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Safe Utilization of Treated Water in Agriculture

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Abstract

Safe use of treated water in agriculture can ensure food production that is sustainable and alleviate concerns about water scarcity. As a result of widespread worries about pollution, urbanization, population growth, and the purity of water, agriculture is depending more and more on alternative water sources. This comprehensive study explores the proper use of treated water in agriculture, emphasizing the complex relationship that exists between water quality, technical improvements, environmental protection, and regulatory framework. Physical, chemical, and biological factors are all included in the examination to give a detailed understanding of water quality standards. Water treatment techniques aim to remove impurities, dangerous microorganisms, heavy metals and extra nutrients from water to guarantee its purity. It looks at the effects on environment, public health and economy with particular emphasize on soil quality, plant growth, water resources and microbial communities. Risk assessment is crucial to verifying that treated water is efficiently utilized for agricultural purposes. Routine monitoring and evaluations are vital to assure these rules are being followed, and how important it is to run public awareness efforts to reduce fears and encourage the use of treated water in agriculture. More research is crucial to fully grasp and assess the potential risks and advantages of using treated water in the agriculture. By integrating the most recent advancements in risk assessment methods, water treatment technologies, and safety regulations, it is possible to provide a secure, long-lasting, and expanded water supply for agricultural purposes while also minimizing water shortages and reducing environmental effects.

Key words: treated water, agriculture, safe use, sustainable food production, water scarcity, quality standards, treatment

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1. Introduction

It is vital to investigate alternative sources of water for use in agriculture due to the limited availability of water resources and the growing need for food production. As treated water passes through wastewater treatment facilities (WWTPs), it is cleaned to remove contaminants and meet quality standards. It helps preserve priceless freshwater resources and eases the strain on freshwater sources used for irrigation in agriculture. The quality of treated water, potential hazards, legal frameworks controlling its use, and best practices are some of the key elements of the safe use of treated water in agriculture. It aims to provide a broad overview of these elements and their roles in promoting sustainable and safe agriculture practices. The suitability of treated water for agriculture is largely dependent on its quality. Important variables that affect this include the levels of pH and alkalinity, total dissolved solids (TDS), electrical conductivity (EC), nutrient contents (phosphate, nitrate), heavy metals (like mercury) that can be harmful to humans if consumed in excess, and microbial contamination from pathogens, dangerous microorganisms and bacteria species like *Escherichia coli* [1].

Ensuring that treated water fulfills the required quality criteria for safe agricultural use requires routine testing and monitoring of the water's quality. Despite the fact that treated water is usually cleansed, utilizing it in agriculture still has some dangers. The principal issues include the buildup of salts or other unnecessary materials in soil as a result of extended usage of treated water, microorganism contamination, and leftover chemicals from the treatments. The aforementioned concerns emphasize the necessity of implementing suitable control measures, such as efficient water treatment techniques and health monitoring systems, to alleviate the potential risks and guarantee the safe utilization of processed or treated water. At the national, regional, and international levels, among others, regulatory frameworks and recommendations pertaining to agriculture have been produced. To ensure the safe use of this type of water in agriculture, frameworks and recommendations have been developed at several levels, including national, regional, and international organs. These regulations establish guidelines for quality standards, pollutant content measurement techniques, and sanitation procedures. Respecting these guidelines is essential to safeguarding public health, preserving the environment, and maintaining the purity of agricultural goods [2].

2. Background on increasing demand of treated wastewater use in agriculture irrigation

There is a notable increase in the need for treated water in the agriculture industry due to many factors. Water scarcity, urbanization, population increase, and climate change are some of the main causes. The necessity for food production rises in response to the population's growing needs, as urbanization and population growth. Particularly in developing countries, urbanization is rising swiftly. UNDESA (2008) projects that between 2010 and 2030, there would be an increase in the number of people living in urban areas worldwide, from 254 million to 539 million in lower-income countries and from approximately 2.59 billion to 3.99 billion in developing countries. This puts pressure on farming methods to improve in productivity and efficiency. Freshwater available for irrigation is decreased as a result of urbanization, which turns agricultural land into urban areas. Many factor contributes to the agricultural industry growing need for treated water. Urbanization, population increase, climate change, and water scarcity are the main contributors. In order to maintain food production, treated water becomes more and more necessary as urbanization and population growth drive up food demand. Treated water allows for water resources reuse, addressing the water scarcity caused by climate change [3-6].

Climate Change's influence on precipitation patterns is increasing the frequency and severity of droughts, leading to agricultural water shortages. Treated water offers a dependable and different source of water for irrigation, making it a valuable resource in times of water scarcity. These modifications may cause traditional agriculture to be disrupted by extending the dry seasons. Promoting the sustainable use of treated water systems is one strategy to lessen dependency on freshwater resources. It guards against excessive groundwater abstraction and aids in maintaining environmental equilibrium. Long-term agricultural sustainability depends on optimizing water use, which can only be achieved with improved irrigation systems. The trend of reusing water in agriculture is being encouraged by environmental organizations and governments. Recommendations and regulations have been put into place to promote irrigation using treated water. A growing number of agricultural activities are employing treated water as a result of incentive programs and incentives. Due to developments in water treatment technologies, irrigation for agriculture is now more economical and efficient. As a result, farmers now have much simpler access to clean water. Reverse osmosis, membrane filtration, and ultraviolet disinfection are some of the technologies that produce high-quality treated irrigation water. Finances: Reclaimed water has the potential to be more cost-effective than regular water. Long-distance water transportation requires affordable supplies [7].

3. Objectives and scope of safe utilization of treated water in agriculture

The primary goal of secure utilization of treated water in agriculture is to foster sustainable and responsible practices for use of wastewater or reclaimed water for irrigation and other agricultural uses. It addresses the global situation and methods of reusing treated sewage water for agricultural irrigation, emphasizing the effects on the environment, human health, and the economy. It draws attention to the risks connected to food production, public health, soil fertility, and economic variables. These goals encompasses multiple dimensions. The main aim is to make sure that treated irrigation water used in agriculture doesn't include any chemicals that can be bad for the environment or human health. This entails conducting water quality tests and putting in place suitable treatment procedures to get rid of or lessen possible hazards. Use of processed water helps in decreasing the amount of freshwater required by agriculture, thus saving regional water supplies. This becomes especially crucial in areas when water scarcity or other types of stress are being experienced. By allowing farmers to continue their operations during periods when their access to clean freshwater is typically restricted, safe use of treated water aims to promote sustainable agricultural practices. Reusing treated wastewater can improve soil fertility, maintain crop yields, and reduce dependency on freshwater resources. Securing local, national, and worldwide regulatory compliance is ensured by using safe utilization procedures for treated water in agriculture. This adherence lowers potential hazards related to the use of treated water, protecting the health of crops, animals, and customers. According to the goals and parameters stated, the responsible use of treated water in agriculture promotes efficient and diligent water management techniques while reducing the negative impacts on the environment and public health [8].

4. Quality standards for irrigation water and monitoring

4.1. Techniques and tools for monitoring and assuring the quality of water in treated water

Secure implementation of water quality standards necessitates advanced technologies and reliable monitoring techniques. The following techniques are frequently used to check the quality of treated water. Nonetheless, the most important factor in predicting, controlling, and minimizing soils damaged by salt is the quality of the irrigation water being utilized. Irrigation water quality can affect crop yield and soil characteristics, but it can also affect the need for fertilizer, the efficiency and durability of irrigation systems, and how much water is used. Thus, understanding irrigation water quality is essential to deciding what management changes are needed for long-term output [9].

4.1.1. Physical parameters

Ensuring the safety of treated water for use and consumption requires the establishment of physical parameters. The list that follows offers comprehensive details on a few important physical parameters. Field kits and portable meters are used to measure parameters. pH (concentration of hydrogen ions) and alkalinity: Irrigation water should have a pH between 6.0 and 7.5. The pH of the soil affects the availability of nutrients. It can impact the solubility of nutrients if the water is excessively alkaline or acidic. pH is used to express how basic or how acidic agriculture water is. Alkalinity, often known as high bicarbonate and carbonate concentrations, is a common cause of high pH values exceeding 8.5. Impact on irrigation equipment is the biggest immediate risk associated with an elevated pH in water. For unique water, equipment selection must be careful [10].

