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Review

Recycled Wastewater Usage: A Comprehensive Review for Sustainability of Water Resources

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Abstract

Water recycling is a potential tool for reducing the dependency on traditional water sources, which would eventually reduce the likelihood of volumetric restrictions and their impacts on the water sector. Therefore, exploration, development, and use of alternative water sources are required for sustainable development. Scientific studies on the efficient and economical use of nontraditional water sources developed using the recycling process have attracted the attention of agriculturists, planners, and engineers for the last two decades. Recycled wastewater types, including greywater, sewage, stormwater, and industrial wastewater, have been discussed in this study. This article reviewed various forms of recycled wastewater, especially wastewater from treated sewage, and their effects on human health and irrigated environment. In addition, the necessity of exploration and usage of alternative sources of water in agriculture over traditional sources has also been reviewed. Legislations and guidelines of three major countries regarding the water recycling process and subsequent use have also been presented. The key finding of this article is that the agriculture and water recycling industry can only be connected sustainably when recycled wastewater complies with agronomical, environmental, and sanitary requirements. Because of the rapid advancements in wastewater recycling technologies, water recycling and recycled water usage have great potential to manage the increasing burden on freshwater resources. Finally, the sustainable use of recycled wastewater is crucial to minimize the negative effects on agriculture, the environment, and human health.

Keywords

Alternative water sources; greywater; industrial wastewater; recycled water usage; recycled water risk; stormwater

1. Introduction

The major aim of the United States 2030 Agenda is ending global hunger and establishing a sustainable agriculture system through proper optimization of inputs and resources used in the agricultural production system [1]. Water is one of the scarce natural resources essential for the functioning of the ecosystem services, environment, and living beings, including animals and plants [2, 3]. Water alone has a 25% contribution to improving crop productivity [4]. However, because of many reasons, including competition among end-users, population growth, and economic development, together with changing climatic patterns, pressure on the water sector is increasing worldwide [5, 6]. Approximately 57% of large-size groundwater aquifers have been overexploited to satisfy the water requirements of different end-users [7, 8]. A study indicated that the scarcity of freshwater resources in Mediterranean countries may cause permanent water scarcity in the region by 2025 [9]. According to another study [10], water availability in the global agricultural industry has decreased by 17% to satisfy the demand from various other sectors. On the basis of a survey of 900 recognized experts, the World Economic Forum indicated that the water crisis would have the highest level of societal effects in the coming decades [11]. Historically, the agriculture sector has been consuming water the most, utilizing nearly 70% of the global freshwater withdrawals; therefore, it is under constant stress from competitors to cut down its share [12-14]. Therefore, water is the central issue in the debate on development worldwide and requires the exploration of alternative water sources and their efficient use in irrigated agriculture for sustainability [11, 15-17].

Crop water requirements are primarily satisfied by using three sources: a) groundwater; b) surface sources, such as streams, rivers, wetlands, and reservoirs; and c) localized rainfall [18]. Groundwater represents the largest store of available freshwater [18, 19] and is more popular than other sources due to its reliable supply and ease of availability to individual farms [20-22]. Because of advancements in science and technology and subsequent improvements in drilling and pumping operations, groundwater irrigation has intensified globally since 1970 [20, 23]. A rough estimate indicates that 43% of the total worldwide irrigated area, i.e., 301 million ha is irrigated using groundwater with an abstraction rate of 600 to 1100 km^3 per year [24-26]. However, the rapid expansion in groundwater irrigation has led to groundwater depletion, aquifer deterioration, and groundwater quality degradation [19, 26-28]. Groundwater depletion is becoming a global problem, affecting the farming business in many famous agricultural production regions. To minimize the effects of groundwater depletion, alternative sources of water, including rainwater and recycled wastewater, must be made available to farmer's fields [29, 30]. The rate of groundwater recharge in arid and semiarid regions is less; therefore, in the absence of alternative sources of water, groundwater withdrawals can exceed aquifer recharge and can result in serious degradation of water quality [23, 25].

