, and engaging communities for local acceptance. Capacity building and knowledge transfer initiatives empower communities to operate and maintain wastewater treatment infrastructure. These efforts align with the United Nations Sustainable Development Goals (SDGs), particularly Goal 6 (Clean Water and Sanitation) and Goal 2 (Zero Hunger). Leveraging Tshwane's success, other regions can contribute to these SDGs by establishing wastewater reuse programs, enhancing water sustainability, supporting agriculture, and fostering overall development.

- **Egypt**

In Egypt, the "Wastewater Use in Agriculture" program has been crucial for promoting the safe reuse of treated wastewater in farming. They've invested a lot in treatment facilities to make the water better, especially for irrigating fields in the Nile Delta and other farming areas. Interestingly, some of the treated water is used to water a big 400-acre park with fruit trees. This smart idea has really helped farming in Egypt, making more food and ensuring there's enough to eat, as shown by Bardossy (2008). Other African countries can learn from Egypt's success. By investing in treatment facilities and reusing water wisely, they can make more food, guarantee food security, and help the whole country develop. Egypt's achievements highlight the potential for many African nations to use similar water reuse plans, stressing the real benefits for farming and national progress. Learning from what Egypt did can help other countries make the most of water reuse, making them stronger against water challenges and supporting sustainable growth across the continent.

- **Valencia, Spain**

In Valencia, Spain, the "Tertiary Treatment of Urban Wastewater Project" stands out as a successful example of reusing wastewater in agriculture. This project uses advanced methods like membrane bioreactors and reverse osmosis to treat the wastewater thoroughly, creating high-quality reclaimed water. They use this water to irrigate the famous orange groves in the area. The success of this project highlights how using advanced technologies for treating wastewater can make sure the reclaimed water is safe and good for farming, as pointed out by Guerrero (2020). This achievement in Valencia is something that other African and developing countries can learn from. They can use similar advanced methods to treat wastewater, creating safe water for agriculture. However, it's important to recognize the challenges that might make it hard for these countries to adopt such technologies. These challenges could include the high cost of setting up and maintaining advanced treatment facilities, the need for skilled personnel to operate and manage these systems, and the overall infrastructure requirements. Overcoming these challenges will require careful planning, investment, and international collaboration to ensure that advanced wastewater treatment technologies can be effectively implemented in diverse socio-economic contexts. Learning from Valencia's experience can help developing nations navigate these challenges and harness the benefits of advanced treatment technologies for sustainable agricultural practices.

- **Sde Warburg, Isreal**

In a place with very little water like Sde Warburg in Israel, they are doing something special with their used water. They are treating the water that has been used in the city and using it to help grow important crops like grapes and pomegranates. This has made a big difference in two ways: more food is being grown, and they are not using as much fresh water. The case study looks really closely at how they are doing this and talks about how it's good for the economy and the environment. It says that using treated wastewater is really important for farming in places where there's not much water (Hoffman et al., 2019).

To do this kind of smart water treatment and reuse, there are important things to keep in mind. One is making strong rules about the quality of the water to make sure it's safe. This means using really good technology to clean the used water. It also means telling everyone in the community about these methods, making strong rules to follow, and checking regularly to make sure the water is clean and safe. Working closely with everyone involved is really important. This helps everyone agree on using wastewater in farming in a way that's good for the environment and can keep happening for a long time. This is super important, especially in places where there's not a lot of water (Ardakanian, 2016). This connects to an important goal called Goal 6, which is about having clean water and good sanitation for everyone. The case study in Sde Warburg fits this goal because it shows a clever way of using water wisely and safely for farming. For countries that are still growing and getting better, it's a good idea to do these things too. This means making strong rules about the quality of water and making sure everyone knows about them. Using good technology to treat wastewater, having strong rules to follow, and working closely with everyone involved is really important. Sometimes, things that might make it hard are not having enough rules, not enough technology, or people not agreeing on how to use wastewater in farming in a good way. So, it's really important to think about these things when trying to use wastewater in farming. This can help make farming better and safer, especially in places where there's not much water.

RISKS AND PLAUSIBLE BENEFITS OF WASTEWATER REUSE IN AGRICULTURE

Wastewater reuse in agriculture presents a contrast of risks and benefits. The environmental risks associated with the use of untreated or poorly treated wastewater in agriculture are substantial (Jaramillo & Restrepo, 2017). Such wastewater can contain a combination of contaminants, including pathogens, heavy metals, organic pollutants, and excess nutrients (Kretschmer et al., 2002). When applied to fields without adequate treatment, these pollutants can infiltrate the soil, leach into groundwater, and contaminate surface water bodies, posing serious threats to ecosystems, aquatic life, and public health (Zaidi, 2007). Moreover, the spread of pathogens through untreated wastewater can jeopardize food safety and lead to foodborne illnesses. Ganoulis, (2012) asserts that the excess nutrients in wastewater also contribute to nutrient overload in water bodies, leading to issues like eutrophication and harmful algal blooms.

The levels and types of pathogens and chemical substances in wastewater exhibit regional variations influenced by the sanitary and socioeconomic conditions of specific communities (Gerba, 2003). In developing countries, the concentration of viruses, protozoan parasites, and helminths in wastewater can be 10 to 1000 times higher compared to developed countries (Jimenez et al., 2010). Table 3 outlines the key enteric pathogens and substances of sanitary concern commonly identified in wastewater utilized for agricultural irrigation. This information underscores the diverse chemical and biological risks associated with the application of untreated wastewater in agriculture, emphasizing the importance of effective wastewater treatment processes to mitigate potential health and environmental hazards.