The second is electrical conductivity (EC). The crop and soil type determine the ideal EC range. Nonetheless, it typically ranges from 0.5 to 3.0 dS/m. EC gauges the salinity of the water. High EC might be a sign of high salinity, which is bad for crops. Since standards are typically stated in this, electrical conductivity is typically a more practical way to quantify salt concentration. . This comprises both positively and negatively charged ions, such as Cl^-, NO^{-3} and Ca^{++} and Na^+. TDS has an optimal range that fluctuates, but it is often less than 1000 ppm, much like EC. Total dissolved solids (TDS) quantifies the amount of all dissolved materials in water. Increased mineral content may be indicated by elevated TDS levels. The best temperature range for irrigation water is between 10 and 30°C.The metabolism of plants and soil microbial activity can be impacted by extremely high or low temperatures [11]. One crucial factor that affects both human health and agronomic practices is turbidity. Less than five NTU (Nephelometric Turbidity Units) is considered low turbidity. High turbidity levels can hinder light absorption in water, which can have an impact on plant photosynthesis. Crystal clear water is ideal. The presence of pollutants or organic matter may be indicated by color. Overuse of color can have an impact on photosynthesis and light absorption. A level of dissolved oxygen should be greater than 5 mg/L. Plant roots and soil microbial activities depend on sufficient oxygen. Damage to roots may result from low oxygen levels. Ideally, the water should have no odor. Organic materials or pollutants may be present when foul odors are present. Low levels are desired in the optimal range. Excessive suspended particles have the potential to clog irrigation systems and cause soil erosion. Hardness: Generally speaking, water hardness levels under 180 ppm are considered optimal. The production of scales may result from excessive hardness. In order to promote healthy plant growth and reduce the possibility of problems with soil and plant health, regular monitoring of these physical parameters will assist guarantee that the treated water used for agriculture fulfills th[9]e appropriate quality criteria [12].

4.1.2. Chemical parameters

To determine the quantities of ions, nutrients, heavy metals, and other chemical components, standard laboratory tests are carried out. Online monitoring systems and in situ sensors provide real-time chemical product information, allowing for quick adaption. In agriculture, the sodium absorption ratio (SAR) is a common indicator of soil and water sodicity and is used to determine whether irrigation is appropriate based on ratios of sodium content and other cations like calcium and magnesium. It also helps predict how water will alter soil structure, particularly if it results in soil dispersion, decreased permeability, crop growth, or other significant effects. Based on the ratio of total calcium (Ca) and magnesium (Mg) ions to sodium (Na) ions in a sample, SAR calculates sodicity. The SAR is used to estimate the sodicity risk of the water; all concentrations are expressed in meq/L, and SAR = Na 0.5 (ca mg) [13].

Calcium (Essential for cell wall structure, cell division, and plant stability), magnesium (a part of chlorophyll that is necessary for the activation of enzymes and photosynthesis), phosphorus (key in nucleic acid synthesis, root growth, and energy transfer (ATP), potassium (controls the intake of water, and the general metabolism of plants) [14]. In the majority of irrigation fluids, chloride is a common ion. Even though chloride is necessary for vegetation in small amounts, in concentrations of large, it may pose a threat to delicate crops. In many of the environments, the sulfate ion is a significant source of salt. Sulfate in irrigation water offers fertility effects. Nitrogen is a nutrient for plants that promotes crop growth. The traditional sources of nitrogen are naturally occurring in the soil or fertilizers that have been added, However, nitrogen in irrigation water has a similar impact to nitrogen added to the soil as fertilizer, and too much nitrogen will have the same negative effects as too much fertilizer. A class of compounds known as "trace elements" is generally present in common irrigation fluids at relatively small concentrations, usually less than a few mg/l. Among them are the following: arsenic, cadmium, lead, chromium, and mercury. It has been established that plants that consume heavy metals, a particular class of trace elements, face obvious health hazards [15].

4.1.3. Biological parameters

To evaluate microbial contamination, common techniques including polymerase chain reaction (PCR) and membrane filtration are used. Potential problems can be found by using particular organisms, such as the presence of particular bacteria or algae, as markers of water quality. Total coliforms, fecal coliforms, and E. coli are examples of indicator species. The quantity and content of algae observed during algal blooms [16]. The quantity and content of algae observed during algal blooms. Algal blooms, which are characterized by fast and excessive algae growth in aquatic environments as well as generally high levels of nitrogen, phosphorus, and other nutrients as well as soil enzyme activity (such as dehydrogenase, a marker of microbial activity and soil health), can upset the aquatic food chain [17]. Organic compounds have the ability to alter the color and smell of water in addition to attracting insecticides and serving as nutrition for microbial development. To address these negative effects, authorities and organizations set limitations for BOD5, CBOD5, and COD as part of their policies and guidelines [18].

5. Sources of Agricultural Wastewater

Agricultural wastewater is produced by different farming techniques and may include different types of pollutants. These are a few typical sources of wastewater from agriculture. Figure 1 illustrate major source of water pollution. If this wastewater is not appropriately managed, it may contain contaminants that are harmful to human health and ecosystems, creating environmental problems. Water has become increasingly scarce as a result of population increase and human activity. Wastewater is produced by three main industries: agriculture, industry, and residential use. These wastewaters, which are high in both organic and inorganic materials, cause eutrophication by depleting nutrients in aquatic bodies. Reusing wastewater can enhance water treatment by removing contaminants. Comprehending the constituents of wastewater is imperative in order to devise appropriate methodologies for treating it prior to its reuse or recycling [19].

6. Techniques for treating wastewater for agricultural use

Modern farming techniques are complex, dynamic, and challenging, including raising stock per m^2. Additionally, large tracts of land allow for the collection of rainfall, which can be used in agricultural processes. The agricultural sector has the potential to be a significant source of contaminated water. The main causes of pollution are leftovers and agricultural sludge. The amount of slurry that can be dispersed is constrained by constraints governing the spread of nitrogen. So, efficient technologies to extract nitrogen from slurry are now required in order to permit dispersal of this organic refuses on land. Water is used extensively in commercial agriculture, which results in significant wastewater production. Effective water filtration and wastewater treatment are essential in any scenario [2].

6.1. Background information about different technologies

Traditional wastewater treatment methods have high operational and capital costs and demand a lot of energy for mechanical components. Because of high operating and maintenance expenses, a lack of expertise, and a lack of authority, current wastewater treatment systems in the majority of developing nations are unable to adequately treat wastewater. Additionally, the dumping of raw wastewater into bodies of water declines the quality of the water and contaminates freshwater sources, harming some water resources. , having a negative influence on fish production, irrigation, and recreational activities. The primary threat to public health in certain developing nations is water contamination. After all, to be able to reduce the scarcity of freshwater resources, recycling and the recovery of human-generated wastewater are essential. Owing to the population growth, it is more important than ever to develop a set of policies that manage water demand, supply high-quality water, and lessen long-term strains on water resources. However, there are several variables that could impact the approach taken to address the water scarcity in certain areas, including geography, soil characteristics, and the availability of technical and financial support. In order to effectively treat wastewater over the long term, it is crucial to utilize sustainable treatment technology. Since it is frequently economically unviable, combining high-tech systems for wastewater treatment seems improper. Therefore, there is a huge requirement to create efficient, quick, and affordable wastewater treatment and reuse methods as opposed to conventional, expensive treatment systems (Kumar et al. 2012). According to Norton-Brando et al. (2013), contaminants like salinity, infections, heavy metals, and fertilizers are the main concern. Additionally, a breakdown of the benefits and drawbacks of these technologies is provided.

6.2. Waste to resources

Waste to resource refers to the process of transforming wastewater into valuable products for domestic and commercial use. The process involves three main stages: primary treatment, secondary treatment, and tertiary treatment. Figure 2 shows wastewater treatment steps. Primary treatment involves channeling wastewater into holding tanks to settle solid particles and chemicals, while secondary treatment breaks down solid waste using aerobic bacteria. Tertiary treatment filters wastewater to remove harmful nutrients and particles and passes it through additional lagoons to remove any remaining impurities or chemicals before presenting the final product for desired use. The first step in the wastewater treatment process is preliminary treatment, which uses a screening mechanism to remove both coarse and fine solids. Depending on the intended application of the finished product, this process removes more than 60% of the solid ingredients. This stage can remove more than 80% of the materials in drinking water. The best disposal strategy is determined by the quantity of solid materials extracted. The second stage of wastewater treatment, known as primary treatment, lets wastewater run through grit tanks in order to settle tiny sand particles. Finer particles might still exist, though. Wastewater is allowed to flow into sizable primary sedimentation tanks, where solids settle to produce sludge, in order to remove these. 60–70% of suspended solids are removed during first treatment; however, as the residual liquid typically contains dissolved debris, further treatment is necessary to remove any remaining particles. Primary sedimentation eliminates any solids that are good for drinking and cooking, but if the sediments don't contain any hazardous chemicals, they might be suitable for irrigation [20].

Secondary treatment is a biological procedure that uses microorganisms to remove 70–90% of the suspended solids in wastewater. Because of their oxidative energy for dissolving, aerobic microorganisms are frequently employed. Oxygen availability affects how quickly stuff is removed. Filter beds and activated sludge are two procedures utilized in secondary treatment. In filter beds, the wastewater is sprayed progressively over gravel or broken stones to maximize the surface area available for oxidation. Secondary sedimentation may have removed suspended elements from the wastewater collected at the base [21]. Tertiary treatment is the method used to get rid of harmful substances from wastewater that primary and secondary treatments are unable to eliminate, like nitrogen and phosphorus. In particular for irrigation, it entails employing instruments such as UV lights, filter membranes, and disinfectants to guarantee that the finished product is free of hazardous materials. The treatment targets particular chemical compounds in wastewater and filters it thoroughly to remove any potentially dangerous substances. Tertiary treatment is crucial for sustainability because treated wastewater is a major source of clean, safe drinking water for cities all over the world [22].