To manage the pressure from competitors, the agriculture industry has been compelled to explore alternative water sources and to improve efficiency, particularly physical and economic water productivity, together with fertilizer use efficiency [4, 31]. Because of the increasing water demand and expected reduction of freshwater availability in the future, some studies [14, 32, 33] have recommended identifying alternative or nontraditional sources and adopting novel water management strategies for saving water while maintaining satisfactory levels of crop production. Most agricultural operations do not have direct access to municipal water supply; therefore, consideration of alternative sources of water is essential [34]. Water can be derived from several sources, including surface water (rivers and creeks), groundwater from bores and aquifers, rainwater, and treated wastewater. However, water quality varies among sources, thereby affecting soil health and the crop development process, especially when a quality parameter rises above the recommended range. The quality of irrigation water is defined by certain physical, chemical, and biological characteristics, and the frequent problems resulting from irrigation using poor quality water are salinity, sodicity, low permeability, and toxicity [35-37].

A major constraint in crop production, particularly in developing countries and those with less natural rainfall, is the availability of enough water with optimal quality [38, 39]. Certain drivers, including urbanization; population growth and industrialization; and corresponding increases in the demand for food, energy, and environmental sustainability; have seriously impacted the existing water planning, management, and allocation processes [40, 41]. The changing rainfall patterns due to global warming and climate change, the pressure of the growing population, and the increase in competition among sectors (e.g., municipal and industrial) are driving the agricultural sector to explore additional and more sustainable water sources [42, 43]. In addition, the rapidly changing quality of irrigation water warrants closer attention to understand and predict long-term effects on soils and food crops in an increasingly freshwater-stressed world [44]. In the context of increasing stress on water sources, such as surface water and groundwater, alternative sources for irrigation in arid and semiarid regions must be explored; the most promising option could be treated wastewater produced in urban centers [45]. To minimize the challenges and pressure on freshwater resources, research on all dimensions of water, including exploration, development, and management is required.

2. Major Sources of Water for Recycling

Studies have indicated that wastewater is derived from industrial, domestic, and stormwater [46-48] (Figure 1). Treatment of wastewater to a level required for its intended use results in the production of recycled water (RW) [47, 48]. A study [48] estimated that 359.4×10^9 m^3 of wastewater is generated annually worldwide; of which, approximately 52% is treated. The use of RW is associated with substantial benefits and has been applied to areas such as agricultural irrigation, groundwater recharge, landscaping and parkland watering, toilet flushing, and construction activities [30, 49]. The use of RW could be a latent strategy in the management of global freshwater scarcity [50]. The following subsections (2.1 to 2.3) present a brief review of the types of recycled wastewater and their implication.

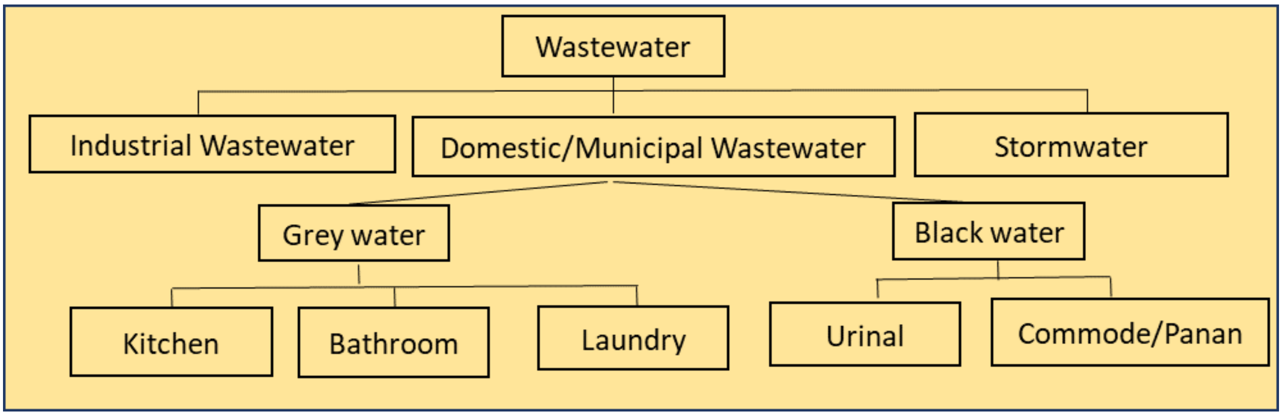

Figure 1 General classification of wastewater.

