
Assessing the impact of Treated Wastewater Irrigation: A Comprehensive Review

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Abstract:- Water scarcity is one of the biggest problems, the globe faces since millions of people lack access to clean drinking water. In nations where wastewater production is substantial, using wastewater for irrigation has become a valuable resource and a favored approach to alleviate water constraints. Agricultural irrigation is currently the world's largest consumer of treated wastewater, indicating significant future opportunities for water reuse in both developed and developing nations. Therefore, health risk assessments for WW irrigation are essential, especially for adults. The effects of wastewater irrigation on crops can be attributed to various factors, including wastewater features, crop type, plant species, ability to thrive in low-nutrient conditions, and susceptibility to environmental and climatic variations. Prolonged irrigation with treated wastewater can potentially degrade soil physicochemical properties while enhancing soil microbial activity. This review shows the risks associated with exposure to treated wastewater and offers a detailed analysis of the potential for reusing treated wastewater in agricultural practices.

***Keywords**: Treated Wastewater, Health risks, Irrigation.*

1. Introduction

Water is a vital resource as it is essential for sustaining life and facilitating industrial operations. Water scarcity is one of the world's biggest challenges, as millions lack access to safe drinking water [1]. Worldwide, agriculture consumes 92% of the total water supply, with roughly 70% of this freshwater being utilized for irrigation, drawn from both surface and sub-surface water sources [2], [3]. Many research reports revealed that around 40% of the global population is reeling from a water crisis for agricultural purposes. Hence, the reuse of wastewater (WW) for irrigation will promise an optimal replacement of fresh water usage in irrigation. Treated Wastewater (TW) is typically used for non-potable uses such as irrigation, toilet flushing, groundwater recharging, washing purposes, and various activities [4], [5], [6]. Globally, the reuse of WW for agricultural purposes supports the crop yield and lives of millions of farmers [7]. Over 10% of the world's population is dependent on agricultural products, grown with the help of WW irrigation[8]. With an estimated 1.3 million hectares of WW reuse, encompassing China, Vietnam, India, and Pakistan with China being the leader in Asia [9]. According to the estimates, just 37.6% of India's urban WW is currently being treated[10].

Numerous low-income countries in Africa and Asia rely on untreated WW for irrigation, while in contrast, middle-income countries like Jordan and Saudi Arabia utilize TW for this purpose [7], [11], [12], [13]. Numerous nutrients are present in both domestic and industrial WW such as Nitrogen, Phosphorus, Potassium, and Sulfur. However, WW is a typical resource for irrigation since plants can easily absorb a sizable quantity of the nitrogen and phosphorus present in it [14], [15]. Rich nutrient availability is recovered, WW improves soil fertility, boosts crop output, lowers the need for fertilizers, and may even lower agricultural production costs[16], [17]. Reuse of WW for irrigation causes several health problems, due to the presence of pathogens and heavy metal (HM) contamination[8], [16], [18]. HM, which includes non-biodegradable elements with extended biological half-lives, comprises a range of toxic substances. These heavy metals accumulate in the upper layer of soil and, via plant root uptake, make their way into the human and animal body through the consumption of leafy vegetables and inhaling contaminated soils[19], [20]. Consequently, it is crucial to conduct health risk assessments for WW irrigation, particularly in adults. To achieve this goal, it is essential to implement an advanced WW treatment method before discharging WW into water sources, agricultural areas, and land[21].

Over the last decade, WW reuse has arisen as a global health concern, intertwined with public health and environmental concerns. Reusing WW or greywater poses inherent health risks due to the presence of microbial hazards [22]. Many studies have documented that exposure to WW may lead to infectious diseases, which in turn are associated with anemia and can hinder both physical and cognitive development[8], [23]. The use of WW is expected to expand in the next years due to the rising population and a growing gap in water demand and availability. The use of TW is subject to strict laws and restrictions in developed countries. Nevertheless, in developing nations, the evident practice of directly using untreated WW without solid regulatory policies gives rise to significant environmental and public health concerns[1], [12].