6.3. An overview of advanced technologies for treating water for agricultural reuse

6.3.1. Technologies for physical wastewater treatment

One of the earliest wastewater treatment technologies was physical methods, which use physical forces to remove impurities. In the majority of wastewater treatment process flow systems, they are still utilized. These techniques are often used when the water is severely polluted. The following are the most popular physical wastewater treatment techniques. Sedimentation, which uses gravity settling to separate particles from a fluid, is an essential wastewater treatment technique. This method removes suspended particles, grits, and silts by leaving water in various types of tanks undisturbed or semi-undisturbed for variable periods of time. It can be classified into three types: Type 1, where particles settle at a constant velocity, Type 2, where particle size variations effect settling velocity, and Type 3, where high concentrations form different zones. It lowers solid concentration prior to coagulation. The effectiveness of solid removal can also be impacted by organic compounds' ability to adsorb on suspended materials. Thickening, flocculation, and gravity sedimentation all affect how effective sedimentation is. Up to 60% of suspended particles can be eliminated just using gravity separation [23].

Degasification is the process of extracting dissolved gases from wastewater by calculating the partial pressure of the gas using Henry's law. By removing the gas, it raises the pH of the water. Tank volume, ultrasonic power, and temperature all affect how long the degasification process takes. The process can be impacted by a number of variables, including heating, pumping, spraying, and ultrasonic energy [24]. Waste water can be filtered to remove impurities and then reused for a variety of purposes. Particle and membrane filtration are the two main categories of waste water filtering. Particle filtering eliminates particles bigger than one micron. The two main types of filters used for filtering of contaminated water are bag and cartridge filters[25]. Whereas cartridge filters catch solid particles outside the filter medium, bag filters trap solid wastes inside bags. Limitations of cartridge filters include selection of filter mat erial and air reversal. Microorganisms, particulate matter, suspended particles, and other chemical pollutants can all be eliminated using filtration [26].

6.3.2. Technologies for chemical wastewater treatments

The processes of flocculation and coagulation, which need the addition of coagulants to agglomerate smaller particles and destabilize colloidal suspensions, are essential for the treatment of industrial waste water. Through mechanical agitation, destabilized particles clump together to form bigger ones during flocculation. The coagulants that are used determine how effective the process is. Usually, flocculation and coagulation occur at the same time. Catalytic inorganic salts are utilized as coagulants, and long-chain anionic or non-ionic polymers are used as flocculants. Charge neutralization and bridging are steps in the process that make it easier to remove micro-flocs by sedimentation or filtration [27]. Figure 3 illustrates the examples of different coagulants and flocculants. Ozone has drawn a lot of interest in industrial water treatment technology because of its strong oxidation and disinfection capabilities. It is used in waste water oxidation to eliminate compounds that give off an unpleasant taste, smell, or color, raise the oxidation state of inorganic compounds, and eliminate molecules that are infrequently biodegradable. Through the production of hydroxyl radicals, ozone can interact directly or indirectly with materials found in wastewater. Indirect reactions require the creation and termination of hydroxyl radicals, whereas direct reactions entail cyclo addition, electrophilic reaction, and nucleophile mechanism. The process target determines how much ozone is utilized; it is generally used for decolorization, disinfection, detoxification, sludge reduction, micro pollutant removal, and Chemical Oxygen Demand reduction[28].

Pollutants that are dissolved in water can readily be skimmed off the surface of the water during precipitation because solid precipitates are formed when the solubility of the pollutants is reduced. Even though oil and grease effectively removes metal ions and organics, their accumulation could lead to precipitation issues. The solubility of dissolved contaminants decreases with the addition of chemicals or a decrease in water temperature. Theoretically, the solubility of the pollutant may be reduced by adding organic solvents to the water, but this process is expensive when done on a big scale. These substances react with soluble pollutants to generate precipitates. The most often used materials for this include sodium bicarbonates, alum, ferric chloride, lime, and ferrous sulphate [29]. Temperature & pH are the two most important influencing factors for it. 60% of contaminants can be removed by precipitation. With the help of this technique, wastewater from the nickel- and chromium-plating industries may be cleaned up and recycled. Several applications include the elimination of heavy metals, phosphates, and softening of water. The primary problem with precipitation is how to handle the enormous amount of sludge produced [30].

One popular technique for eliminating organic and natural contaminants from the environment is adsorption. It falls into one of two categories. The physical adsorption or chemical adsorption, and it entails the chemical overlap of two phases. The physical absorption and chemical adsorption are the two categories into which adsorption extraction falls. Adsorption is easy to use and reasonably priced. Absorbable chemicals come into touch with a high-porosity solid material during the waste water treatment process. Adsorbent capacity is influenced by a number of variables, including dosage, pollutant concentration, temperature, pH, and contact time. Adsorption isotherm and kinetics, surface area, polarity, porosity, and functional groups on the adsorbent surfaces all influence adsorption efficiency. Press swing, thermal, and electrochemical regeneration are ways for regenerating adsorptive materials. Adsorbents are categorized according to where they come from. Natural adsorbents come from sawdust, cellulose, activated carbon, wood, coal, clay, fruit peels, and microbial biomass [31].

Ion exchange is the process of using ion exchangers to replace toxic ions in wastewater with non-toxic ones. These resins, which include acrylic, zeolites, and sodium silicates, can reduce chemical concentrations by up to 95% by eliminating trace amounts of both organic and inorganic materials. It is employed in several industries, including as the manufacturing of medications, water, and pollution control [32].

6.3.3. Technologies for biological wastewater treatment

Utilizing microorganisms to decompose organic contaminants in wastewater is known as biological wastewater treatment. Different approaches are used to take advantage of the microbial degrading processes that occur naturally. These are the main technologies used in biological wastewater treatment. These techniques include of bioremediation procedures as well as aerobic and anaerobic treatments. Aerobic activities in wastewater involve bacteria degrading biodegradable organic matter, influenced by temperature, retention duration, oxygen availability, and biological activity. This method can eliminate pollutants like phosphates, nitrates, volatile organic compounds, and chemical oxygen demand, reducing biodegradable organics by up to 90%. However, it generates bio-solids, requiring costly management and treatment [33]. Anaerobic digestion is a sluggish process that can take three months due to extensive degradation. Anaerobic bacteria in sludge are used in a bioreactor to break down decomposition materials into particles with low oxygen demand, chemical oxygen, full suspension, and biogas products. Acidification and methane generation are the two stages of the process. The anaerobic digestive system can break down organic materials in contaminated water in enormous artificial ponds known as anaerobic ports. These ponds have a firm mud layer and a wet sheet that serve as oxygen barriers [34].

Oxidation is a crucial chemical process in biological and chemical systems, involving the loss of electrons and an increase in a substance's oxidation state. It is essential for energy production, metabolism, and industrial applications. Oxidation is crucial for cellular respiration, which uses oxidation to produce ATP, the primary energy currency. However, excessive oxidation can lead to oxidative stress, damaging cellular components. Antioxidants, like vitamins C and E, help mitigate oxidative stress. Oxidation is also used in industrial processes like chemical synthesis, water treatment, and fuel production [35]. Large, shallow stabilization ponds called "oxidation ponds" are used to treat wastewater by utilizing bacteria, algae, and sunshine. Organic materials are oxidized by bacteria, which releases ammonia, water, and carbon dioxide. By using inorganic waste and releasing oxygen, algae develop and produce sludge that can be applied as irrigation. This approach is still being developed and works well for isolated units. An aeration tank, a settling tank, and a settling tank are the three main parts of the 20th-century activated sludge process. Microorganisms in the sludge use the organic matter as a food source to transform colloidal components into activated sludge. Aeration lagoons are deeper than oxidation ponds because aerators provide oxygen instead of encouraging the photosynthetic activity of algae, as in oxidation ponds. The microbial biomass is kept floating by the aerators, which also provide enough dissolved oxygen to maximize the aerobic process. The success of this procedure depends on well mixed liquid formation in the tank or lagoon despite the absence of deposition or sludge return. The wastewater from the food industry is an example of an effluent that is both strong and biodegradable, making aeration lagoons acceptable. Under aerobic circumstances, a sizable bacterial colony is suspended in wastewater using the activated sludge technique [36]. With unlimited nutrition and oxygen, it is possible to attain higher levels of bacterial respiration and growth, which can lead to the oxidation of available organic molecules into byproducts or the development of new microorganisms. The bioreactor, activated sludge, aeration and mixing system, sedimentation tank, and returned sludge are the five interconnected components that comprise the active sludge system. A well-liked method for remediating wastewater while minimizing operational costs is the biological process with activated sludge [34].