2.1 Industrial Wastewater

The wastewater generated from industries is commonly known as industrial wastewater and contains heavy metals, metalloids, and volatile or semivolatile compounds [51, 52]. The rapid population growth has led to increased production of goods, thereby causing rapid industrialization. Moreover, the economic growth and long-term poverty reduction of any country are impossible without industrialization. However, rapid industrialization is responsible for increasing wastewater, which is a major source of water pollution [52]. Industrial wastewater is mostly untreated or partially treated when it is discharged into the water bodies, thereby causing water-borne diseases in humans and negative effects on the ecosystem [53, 54]. A substantial footprint and various other hazards are caused when industrial wastewater is released into the environment [54].

In 2018, WHO and UN Habitat reported that approximately 59% of domestic wastewater is reused with some level of treatment; however, the information on industrial wastewater remains unknown because of insufficient studies. The wastewater produced from one industry can be reused directly or after necessary treatment by other industries; therefore, symbiosis might become an alternative to managing industrial wastewater [55, 56]. The hybrid ozonation process is successful for industrial wastewater treatment, where organic pollutants are degraded and mineralized by using ozone, a strong oxidant [57]. The membrane technology is widely used for industrial wastewater treatment. A study [58] confirmed that 580 membrane plants have been established in China for industrial wastewater treatment. Similarly, several treatment technologies have been identified and used for industrial wastewater according to the type of contaminants in the discharge. Two studies [59, 60] briefly explained different methods of removing contaminants, especially heavy metals, from industrial wastewater. The methods include physiochemical methods, chemical precipitation, coagulation and flocculation, electrochemical treatments, ion exchange, membrane filtration (such as ultrafiltration, polymer-supported ultrafiltration [PSU], and reverse osmosis [RO]), and biological methods. Physiochemical treatment is rapid, easy to operate and control, and cheaper; however, the operational cost remains high because of the chemical used in the process, the consumption of high energy, and the added cost of toxic sludge disposal. By contrast, the biological method has huge potential in industrial wastewater treatment as it is effective and economic, both in construction and in operation; moreover, it is proven to be environmentally friendly.

2.2 Stormwater

Stormwater is the runoff from precipitation (storm) or occurs after the melting of snow if it does not infiltrate into the ground. Stormwater collects most of the pollutants, such as sediment, oil and grease, leaves, animal dropping, and dissolved chemicals, from exposed soil, roads, gutters, lawns, and gardens; the process disturbs the original river flow; changes flooding patterns; increases flow velocity, turbidity, and erosion; and invites natural disaster [47]. Stormwater harvesting has emerged as a viable alternative source of water, which may be used in different sectors after suitable treatment or filtration [61, 62]. Because stormwater was considered a waste, quick disposal of runoff was the focus for most of the 100 years prior to the 1960s [63]. Subsequently, the source control principle or “water-sensitive urban design” was initiated in Australia and other parts of the world, with a focus on stormwater quality improvement devices, low-impact urban development and design, integrated urban water management, sustainable urban drainage systems, best management practices, and stormwater management and reuse [63].

A higher fraction of impervious surface and channelized flow because of urbanization has enhanced the peak runoff [64], resulting in negative consequences, such as a high risk of urban flooding [65], deterioration of water quality in most recipient water bodies [66], and damage of urban ecological environment due to bank or bed erosion [67]. A study analyzed 20 samples from three separate urban storm sewers [66] and identified 55 chemical substances among 88 monitored substances. These pollutants were gross pollutants (particles >5000 µm), suspended solids, microorganisms (protozoa and bacteria), nutrients (N and P), metals (Cr, Cu, Ni, Pb, and Zn), and toxic organic oils and surfactants [64].