TABLE 3: Chemical and biological risks associated with the use of raw wastewater in agriculture.

Type of Risk		Pathogen
Biological	Bacteria [1]	*E. coli, Vibrio cholerae, Salmonella* spp., *Shigella* spp.
	Helminths [1]	*Ascaris, Ancylostoma, Tenia* spp.
	Protozoans [1]	*Intestinal Giardia, Crysptospridium, Entamoeba* spp.
	Virus [1]	Hepatitis A and E, Adenovirus, Rotavirus, Norovirus
	Schistosoma [2]	Blood-flukes
Chemical	The substance of sanitary interest	
	Heavy Metals [2]	Arsenic, Cadmium, Mercury
	Hydrocarbons [2]	Dioxins, Furans, PCBs
	Pesticides [1]	Aldrin, DDT

Data source: (Jones et al., 2021).

In contrast, Michetti et al. (2019) argue that the controlled and safe reuse of treated wastewater in agriculture presents several compelling benefits. This practice can significantly enhance crop yield and quality, especially in water-scarce regions, by providing a consistent source of irrigation water and valuable nutrients. Utilizing treated wastewater promotes water conservation by diminishing dependence on freshwater sources for agricultural purposes, a vital step in regions grappling with water scarcity. Additionally, according to Jaramillo and Restrepo (2017), responsibly using treated wastewater reduces pollution risks by either removing or significantly reducing contaminants and pathogens. This not only safeguards environmental and public health but also supports sustainable agriculture by encouraging efficient resource utilization and economic viability for farmers and communities. In essence, harnessing the benefits of wastewater reuse in agriculture while mitigating its risks hinges on ensuring proper treatment, regulatory oversight, and responsible farming practices, as underscored by Ofori et al. (2021).

ECONOMIC VIABILITY AND SOCIAL ACCEPTANCE

The implementation of advanced wastewater treatment technologies demands a thorough cost analysis, covering initial capital expenditures, such as equipment and facility investments, alongside recurring operational costs like energy, chemicals, labor, and maintenance (Ormerod, 2017). Despite the substantial upfront investments these technologies necessitate, they offer the potential for enduring advantages, including reduced environmental compliance costs, mitigated water resource depletion, and improved public health (Toze, 2006). Therefore, conducting a comprehensive cost-benefit analysis before their deployment is imperative to assess their economic viability (Campisano et al., 2017). Furthermore, the successful adoption of advanced wastewater treatment technologies hinges on social acceptance, a construct influenced by cultural, psychological, and community factors. Cultural values profoundly shape perceptions regarding water, sanitation, and environmental conservation, while psychological aspects like trust and safety significantly impact public acceptance (Wolsink, 2018).

Additionally, community viewpoints, encompassing local environmental concerns and property values, significantly mold opinions on these technologies. To cultivate social acceptance, transparent communication, active stakeholder engagement, and addressing concerns are pivotal (Ormerod, 2017). Achieving this necessitates a nuanced understanding of cultural, psychological, and community dynamics, underscoring the importance of continuous public engagement throughout the implementation process. This ongoing engagement establishes a robust connection between the technology and the communities it serves (Kalavrouziotis et al., 2015).

CONCLUSIONS AND RECOMMENDATIONS

In conclusion, this review underscores the critical importance of managing agricultural wastewater to protect water quality, ecosystems, and public health, particularly in light of evolving farming practices and increasing chemical use. Advanced wastewater treatment methods such as biofiltration, membrane bioreactors, and electrocoagulation show promise in effectively treating agricultural wastewater. However, their successful implementation requires a thorough cost-benefit analysis and the fostering of social acceptance through transparent communication and stakeholder engagement.

Case studies from diverse regions highlight the economic and environmental advantages of responsible wastewater treatment in agriculture. While acknowledging existing risks, these studies demonstrate that proper treatment can significantly enhance crop productivity, conserve water resources, and promote sustainable farming practices. In an era marked by water scarcity and environmental challenges, responsible agricultural wastewater management emerges as an indispensable component for ensuring the sustainability of agriculture and addressing global issues.

Despite the evident benefits, the adoption of advanced wastewater treatment technologies for agricultural reuse remains limited in many African countries. Various barriers, including financial constraints, limited technology access, and a lack of awareness regarding the benefits of these advanced treatment methods, contribute to the slow integration of innovative technologies. Many African nations face challenges in prioritizing immediate needs over long-term sustainability, hindering the widespread adoption of technologies such as biofiltration, membrane bioreactors, and electrocoagulation.

Overcoming these challenges necessitates collaborative efforts, international partnerships, and targeted capacity-building initiatives to empower local communities and governments to embrace these innovative solutions for wastewater treatment and reuse in agriculture. By addressing these barriers and promoting the adoption of advanced wastewater treatment technologies, African countries can enhance their water management practices, ensure food security, and contribute to overall social and economic development.

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DECLARATION OF COMPETING INTEREST

The authors declare no competing financial interests or personal relationships that could have influenced the work reported in this paper; there is no conflict of interest.

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