A biological wastewater treatment method called bioremediation employs microorganisms to convert pollutants into less dangerous forms. Organic contaminants in wastewater are efficiently addressed by this environmentally friendly technology. The study emphasizes how sustainable and flexible bioremediation methods are because they adhere to green chemistry principles. A long-term method for lowering environmental contamination and preserving aquatic habitats is bioremediation. It can survive in both anaerobic and aerobic settings, where microorganisms in wastewater break down chemicals or ions to produce energy [37].

6.4. Technologies for wastewater treatment Restrictions and Future Prospects

6.4.1. Technology combining physics and chemistry

The use of chemicals, sludge disposal, and increased energy and space requirements are just a few of the problems now plaguing conventional wastewater treatment processes. The effective removal of organic materials that are resistant to treatment, the incapacity of the system to handle more wastewater than its limited design capacity, and a labor shortage are some of the main operational issues with these systems. Advanced oxidation processes, membrane technology, low-cost adsorption materials, a new class of nanoparticles for wastewater treatment, less chemical or biological flocculants, and, if sludge is generated, methods to use it instead of disposing of it at the dumpsite are all necessary components of modern wastewater treatment methods. Although there has been a lot of research on the aforementioned subjects, there are still certain gaps in the open literature that need to be filled in order to address the worries about advancements in wastewater treatment techniques. Utilizing historic methods along with contemporary wastewater technologies may result in more effective wastewater treatment as well as increased reuse and recycling of treated water [38].

6.4.2. Technologies based on life (biology)

A promising technique for handling urban wastewater and industrial effluents is biotechnology. Its drawbacks include fouling, odor generation, and slower startup times, despite its benefits of cheaper capital expenditures, operating expenses, maintenance needs, and monitoring requirements. Bioremediation can only be carried out by biodegradable substances; nevertheless, secondary pollutants might be more dangerous. To achieve efficient system performance, the technique necessitates meticulous management and manipulation of environmental elements. Working together across disciplines is crucial to the development of new concepts, strategies, functional elements, and metabolic pathways. This technology could develop into a highly effective method for cleaning up wastewater and the environment [38].

6.5. Importance of wastewater treatments technologies

Because of how wastewater affects the environment, treatment is essential. The production and handling of wastewater has grown in significance in the twenty-first century due to rising industrialization and urbanization. The ecosystem's long-term survival is ensured via wastewater treatment. To combat the issue of increasing environmental pollution, a variety of wastewater treatment solutions are used. Certain types of treatment may result in the production of secondary pollutants. Effective wastewater treatment solution use in water resource management necessitates planning, activity, design, storage, and operation. The ability to create water of almost any quality has been made possible by advancements in wastewater recycling [39]. Systems for recovering water utilize a number of safety measures to lessen the risks to the environment from diverse reuse uses. Both the underlying science and the creativity used in water treatment systems have undergone ongoing developments. However, it is challenging to achieve significant wastewater treatment using a single treatment technology based on the currently used treatment techniques. Improved or integrated wastewater treatment technologies are desperately needed to ensure high-quality water, reduce chemical and biological pollutants, and optimize industrial production processes. Integrated strategies appear to be promising solutions for effective wastewater remediation since they may go beyond the limitations of single treatment procedures. Unfortunately, the majority of effective therapeutic methods are limited in scope and have little commercial viability [40].

7. Microbial safety

7.1. An extensive examination of microbial hazards in treated water for agricultural uses

Crop safety, public health, and the integrity of the food supply chain all depend on the quality of agricultural water. However, the frequent use of treated water in agricultural settings raises the possibility of microbial hazards. Pathogenic bacteria, viruses, and parasitic protozoa are examples of common microorganisms. Assessing the risks posed by these contaminants requires an understanding of their sources, persistence, and routes of transmission. Microbiological risks can also be caused by untreated municipal water, animal excrement, improper sewage disposal, and agricultural runoff. It is crucial to comprehend the longevity and frequency of these bacteria in order to create appropriate mitigation strategies [41].

7.1.1. Microbial hazards identification

Adenovirus, *Cryptosporidium*, *Legionella pneumophila*, water-soluble enteric bacteria, and *Escherichia coli are* among the frequent waterborne bacteria that can be extremely harmful to human health. Legionnaires' illness is caused by *Legionella pneumophila*, whereas water contamination is indicated by *E. coli*. Adenovirus that can contaminate water and cause digestive and respiratory issues. Although *Cryptosporidium* is resistant to standard therapy, soluble gastrointestinal bacteria can induce gastroenteritis. The severity, incidence, contagiousness, and demographics of diseases all have an impact on public health. The number of infections exposed is influenced by the immune system, infection, dose, and aggression. The risk of microbiological quantification is a helpful instrument for lowering these hazards [42].

7.1.2. Reservoirs and sources of microbial contamination in treated water

Water sources can get contaminated with microbiological pollutants due to agricultural practices, untreated sewage, and industrial discharges from urban and industrial zones. This can result in the spread of microbial illnesses such as E. coli and Cryptosporidium. These contaminants are stored in sediments, where infections can adhere and thrive. Pollutant dispersion can be influenced by factors that affect the transport and recovery of sediment. Pathogens such as Legionella and Norwalk may be present in sewage from cities and factories. Bacteria, such as Legionella, can thrive in biofilms found in water distribution systems. Places with high disease prevalence and inadequate sanitation can become contaminated by groundwater [43].

7.1.3. Effect of microbial contaminations on crops and soils

Plant health can be impacted by bacterial infections which can interfere with water transport systems and photosynthesis. Pathogen-induced microbiological imbalances can upset soil ecosystems, lowering the number of beneficial bacteria and influencing nutrient availability. Soil-borne illnesses resulting from contaminated water can negatively impact soil fertility and new crop growth. These infections may cause long-term consequences like acidification or nutritional imbalances by releasing toxins or changing the composition of the soil [44].

7.2. Strategies and technologies for ensuring microbial safety in treated water

For the sake of public health, treated water must be microbiologically safe. Advanced treatment techniques, monitoring, and disinfection are among strategies. UV light is a non-chemical technique that destroys the genetic material of germs, whereas chlorination is a commonly used disinfection approach. Monitoring technologies for identifying and measuring microorganisms in water include biosensors and real-time PCR. Membrane filtration and sophisticated oxidation techniques are examples of advanced treatment technologies. Upholding industry standards and getting regular updates from reliable sources help to keep water clean and keep the public health. A thorough approach is ensured by putting into practice a comprehensive strategy for microbiological safety in treated water [45].

7.2.1. Chemical treatment methods

- ***Chlorination***

Common chemicals used to treat agricultural water include chlorine gas, sodium hypochlorite, calcium hypochlorite, chlorine dioxide, and activated per oxygen. These oxidative biocides work by removing sensitive electrons from macromolecules, altering their structure. The target organism, the biocide's condition, and formulation can affect its action. Higher exposure time may be necessary due to resistance in prokaryotic organisms [46].

7.2.2. Physical treatment methods

- ***UV Irradiations***

France was the first country to employ UV radiation—which has four spectrum sections: vacuum UV, UV-A, UV-B, UV-C, and vacuum UV—to purify drinking water. The most effective wavelength for deactivating bacteria is UV-C. Water treatment uses UV lights, usually low-pressure mercury vapor lamps. UV technology has becoming more widely used for water treatment as a result of worries about chemical residues. More than 2,000 extensive UV water treatment facilities are located in Europe. UV technology needs further study and teaching to be optimized[47].

- ***Filtration***

ZVI is a new technique that has demonstrated the ability to remove chemical contaminants from groundwater by reacting with amorphous iron hydroxides, oxides, and oxy hydroxides through the reaction of dissolved oxygen and protons. Because of their high pH, these hydroxides can adsorb bacteria and viruses through electrostatic interactions. This creative method might give farmers an economical and long-lasting way to clean their irrigation water[48].

7.2.3. Biological treatment methods

- ***Filtration by sand***

By creating a biofilm crust on the filter surface, sand filtration helps to rid water of microorganisms. Waterborne bacteria, viruses, and protozoa can be reduced by 99.98%, 99%, and different percentages with this procedure. High flow rate, low maintenance, ease of use, and sturdy equipment are among the advantages. Some drawbacks are reduced effectiveness, harm to the bilayer, inadequate residual protection, and trouble moving the equipment. There may be issues with space when there is a strong demand for irrigation [49].

8 Effects on the environment of irrigation with treated wastewater

Reusing treated wastewater for irrigation offers both environmental benefits and challenges. The quality of the effluent, chemical makeup, concentration, solubility, and toxicity of compounds, as well as irrigation frequency and rate, significantly impact the environment [50].