Urban stormwater harvesting and the adoption of suitable measures for its safe use could control the adverse environmental impacts of stormwater runoff. Water-sensitive urban design is an emerging approach to urban stormwater management and includes the construction of wetlands, bioretention, and green roofs that closely mimic the watershed’s natural ecological and hydrological functions [68]. A study [69] evaluated the global policy associated with low-impact development (LID) practices in stormwater management in urban regions and discovered that the driving forces and attitudes in LID implementation vary worldwide. For example, in the western region like the United States, the restoration of water quality is crucial, whereas in the eastern region like China, flood prevention and rainwater harvesting are emphasized. A study [70] reported that a blue-green infrastructure is an ecosystem-friendly tool for the sustainable management of urban stormwater. Through this infrastructure, the stormwater quality and quantity can be managed using a biological process that involves detention, storage, infiltration, and biological uptake of pollutants.

Sustainable city planning is crucial to mitigate stormwater runoff; however, several challenges remain to be resolved. Green roofs or the rooftop plant production system is an emerging strategy to mitigate stormwater in the city [71]. Here, the flow of rainwater from the rooftop to the street is controlled through the absorbance of rainwater by growing either ornamental plants or food crops in raised beds, row farming in open planting, or a hydroponic greenhouse. A study [71] observed that approximately 40% of rainwater could be retained by an open green roof planting system, which covers 80% of the roof in any given location. Another study [72] observed that approximately

73% of rainwater was retained by green roofs and concluded that because of warm and dry climatic conditions, the average retention in their experimental modules was higher than that in similar green roof studies, where rainfall retention was 5% to 80%. A study [73] suggested that a drier climate causes the retention of a greater percentage of cumulative stormwater through green roofs compared with identical green roofs installed in humid regions. The study also emphasized that antecedent moisture condition is a suitable predictor of stormwater retention performance in any climate. The study further concluded that green roofs retain 16% to 29% of their precipitation in storms greater than 45 mm. Another study [74] explained a settle sediment method for removing pollutants in stormwater, where solids entrained in runoff could be easily removed either by filtering or setting.

The harvested stormwater has tremendous beneficial uses, such as irrigation, drinking, washing, bathing, cooling, and flushing. According to a study [75], the growth of vegetable crops is not affected by stormwater treated using biofilters. Moreover, the accumulation of heavy metals was within the edible range; however, Cd and Pb concentrations exceeded the WHO guidelines. A study [76] reviewed the perspectives of water treatment residual (WTR) in removing pathogens from stormwater, indicating the potential application of WTR. Another study [77] suggested that water from vertical subsurface flow systems constructed on the wetland for the first flush of stormwater, can be reused for irrigation purposes. A study [78] mentioned that urban stormwater in the US and globally has successfully met the nonportable water demand; however, the uncertainty in the treatment and water quality remains a challenge in the wide-scale adoption of treated stormwater.

2.3 Domestic Wastewater

Wastewater generated from household activities is known as domestic wastewater, which primarily includes greywater and black water. Section 2.3.1 critically reviews greywater, whereas the rest of the sections highlight different dimensions of sewage derived from toilets, i.e., black water.

2.3.1 Greywater

Greywater is the wastewater from baths, showers, hand wash basins, laundry, dishwashers, and kitchen sinks [79]. The National Aeronautics and Space Administration first treated and reused greywater in 1975 [80]. Since then, greywater has been commercially available and used in different applications, especially in countries facing water scarcity, including Australia, Japan, and Israel. In particular, greywater has been used in garden watering, toilet flushing, and vehicle washing. The quality of greywater depends on the household characteristics, such as the number of family members, age, lifestyle, health status, water usage pattern, and cleaning and personal care products. Therefore, the risks associated with greywater also vary accordingly. Because greywater contains several contaminants, including fat, oils, food scraps, nutrients, salts, sodium, phosphorus, detergents, and cleaning products, their cumulative effect on soil and plant life might be severe if they exceed the recommended limit [79, 81]. Therefore, the possible risks and impacts of greywater on soils, garden plants, and the surrounding environment must be monitored.