8.1. Impact of soil

8.1.1. Supply of nutrients

Wastewater irrigation is a crucial source of essential macro- and micronutrients, such as nitrogen (N), potassium (K), phosphorous (P), zinc (Zn), iron (Fe), manganese (Mn), and copper (Cu) . Research shows that wastewater irrigation results in an increase in soil nutrients, including nitrates and potassium. The quality of arable soils must be maintained and improved through irrigation using treated wastewater. Nitrogen is essential for plant growth and development, aiding in the growth and development of stems, leaves, and other vegetative organs. It is also crucial for photosynthesis, the process by which green plants produce food[51]. Nitrogen shortage can negatively affect crops and lower production, leading to stunted growth, chlorosis, low seed protein content, decreased crop production due to early maturity, and loss in radiation usage efficiency. Treated wastewater is a good source of inorganic nitrogen (ammonium and nitrates), acting as a fertilizer and increasing the nitrogen content of soil when used for crop irrigation. This makes more nitrogen available to the land and speeds up mineralization, making it easier for plants to absorb nitrogen[52]. One-third of the world's food output could be lost if the soil is not given enough nitrogen. Phosphorus is another crucial nutrient for crop growth and yield. It is essential for root and stalk development, glucose metabolism, cell division, and seed germination. Phosphorus is involved in numerous biological processes in plants, and its lack can lead to crop deficiencies and decreased production[53]. The application of treated wastewater for irrigation can indirectly recycle soil phosphorus, which is a non-mobile nutrient in soil. Potassium affects how well crops can withstand drought stress and fight against pathogens. Micronutrients function as enzyme activators and catalysts, and are needed in lesser amounts. In conclusion, the addition of nutrients to the soil through wastewater irrigation significantly contributes to agriculture sustainability [54].

8.1.2. Matter/organic carbon

Water is a better source of organic carbon than soil because it contains more organic carbon per volume than other water sources. Research revealed a high percentage of organic carbon and other components, as well as land use, in soils that are irrigated with wastewater. Because it aids in the persistence of microorganisms in the soil, organic carbon is crucial for adequate soil displacement and drainage [55]. By doing this, you can lessen agricultural flooding after heavy rains and ensure that there is enough water available for plant roots and aeration for microbial activity. Increased organic matter in the soil also improves nutrient availability, consistency, and ability to fend off compaction and acidity [56].

8.1.3. Soil Salinization

Soil salinization refers to the buildup of salts or species soluble in water, such as cations or anions. It is crucial when determining the suitability of irrigation water. The high salinity in wastewater can cause temporary and long-term salinization, impacting agricultural yield and food security. High soil salinity can lead to altered plant physiology, reducing water uptake and causing osmotic stress and ionic stress in plants. Basil plants and canola cultivars have been found to experience physiological water shortage due to high osmotic stress, while non-salt-adapted plants may experience chloride ion-induced salinity. Plants determine the amount of saline in the soil, and the negative effect could be harmful to non-salt-adapted plants but less so to salt-adapted plants [57].

8.1.4. Soil morphology and hydrological characteristics

Water used for irrigation affects soil composition and characteristics, particularly in long-term plans. Treatment wastewater has a greater detrimental effect on soil than tap water, surface water, and groundwater. Long-term wastewater irrigation in Israel negatively impacts soil hydraulic characteristics, altering water flow patterns.

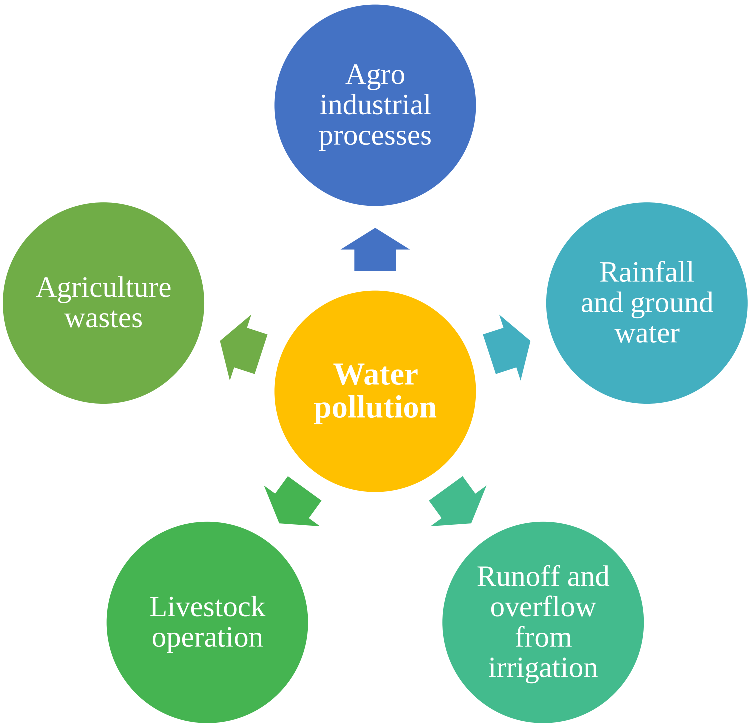

Figure 1. Major sources of water pollution

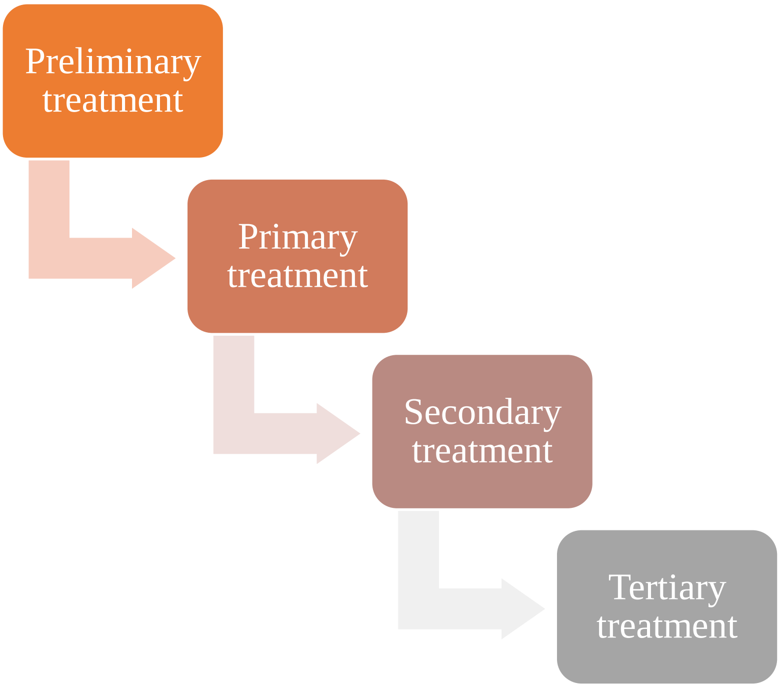

Figure 2: Wastewater treatment steps

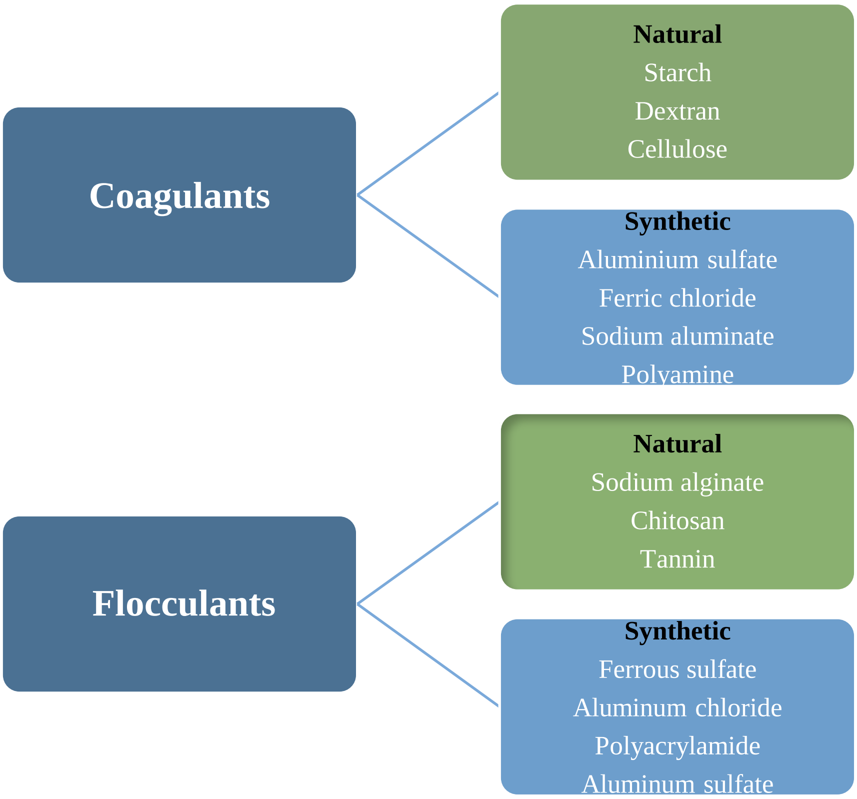

Figure 3. Examples of coagulants and floculants

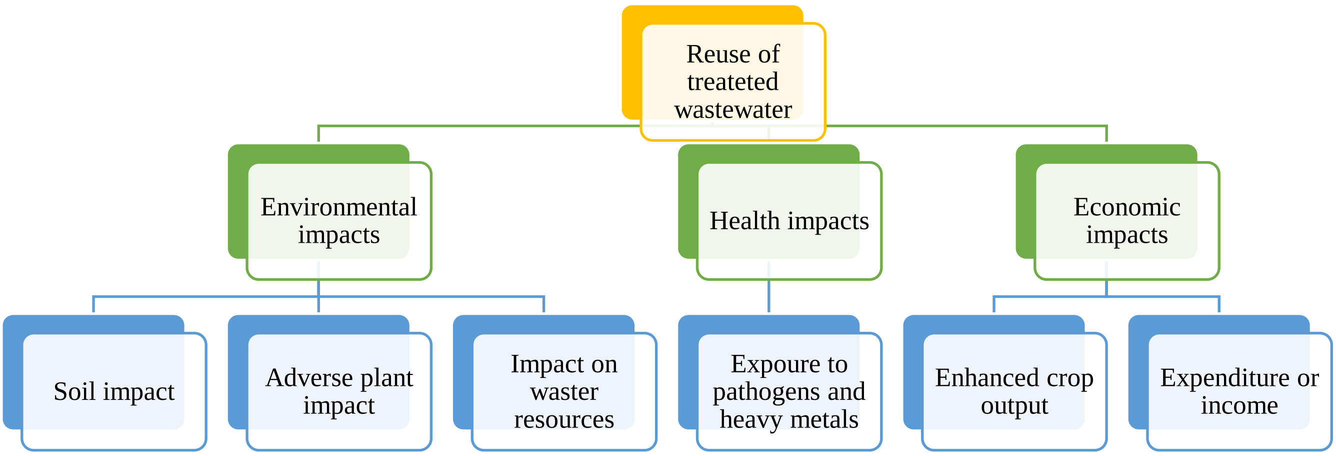

Figure 4. Potential impact of treated wastewater use in agriculture

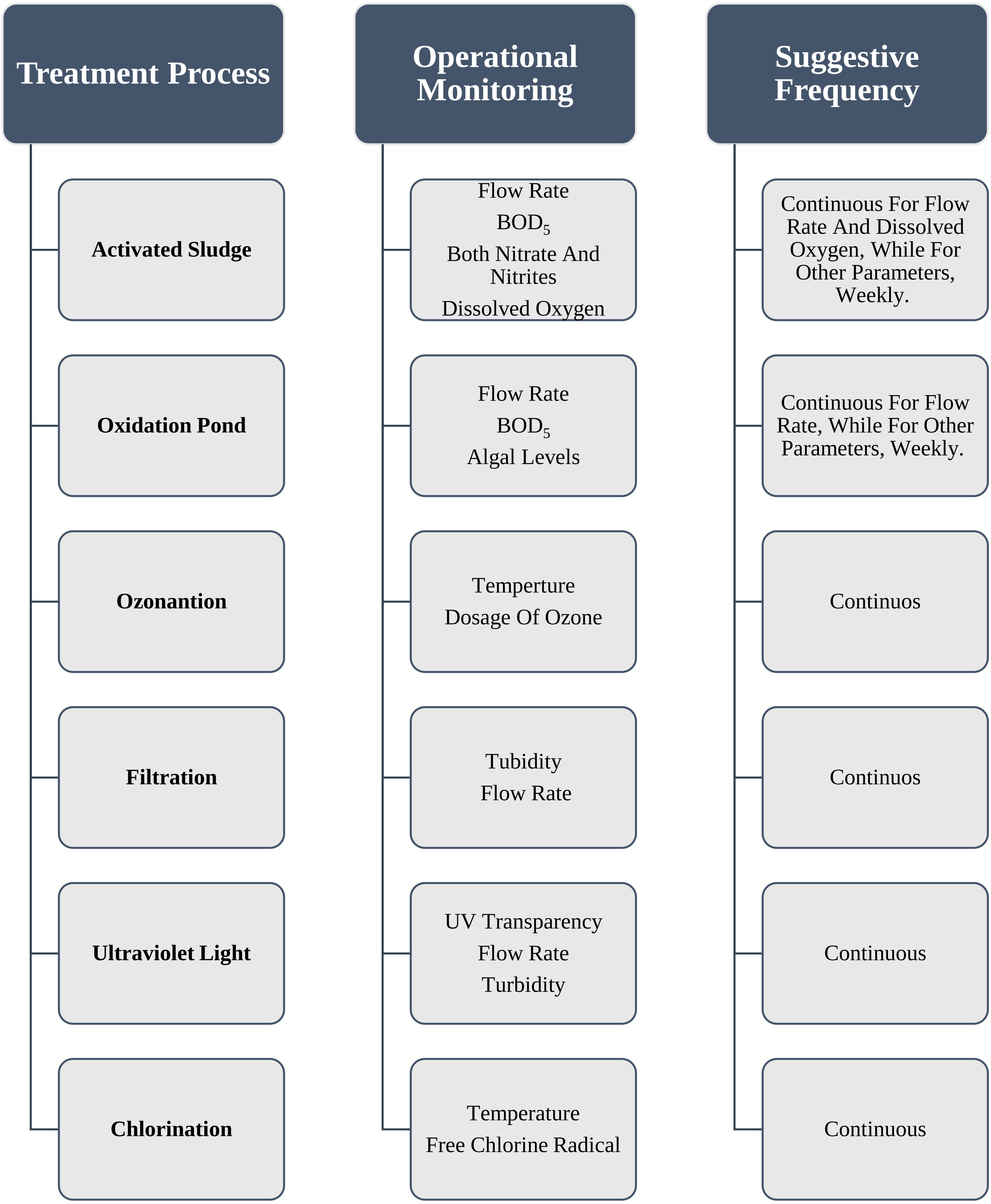

Figure 5. Examples Of Operational Monitoring For Several Treatment Processes

Table 1. Parameters applied to access the quality of agricultural water

PARAMTERS	SYMBOLS
Physical	
• **pH and alkalinity**	**pH**
• **Electrical Conductivity**	**Ecw**
• **Total Dissolved Solids**	**TDS**
• **Temperature**	**T**
• **Color/Turbidity**	
• **Hardness**	
Types and concentrations of cations and anions	
• **Magnesium**	Mg^{++}
• **Calcium**	Ca^{++}
• **Sodium**	Na^{+}
• **Carbonate**	CO^{3-}
• **Bicarbonate**	HCO^{3-}
• **Sodium Adsorption Ratio**	**SAR**
• **Boron**	**B**
• **Potassium**	**K**
• **Trace metals**	
• **Heavy metals**	

Table 2. Different physical wastewater treatment methods and their advantages and disadvantages

Physical Methods	Advantages	Disadvantages
1 Sedimentation	1. No energy needs 2. High degree of repeatability	1. A method that is selective 2. Lack precision
2 Degasification	Reduces the amount of chemicals needed for additional processing	Restricted ability to remove pollutants
3 Filtration	In rare circumstances, autoclaving is possible	1. It's a laborious procedure 2. Filters could clog

Table 3. Different chemical wastewater treatment methods and their advantages and disadvantages

Chemical Methods	Advantages	Disadvantages
1 Coagulation and Flocculation	1. Used to remove tiny particles 2. Removes color, turbidity, and metals.	1. Multiple steps in the process 2. Toxic if misused 3. High operating expenses 4. High generation of sludge
2 Ozonation	1. No need for chemicals 2. Greater effectiveness against germs 3. The removal of a wide range of microorganisms and inorganic substances 4. There's no need to adjust temperature or pH	1. Ozone is less soluble and requires certain mixing techniques 2. It is more expensive than other methods 3. There may be toxicity concerns and fire hazards during ozone generation.
3 Precipitation	1. Simple process management 2. Minimal running expenses 3. Regulated pH 4. Effective across a broad range of temperatures	1. Sludge production in big quantities 2. The challenge of getting rid of sludge
4 Adsorption	1. Minimal running costs 2. Relatively high productivity 3. Simplicity of design 4. Non-toxic procedure 5. The process of regeneration	1. Adsorbent with low selectivity 2. Issues with disposal
5 Ion Exchange	1. Resin can renew 2. It is possible to reach zero hardness 3.Quick process of separation	1. The majority of effluents require pre-treatment. 2. Competition between Ions 3. Matrix fouling

Table 4. Different biological wastewater treatment methods and their advantages and disadvantages

Biological Methods	Advantages	Disadvantages
1 Aerobic Treatment	1. Ease of use 2. Limits odor production 3. Reduces infections and lipids.	1. Expensive in price 2. A maintenance issue
2 Anaerobic Treatment	1. Generates energy that is sustainable 2. Decreased contamination of the environment	1. High initial investment 2. Odor interference
3 Oxidation pond	1. Exceptionally focused 2. A relationship of symbiosis exists	1. Odor issue 2. Requires additional space
4 Activated sludge	1. Offering a respectable return on investment for a start-up 2. Not requiring additional space	1. Excessive operating expenses 2. Issues in disposing of sludge
5 Bioremediation	1. Organic method 2. On-site therapy 3. Economical method	1. Sluggish workflow 2. No heavy metals are released

Reusing water can negatively impact the soil-water connection, negatively affecting crop productivity. The availability of water to plants is impacted by decreases in hydraulic conductivity, water storage capacity, and infiltration rate [58].