Proper treatment and usage of greywater is an alternative solution to water scarcity; moreover, it would reduce the pollution of surface water and groundwater caused by greywater discharge [80, 82]. However, greywater treatment and its sustainable use with a minimum hazard require a combination of careful management and appropriate user education [83]. Moreover, for the conservation and protection of the gardening environment and the betterment of residential gardens, a field-based risk assessment of greywater should be performed [81]. Several studies in Australia and overseas have evaluated community views on effluent reuse, but research on greywater reuse remains limited [84, 85]. A study indicated that the major risks associated with greywater garden irrigation are salinity and sodicity, whereas minor risks are toxicity, acidity, and alkalinity [86]. Although the contribution of treated greywater to demand-side water management is like a drop of water in a bucket, it can induce changes in the efforts for the sustainability of the most precious resource, water.

The major focus of this paper is wastewater generated from toilets (black water); therefore, the next section presents a detailed review of different dimensions of treated effluents, with respect to agriculture and humans.

3. Risk Analysis for the Reuse of Recycled Wastewater

Israel is the pioneer in the development and reuse of wastewater (effluents) for irrigation [14, 87]. The use of recycled wastewater in agriculture has been studied extensively worldwide to understand its applicability as an alternative source of water. Reports have demonstrated that recycled wastewater usage has several advantages for farmers, such as nutrient supplementation, substantial savings of chemical fertilizers, and improvement of crop productivity and quality [14, 40]. Treated municipal wastewater is a sustained irrigation source in places with limited access to freshwater, such as the Mediterranean region, Australia, and the Middle East [88-91]. However, soil and groundwater characteristics might change with the long-term usage of recycled wastewater in agriculture [9, 51, 92]. This would lead to the overloading of the agricultural land with nutrients or salts, thereby causing soil degradation, reduced soil permeability, and an altered soil pH [35]. A study [9] investigated the effects of municipal-treated wastewater on lemon produced in arid environments and provided two major recommendations for sustainability. First, the tertiary treatment of wastewater should be performed for agricultural purposes. Second, recycled wastewater should be integrated with freshwater to minimize the possibility of harmful metalloids in the soil strata and the subsequent deposition in plant tissues.

Most studies related to the water recycling process have indicated that the risks of recycled wastewater usage should be analyzed from two perspectives, i.e., human health and environmental effects [87, 90, 93-95]. A study [96] classified biological and chemical risks as the major threats in the application of reclaimed wastewater. Furthermore, another study [97] suggested that the challenges to be addressed for overcoming the reluctance of urban users to use recycled wastewater are cost and human health issues. An analytical review of different risks associated with recycled wastewater and its consequences on humankind and irrigated agriculture as some guidelines related to recycled wastewater usage has been presented in subsections 3.1 to 3.3.

3.1 Risks to Human Health When Irrigation With Recycled Wastewater

The likelihood of human disease due to irrigation with secondary or tertiary treated wastewater is less [98]. However, a study [99] noted that because a large number of enteric viruses and parasites are present in raw sewage, disease-causing organisms may survive and be reintroduced into environments with chances of direct human contact. In particular, skin and nail problems might occur among farmers using wastewater [46]. In many countries, women play an important role in farming, thereby being vulnerable to the risks of recycled wastewater. Women usually cook meals for their families; therefore, these pathogens may be transmitted to their family members. Moreover, a study [100] noted that approximately one-half of the farmers had had their family members facing skin problems, such as itching and blisters on the hands, feet, and lower legs.

The risks of recycled wastewater usage in humans depend on many factors, such as the method of irrigation used, the type of crop irrigated, and the time elapsed between irrigation and consumption. A study indicated that the health risks from irrigated crops are greater when spray or sprinkler irrigation is used [46]. By contrast, another study [101] reported that the risk of enterovirus infection was in the range of 10^{-4} to 10^{-7}, and the risk to field workers was the maximum when flood or furrow irrigation was used. In Israel, because of high restrictions on recycled water used for irrigation, specific crops without any direct or indirect health risks to humans, such as watermelons (irrigated only before blooming), groves of flora without human access, and fruits that are dried in the sun for at least 60 days after last irrigation, are preferred [102]. A study [103] estimated 6 log reductions of virus levels between irrigation with wastewater and crop consumption if the total time elapsed reached 3 weeks. Another study indicated that each day delay between wastewater application and harvest reduces pathogens (bacteria, protozoa, and viruses) by at least 1 log in hot and sunny weather [104]. Consumption of raw vegetables irrigated with recycled wastewater might also pose a risk to human health. Various risk assessments have been performed on the health impact due to the ingestion of raw vegetables irrigated with sewage. A study indicated that among vegetables, such as cucumber, lettuce, carrots, broccoli, spinach, and cabbage, the ingestion of lettuce poses the highest risk of infection [105]. Therefore, these risks should be minimized through the application of appropriate legislation or guidelines for safe water usage and tertiary level of wastewater treatment, including dissolved air floatation technique.