8.2. Impact of Water Resources

8.2.1. Reduction in water abstraction

Wastewater for irrigation is a significant reason as it can be treated as a water source, providing a substitute for traditional water sources for plant growth [59]. Water abstraction is the extraction of water from surface water sources, groundwater, or storage reservoirs, with 70% of wastewater retrieved and 80% discarded as trash. Reusing marginal quality water (treated wastewater) for irrigation can reduce water extraction and minimize water stress on freshwater sources, especially in areas of water scarcity. Reclaimed water is extensively used for irrigation in countries like China, Israel, and Australia, with over 80% of Israel's wastewater effluent reused for agricultural irrigation. Using treated wastewater for irrigation can protect and improve the quality of freshwater resources by reducing water pollution and reducing the use of mineral fertilizers in agriculture. This reduces the pollution load of the receiving water and prevents eutrophication, which can lead to oxygen depletion, aquatic species death, and a lifeless aquatic ecosystem if not regulated. Wastewater irrigation also reduces the potential for pollution from mineral fertilizers, which can contaminate freshwater through leaching and surface runoff. The fertilization effect of wastewater restricts the amount of fertilizer applied, preventing nutrient leaching and runoff. It can also help reduce groundwater salinization in coastal and salty environments, serving as a defense against water pollution caused by mineral fertilizers and effluent discharges [60].

8.2.2. Water Toxicity

Although wastewater irrigation might save freshwater resources, it can also contaminate surface and groundwater. The source, use, and treatment method of the water all affect the quality of the treated effluent. Chemical, inert/physical, and biological contaminants are all possible. Inorganic materials, heavy metals, nanoparticles, and organic pollutants are examples of chemical pollutants. Non-biodegradable substances including grit, sand, suspended particles, and wood or plastic are examples of inert pollutants. Microbiological contaminants encompass bacteria, helminthes, and viruses. The continuing COVID-19 pandemic is caused by the severe acute respiratory syndrome coronavirus 2, or SARS-CoV-2. Applying wastewater intensively can cause nutrients to leak into groundwater, increasing nitrogen concentrations and lowering groundwater quality. Wastewater suspended particles have the potential to block soil pores, decreasing infiltration and raising runoff. One common phenomenon in contaminated surface waters is eutrophication [61].

8.3. Effects on Plant Growth

Wastewater that has been treated and its nutrients make it a good material for irrigation. It fulfills the agricultural water requirements for crop production and supplies nutrients to promote plant growth. Although having access to nutrients usually encourages plant growth, an excess of nutrients can be detrimental to plants [62].

8.3.1. Increased Availability and Absorption of Nutrients

By enhancing nutrient availability and uptake, wastewater irrigation promotes plant development and increases growth and productivity. In comparison to conventional water, there is a 25.6%, 86.7%, and 63% increase in plant height, leaf area index, and biomass output.

Treated wastewater supplies nutrients to lettuce plants all through the growing season, increasing productivity and seed weight. Nutrient absorption is influenced by both nutrient content and root shape. Nitrates and ammonium, two forms of nitrogen found in treated wastewater, are readily absorbed by plants, promoting their growth and output. For example, putting nitrogen added increased the output of lettuce by up to 50% when it was irrigated with wastewater [63].

8.3.2. Plant Toxicity

A decline in plant quality and growth brought on by an excess of nutrients is known as plant toxicity. When quantities of trace elements in soil and plants above a certain point, poisoning may result from wastewater irrigation. The elements copper, cadmium, lead, nickel, zinc, chromium, and iron are the most frequently accumulated. Over-absorption of zinc can cause chlorosis, wilting of older leaves, and poor germination. Plant toxicity can also be caused by the consumption and accumulation of organic xenobiotic chemicals, such as drugs, hormone-disrupting agents, and personal hygiene products. These compounds are usually present in wastewater that has been treated, and in certain situations, plants may absorb them and become hazardous. Plant toxicity may result from irrigation with treated wastewater due to the bioaccessibility of organic xenobiotic compounds [64].

8.4. Effect on Public Health

The public's health may be at risk due to the presence of heavy metals, organic pollutants, bacteria, and hazardous compounds in treated wastewater. Pathogens and illnesses might result from consuming or breathing in these contaminants [65].

8.4.1. Exposure to Pathogen

In both treated and untreated wastewater, pathogens including bacteria, viruses, and protozoa can be discovered in significant concentrations. Enteric viruses are quite prevalent in secondary treated wastewater, with adenovirus being the most frequent type. To safeguard public health, nations, regions, and local governments enact regulations and guidelines on the repurposing of treated wastewater for agricultural use. Pathogen exposure is still a risk, though, especially with secondary treated wastewater and when regulations are not appropriately followed. Coliforms, fecal enterococci, and E. coli have been identified in the effluent used to irrigate broccoli and tomatoes, indicating the presence of indicator bacteria in the irrigation water of treated wastewater irrigation systems [66]. Since diseases can be contracted through eating or coming into direct contact with irrigation water, farmers and farmworkers are more likely to be infected than customers. Before being applied to crops, all treated wastewater and recovered water used for irrigation must be disinfected in accordance with EU Regulation 2020/741. In order to provide the necessary microbiological quality, operators of wastewater treatment plants, companies employing reclaimed water, and farmers must abide by risk barrier measures [67].

8.4.2. Exposure to Heavy Metal

Treated wastewater contains heavy metals that can build up in ecosystems and make their way up the food chain. Long-term irrigation can alter plant absorption, even at generally low quantities, which can have negative effects on the environment and public health. These metals have the ability to change plant growth and microbial populations, which may cause cancer and damage vital organs. Research indicates that plants that are irrigated with wastewater accumulate high amounts of heavy metals; nevertheless, the majority of studies assess concentrations of copper and cadmium, even when they are above permissible levels [68].

8.5. Economic Effect

To more completely understand and precisely analyze the implications of wastewater that has been treated reuse for irrigation, it is important to consider the financial benefits and costs of such a scheme. Verlicchi et al. (2012) and Giannoccaro et al. (2019) conducted comprehensive technical and financial case studies to evaluate the feasibility of reuse programs. Their research provides valuable information for evaluating the scientific and economical feasibility of wastewater irrigation schemes. Feasibility studies require consolidated tools and practical expertise in the field to examine technical and economic challenges [69].

8.5.1. Farm expenses and earnings

In Morocco's Tiznit area, employing treated wastewater for crop irrigation has greatly raised farmers' incomes and standards of living. By increasing agricultural productivity and decreasing the need for artificial fertilizers, this technique lowers expenses. Reclaimed wastewater irrigation has the potential to increase Israel's welfare by $3.3 billion, according to studies. Water has a non-market worth of up to €0.31 per cubic meter, which can be more than the cost of polishing cleaned wastewater for repurposing. The benefits to the economy are both financial and non-financial, albeit the latter are occasionally disregarded [70].

8.5.2. Enhanced crop output

Water is crucial for the growth of crops. It is regarded as one of the key elements that significantly limits agricultural productivity. A constant supply of water is necessary for crop production in order to meet crop water needs and avoid water stress, which reduces harvestable yields and adversely impacts the physiological and morphological processes of crops. [71]report that recurring droughts caused restrictions on surface water withdrawal, which resulted in a 20%–30% decrease in crop output in the Po Valley of Italy. Utilizing wastewater for irrigation not only supplies farmers with water to boost crop yields but also with nutrients to boost crop output. According to Verlicchi et al. (2012), wastewater is climate independent, meaning farmers will always have access to water for crop irrigation. Regular water supply may be ensured because wastewater reuse programs often produce enough water to satisfy irrigation needs. Farmers may reap more financial rewards as a result of this [71].

8.5.3. WWTPS' financial gains

The decreased energy use from wastewater irrigation could result in financial gains for WWTPs. WWTPs might potentially save a substantial sum of money by not pumping effluent from the treatment plant to the receiving water body. At the Italian Ferrara WWTP, this was the situation. The WWTP might reduce its pumping cost by

€200,000.00 year, according to technical and economic evaluations of a reuse project[71]. The decrease was brought on by the reuse project, which reduced the treated wastewater's conveyance distance from 5 km to 2 km. The decrease in the amount of effluent that needs to be pumped could also help to lower pumping costs. Direct irrigation with wastewater from wastewater treatment facilities (WWTPs) may result in lower energy usage and effluent discharge. 97 million m3/year of treated wastewater might be recovered for irrigation in Puglia, Italy, which could result in decreased pumping costs. Irrigation may be more cost-effective given its advantages to the environment and the economy. Reductions in fees paid to regulators could result in financial benefits from the polluter-pay principle. Utilizing wastewater directly could also encourage new industries and river flow [72].