3.2 Risks of Recycled Wastewater Irrigation to the Environment

The soil–plant–water relationship is disturbed when the irrigation source does not maintain the minimum quality standard required for crop production. The physical, chemical, and biological constituents of recycled wastewater determine its usage for agricultural purposes [106, 107]. Long-term watering with recycled water and overloading the agricultural land with nutrients can degrade the soil structure, decrease permeability, and change soil pH levels [81]. Therefore, to assess the risks associated with reclaimed water and its impacts on crop production, the following issues should be thoroughly discussed.

3.2.1 Salinity

Salinity is a major problem that should be considered by irrigation industries when using recycled wastewater [35]. Physiological drought, nutritional imbalance, and mineral toxicity are caused by high salt content in the soil [50]. This is because of less water availability to the plants resulting from the osmotic inhibition of water absorption and competition among salt ions [94]. The accumulation of excess salts in the root zone, resulting in a partial or complete loss of soil productivity, is a worldwide phenomenon. Globally 11%–30% of the irrigated area is affected by some degree of salinity [12]. Soil salinity is a widespread issue mainly in arid and semiarid regions; however, it is detected in subhumid and humid climates also [108]. Therefore, salinity is a serious issue in the irrigated arid and semiarid regions of the world, and according to a study [108], increasing agricultural production to satisfy food requirements is essential in these very regions. Approximately 80% of the total cropped land in the world, which is equipped for irrigation, lies in arid and semiarid subtropical zones [109]. As competition for available freshwater intensifies and recycled wastewater usage increases to fulfill concrete water recycling, a key question regarding soil quality management arises [110]. Salinity risk with recycled wastewater irrigation increases when poor fertigation and poor irrigation management are combined [110]. Therefore, facilities of either leaching to subsurface drains or deep percolation below the root zone should be provided to protect soil health from excess salinity, especially in greenhouses.

3.2.2 Sodium Hazard

High sodium concentration causes soil dispersion and swelling, which reduces infiltration rate and causes excessive runoff or waterlogging. When treated effluents with a sodium adsorption ratio (SAR) of more than 9 is applied over a long-time on agricultural lands, severe permeability problem occurs in the soil [90, 98]. According to two studies [111, 112], the use of recycled wastewater because of water stress conditions increase the SAR value. Sodicity is a major issue caused by recycled wastewater irrigation [90, 113]. Scientific studies have demonstrated that a significant reduction in hydraulic conductivity occurs when the exchangeable sodium percentage is high and the total percentage is low. Irrigation water with an electrical conductivity (EC) of >0.75 mmho/cm and SAR <8 does not pose a health risk. However, water with EC of 0.75 to 0.3 and SAR of 9 to 10 may pose increased health risks, with the risk being severe when the EC <0.2 and SAR >10 [114].

3.2.3 Heavy Metal Hazards

Plant tolerance to excessive concentrations of certain elements remains limited. The main toxic elements present in treated municipal effluent are sodium, chlorine, and boron. Chlorine ≥355 ppm and boron ≥2 ppm may produce toxic effects on plants, including severe foliage damage, impaired growth, changes in plant morphology, and even complete death [115]. However, the degree of damage depends on the crop, the growth stage, the toxic ion concentration, climate, and soil conditions [115]. The American National Academy of Sciences recommends that any water used for irrigation should not contain more than 0.01, 0.2, 0.2, and 2 ppm of Cd, Cu, Ni, and Zn, respectively; concentrations exceeding these limits may cause toxic effects in agricultural soil and plants. Therefore, the concentration of these ions should be determined to assess the suitability of wastewater quality for agricultural use. Recycled wastewater use in agriculture can have negative effects that are determined by the treatment level; these effects include a risk of residual heavy metals, such as Cd, Ni, and Pb, in soil and phytotoxicity [116, 117]. Furthermore, these heavy metals might enter the food chain, leading to health hazards in humans and animals [90, 93].

3.2.4 pH

Water pH outside the recommended range creates extreme alkalinity or acidity conditions in the soil, thereby affecting plant production. The desirable soil pH for most agricultural plants is 5.5 to 7.0, whereas the normal pH range of municipal wastewater is 6.5 to 8.5; however, industrial waste can alter soil pH significantly [118, 119]. The continuous application of wastewater changes the soil chemistry, including residual nutrient content and soil pH [4]. Therefore, a detailed analysis of water quality before applying to agricultural lands is always recommended, and a pH outside the appropriate range should be carefully monitored and managed.

3.2.5 Nutrient Content

Recycled wastewater has high nutrient content, which may sometimes harm soil and crop health. Runoff from lands irrigated using recycled wastewater with high nutrient contents to adjacent areas is problematic because of several negative effects, such as algal bloom, runoff water contamination, and drain contamination [120]. In addition, over-irrigation with recycled wastewater results in excess groundwater recharge, waterlogging, and secondary salinity. Nitrate percolation is the major cause of groundwater contamination.

The major risks associated with recycled wastewater usage in agriculture are salinity, sodicity, toxicity, acidity, and alkalinity. Some of these are severe; however, most are manageable if proper management techniques are applied. The value of recycled wastewater is well recognized; however, success depends on the minimization of risks associated with nutrient and salt loading through irrigation. A study [96] confirmed that recycled wastewater has the potential to reduce reliance on freshwater resources, thereby reducing the likelihood of volumetric restrictions and their impacts on the agricultural sector. According to another study [80], wastewater treatment and the use of recycled wastewater significantly reduces the present and future burden on freshwater resources; however, wastewater treatment can pose sanitary questions and impact human health as well as the environment in general. The study also recommends that these questions should be answered properly through suitable practices, legislations, and regulations to minimize the negative impact on acceptable standards. The application of treated effluent in agriculture has a long history and requires strong management decisions, including regulations and guidelines for its successful use in crop production [6]. In summary, the sustainable use of recycled wastewater in agriculture can occur only when recycled wastewater complies with agronomical, environmental, and sanitary requirements. Because of the rapid advancements in wastewater recycling techniques, water treatment and reuse have great potential in managing the increasing burden on freshwater resources.

3.3 Key Examples of Recycled Wastewater Regulations and Guidelines

The use of treated wastewater for agricultural purposes is increasing globally, with governments emphasizing revising their regulations to manage the accompanying public health, environmental, and economic risks. Legislation and guidelines on treated effluent must adopt a holistic approach to water treatment processes. These guidelines and legislations are crucial because they help protect human health and the natural ecosystem, as well as increase the opportunity for water availability [107]. The following paragraphs describe the legislation status in three major countries with high usage of recycled wastewater for agricultural purposes.

To minimize the adverse effects of recycled wastewater on soil, crop, and human health, guidelines for the safe use of wastewater in agricultural production have been established in every country and most capital cities of developed countries. In Australia, the Environmental Protection and Heritage Council, the Natural Resource Management Council, and the National Health and Medical Research Council have developed guidelines for the safe use of recycled wastewater [121].

In 2006, the first phase of new Australian guidelines for water recycling, titled Australian Guidelines for Water Recycling: Managing Health and Environmental Risks, was published under the National Water Quality Management Strategy. Recycled wastewater is classified into four categories in Australia, namely A, B, C, and D; moreover, irrigation is further classified as restricted agricultural irrigation, unrestricted agricultural irrigation, restricted urban irrigation, and unrestricted urban irrigation [122, 123]. The most used recycled wastewater in irrigation is the Class A type, which is produced using advanced treatment processes, such as DAFF, and is suitable for unrestricted irrigation to all crops and fodder [124]. The guideline is based on a risk management approach and explains that through a combination of careful management, appropriate use, and education to end users, wastewater can be reused safely and sustainably.