8.5.4. Added Investment Expense

Operators of wastewater treatment plants (WWTPs) and farmers both face increased costs as a result of wastewater irrigation. The cost of polishing wastewater to satisfy reuse requirements is one of the additional investment expenses, along with storage and transportation costs. The cost of the reservoir, pipes, and pumps needed to carry the treated wastewater to the final consumers are included in the transportation expenses, according to Ruiz-Rosa et al. (2016). When farmers do not have direct access to the treated wastewater at the treatment facility, transportation and storage infrastructures are required. Regretfully, new distribution lines must be constructed because wastewater cannot be sent to farms via the current potable water distribution lines. It is possible to replace the distribution lines with tanker trucks, which also need storage tanks at farms. If sufficient financial support is not available, the installation of these capital-intensive infrastructures could place a financial strain on the end-users (farmers) and WWTP operators. Wastewater used for agricultural irrigation must meet a number of quality requirements for safety & protection of public health [73].

9. Regulatory Framework

Water quality requirement for agricultural usage are established by government, taking heavy metals and chemical residues into account. Regulatory framework examine and update these requirements on regular basis. Water treatment companies are required to follow regulations, which include licenses, environmental impact assessment, and operational protocols. This is guaranteed by permission and monitoring systems. Strict monitoring procedures have been established in place to monitor the quality of water throughout time. A financial incentive or tax incentive for the farmer might promote the use of treated water in agricultural practices. Agriculture can use water sustainability due to this dynamic system [74].

9.1. Framework for managing water reuse

The World Health Organization (WHO) recommends a risk management strategy for the safe use of reclaimed water for agricultural irrigation. Rather than relying on reactive responses, this strategy identifies and manages risks proactively. The WHO Guidelines for Drinking Water Quality and the Guidelines for the Safe Use of Wastewater, Excreta, and Grey water provide a conceptual foundation for this approach. The Australian government created the Australian Drinking Water Guidelines and the Australian Guidelines for Water Recycling, which offer a general framework for controlling the quality and usage of recovered water. We refer to the WHO Guidelines for Drinking Water Quality as the "Water Safety Plan" since they incorporate elements of other systematic risk management techniques [75]. To assist in putting these recommendations into practice, the WHO has released a Sanitation Safety Planning (SSP) handbook. The United States Environmental Protection Agency (USEPA) released the most recent edition of the Guidelines for Water Reuse in 2012. It addresses a variety of reuse applications and adopts a similar strategy to lower risks to the environment and public health. 2015 saw the release of rules by the International Organization for Standardization (ISO) regarding the use of treated wastewater in irrigation projects, particularly agricultural irrigation. These guidelines offer direction for the monitoring, upkeep, and operation of water reuse projects in a way that is safe, ecologically sound, and hydrological sound [76].

Water reuse rules were first issued by the State of California, which set strict treatment technology targets and performance standards for a variety of purposes, including agricultural irrigation. Based on these principles and regulations, the EU has released complete recommendations and regulations for water reuse, with certain adjustments for specific uses. One systematic technique for ensuring the acceptability and safety of water reuse practices is a risk management framework. It is adaptable and suitable for different kinds of systems. A risk management team, an explanation of the water reuse system, hazard identification, preventive measures, operational procedure development, process validation, water quality verification, and incident management are some of the components that make up the framework. It is essential for the secure use of recovered water for recharging aquifers and irrigation in agriculture [77].

9.2. Reusing treated water for agricultural irrigation while managing health and environmental risks

The methodology for risk management described in this section addresses environmental and public health concerns associated with the irrigation of agricultural land using recycled water. It describes standard minimum quality standards and safeguards for EU water reuse initiatives. The wastewater covered by the UWWTD is the source of the wastewater, and all treated wastewater needs to meet these standards. Source control procedures and monitoring of commercial and industrial discharges to sewer systems are required to guarantee that wastewater entering a UWWTP is included in Annex III of Directive 91/271/EEC [78]. Irrigation de different types de crops, come non-food, processed, and raw food crops referred to as agricultural irrigation. These classifications, which apply to a variety of crops intended for human consumption, are based on water reuse rules, MS legislations, and EC food safety regulations. To evaluate the risks related to the water reuse system, a risk management team is gathered. With a background in environmental and public health, this team needs to evaluate historical data on water quality, create a flow diagram, and comprehend the system from source to end usage [79].

9.3. Implementing safety precaution to reduce hazards

Preventive actions, such as minimizing exposure, reducing dangers from reclaimed water, and eliminating them through treatment techniques, are necessary to assure the safe use of treated water. To balance the effectiveness of the remaining obstacles, the multiple barrier principle should be applied. The primary barrier to lowering dangers to the environment and human health is the water treatment process. Receiving settings can also be safeguarded by on-site controls. Considerations should be made for des elements including agricultural characteristics, irrigation methods, storage, and the protection of drinking water supplies. Health concerns can be decreased with the use of management strategies, such as access control, buffer zones, withholding times, irrigation schedule control, and monitoring. Signage to lessen inadvertent exposure to recycled water is one of the preventive measures that should be implemented, along with management and employee education and training [80].

9.4. Creation of operational protocols

All system operations, including the entry of raw wastewater into the wastewater treatment plant, wastewater treatments, further treatments, storage and distribution systems, and irrigation systems, should be outlined in this protocol. Simple-to-measure parameters, real-time data reporting, and protocols for corrective action in the event that operational parameters depart from the critical limit should all be included in the protocol. The efficacy of the system depends on these protocols, which are outlined in a number of guidelines [81]. The production of food on a worldwide scale is largely dependent on agriculture, and farming must use water resources sustainably in order to be viable over the long run. As a solution to the problem of water scarcity, the use of treated water in agriculture has drawn attention. A comprehensive system of regulations that includes strict water quality requirements, a well-defined permitting process, and well-thought-out financial incentives supports the use of treated water in agriculture. The establishment and revision of water quality standards, which specify tolerable contamination levels in treated water, are mostly the responsibility of the government [82].

10. Future Perspectives

10.1. Piloting and localization

Numerous factors, including soil quality, plant physiology, climate, and water availability, affect the utilization of treated wastewater for agricultural irrigation. Because various soils react differently to wastewater, reusing wastewater locally can boost the good impacts and lessen the negative ones. A pilot project can aid in the development of a location-specific reuse plan by offering important information on possible problems, the impacts of wastewater irrigation on the environment and human health, and its economic sustainability. With this information, issues like nutrient leakage, soil salinization, over fertilization, plant toxicity, and exposure to heavy metals, CECs, and pathogens can be lessened. To protect public health and environmental security, pilot programs should concentrate on developing reuse laws and regulations that are unique to a given nation or region as well as putting in place risk avoidance measures. By situating wastewater treatment facilities close to agricultural areas, the high cost of conveying treated wastewater to agricultural end users can be decreased. Less time and effort should likewise be needed for shorter pipes. All things considered, recycling wastewater for agricultural irrigation can be an economical and sustainable alternative [83].

10.2. Enhancing irrigation management and infrastructure, increasing irrigation access and efficiency

Irrigation systems worldwide are often constructed and managed by national governments, with varying levels of performance and financial feasibility. Participatory methods, such as farmer-managed systems, can improve infrastructure management and water use. However, large agency-managed systems have often been outsourced due to limited management skills and cost constraints. Capacity development programs and modernization strategies are crucial for these systems. Farmer-led management systems function better when clear-cut institutions enable the transfer of ownership of land and water and offer legal remedies in disputes. These participatory systems are essential for boosting water output. Water resource conservation has increased with the switch from canal-based transportation to pipeline networks and from surface irrigation to pressurized irrigation. However, these improvements may increase energy consumption at farm and system levels. Improved irrigation access leads to higher productivity and nutritional benefits, and investments that ensure equitable access for men and women are essential for ensuring greater food availability and diet diversity for women, children, and deprived [84].

11. Conclusions

The study suggests that wastewater treatment in agriculture should be based on local circumstances, considering factors such as socioeconomic status, environmental conditions, and health. Pretreatment procedures must be completed at the company's expense before discharge into municipal sewers. Coordination of local sewage use fees and national effluent taxes is necessary to ensure consistent communication between wastewater treatment plants and industrial dischargers. Treatments and control measures for industrial discharge, sponsored by the industry, are necessary to safeguard wastewater treatment plant operations and ensure the quality of sludge and effluent for agricultural use. Benefits to the environment, human health, and economy include increased nutrient availability, preservation of water resources, and increased farm profitability when treated wastewater is used for irrigation. However, global adoption of this strategy is limited, especially in areas with little to no water scarcity. Reusing wastewater is still debated, but it can help protect the environment and improve water availability. To treat wastewater sustainably, decentralize treatment procedures, implement cyclical sanitation systems, build institutional and policymaking capacity, and raise public knowledge of related issues.

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