The United States Environmental Protection Agency (USEPA) developed Guidelines for Water Reuse in 2004 on the basis of data generated by research, development efforts, and extensive demonstration projects worldwide [125]. The guideline is divided into eight chapters that cover water reclamation for non-potable urban, industrial, and agricultural reuse; augmentation of potable water supplies through indirect reuse; and recycling as an effective means for conserving limited freshwater supplies. The guideline has described the status, prospectus, and challenges of using recycled water in irrigation by dividing irrigation into four groups, namely restricted agricultural irrigation, unrestricted agricultural irrigation, restricted urban irrigation, and unrestricted irrigation. Moreover, the guideline suggests adopting a suitable management approach, primarily because of the excess salt content and sodium hazard of recycled water.

In Israel, the Environmental Protection Committee approved the effluent quality standards in 2010 to protect public health and prevent water resource pollution by wastewater effluents [126]. Regulations have been upgraded six times since 2000 and include maximum levels for dissolved and suspended elements (for example, sodium adsorption ratio and total dissolved solids) for unrestricted irrigation and waterway discharge. According to Environmental Protection Ministry, the objective of the 2010 regulation is to treat 100% of the country’s wastewater to a level that would enable unrestricted irrigation in accordance with soil sensitivity and without risk to soil and water resources.

In summary, regulations and guidelines for recycled wastewater usage in various countries have set the optimum range of all parameters required to maintain soil properties and crop performance. Values recommended by all referred guidelines are almost similar; however, the methods and procedures of setting these target values are not mentioned anywhere. All guidelines recommend soil testing as a pivotal point before, during, and after installing a wastewater system in each agricultural land or garden to identify the possible risks. However, the standard guidelines alone are not enough unless they are effectively implemented and updated as per requirements. A robust mechanism for enforcing all the regulations, including monitoring and supervision, the authority to conduct inspections, and the power to assess penalties for violations, is mandatory for safeguarding the stated guidelines sustainably. Recycled wastewater irrigation is a growing agricultural practice and inevitable process, thereby requiring special focus to optimize its benefits [127].

4. Outlook

Water recycling has great potential to reduce the dependency on traditional sources of water, thereby reducing the likelihood of volumetric restrictions and their impacts on the agricultural sector. However, the negative effects of recycled wastewater usage on humans and the environment should be managed by applying suitable practices, legislations, and regulations; this would minimize its negative impact on acceptable standards. Risk assessment of recycled water types, including industrial water, greywater, stormwater, and treated effluents from sewage, should be performed in an integrated manner to analyze the entire system from source to end use, leading to a clear definition and understanding of all elements. In addition, relevant studies have indicated that hydraulic loading of recycled wastewater is higher than other sources of irrigation; therefore, a detailed analysis of the leaching requirements should be undertaken before the use of recycled wastewater for irrigation. Furthermore, recycled wastewater can play a pivotal role in managing freshwater scarcity to a large extent. Therefore, more studies should be performed to collect scientific data for increasing the public acceptability of recycled wastewater.

5. Conclusion

In this review, different dimensions of recycled wastewater, such as its type and risks associated with human health and the natural environment, have been critically analyzed. The demarcation of appropriate ranges of water quality parameters during the selection of a water source for crop production is crucial, especially when an alternative water source is under consideration. Therefore, the physical, chemical, and biological characteristics of the water source should be evaluated before applying it in fields to avoid adverse effects on the soil-water-plant relationship. This article agreed with the published studies identifying two types of risks associated with recycled wastewater usage. The major risks associated with reclaimed water in the agriculture sector are salinity, sodicity, and toxicity. The salinity and sodium hazards should be evaluated before using recycled wastewater to minimize adverse effects on soil, environment, and crop production. Through a combination of careful management, appropriate use, and education to end users, wastewater can be recycled safely and sustainably. In summary, this article is in agreement with the conclusion of a study [127] stating that discharge standards, whether for irrigation with reclaimed water or for disposal into waterways, must be based on existing capable and affordable wastewater treatment technologies. This would facilitate the application of recycled wastewater in real situations, thereby protecting the environment and public health.

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