1.1. Environmental Assessment of Wastewater Treatment Plant

As the population is growing rapidly, it is necessary to treat and reuse the sewage water which is generated by humans through various activities. The primary aim of a wastewater treatment facility is to reduce the environmental harm caused by wastewater to natural water bodies such as rivers and oceans[24]. A significant challenge in developing nations is the insufficient number of wastewater treatment facilities. In India, the situation is exacerbated by a considerable disparity between the volume of wastewater produced and the limited availability of treatment facilities. Urban centers and metropolitan areas in India are experiencing rapid and significant development. The existing sanitation facilities are insufficient for the densely populated areas, leading to the discharge of untreated wastewater directly into water bodies [25]. Treatment plant lowers the effects caused by the discharge of wastewater into the water bodies. However, they exert a distinct environmental impact by consuming resources during both the construction and operation phases.

Life Cycle Assessment (LCA) is seen as a more effective approach for evaluating the impact of Wastewater Treatment plants. LCA includes gathering and evaluating a product system's inputs, outputs, and any environmental effects throughout its life. LCA has gained popularity as a method for environmental assessment in complex systems to assess the effects of different inputs and outputs. The LCA technique was initially applied in the 1990s. Recently it has been used in various parts of the world as it helps in finding the impacts on the environment and in identifying better alternatives for the conditions available [26]. In India, the LCA concept is not familiar due to the lack of a database, so it is important to improve the national datasets to implement the LCA methodology which aids in decision-making for legislators and helps researchers to build their databases. Several software is used for LCA in that Gabbi software is more popular. In Environmental assessment, we need to consider impacts at each stage such as at operation phase, construction and demolition phase, utilization of energy by pump, greenhouse gas emissions, and transportation phase [24], [27].

1.2. Characteristics of Wastewater

The attributes of WW are generally categorized into physical, chemical, and biological properties [28]. It was stated that WW comprises various minerals and organic matter and even sometimes traces are poisonous particles. Hence, WW should be treated properly before discharge or else it leads to a direct impact on human health [29], [30]. WW contains microplastics and some kind of fibers which depend on the source [31]. Numerous studies have indicated that TW contains pharmaceutically active compounds [32], [33], [34]. Traditional wastewater treatment methods, such as activated sludge, are ineffective in adequately removing these compounds.

Consequently, many of these chemicals were subsequently found in soils irrigated with TW[35]. Soil microorganisms can be impacted if these compounds accumulate in the soil over many years, potentially transferring to crops and then entering the food chain, posing risks to human health [36]. WW contains a wide range of acids, alkalis, oils, coarse particles, and other substances in a concentrated and complex chemical makeup. Organic, Inorganic, various gases, and some biological constituents are present in the WW, in which some particles are contaminated. These contaminated sources will lead to a negative impact on the environment in various ways [37]. Soluble organic substances have the potential to diminish oxygen levels within streams, introduce undesirable taste and smell to water reservoirs, and introduce harmful materials that can disrupt the food chain and public health [38]. Table 1 categorizes the chemical and biological constituents along with the physical properties of wastewater, including their respective sources and major contaminants of wastewater are shown in Table 2.

Table 1. Physical, chemical & biological parameters of wastewater along with their sources [39]

Parameters	Sources
Physical Parameters	
Color	Various wastes and Organic matter
Odor	Decomposition of waste
Solids	Various wastes, and soil particles due to erosion
Temperature	Municipal and Industrial wastes
Chemical Parameters	
Carbohydrates	Municipal and Industrial wastes
Fats/oils	
Pesticides	Agricultural waste
Volatile organic compounds	Municipal and Industrial wastes
Alkalinity	Domestic waste, Industrial waste, and Groundwater Infiltration
Chlorides	
Others	
Toxic elements	Wastes from Industries
Nitrogen	Farm runoff, Pesticides
Phosphorous	Municipal and Industrial wastes
Sulphur	
CH_4, H_2S and O_2	Decomposition of various wastes
Bacteria and Viruses	Municipal and Industrial Waste and its Decomposition

Table 2. Major contaminants of wastewater[39]

Contaminants	Reason for Importance
Suspended solids	When untreated WW is released into aquatic environments, suspended solids can cause the formation of sludge deposits and create anaerobic conditions.
Biodegradable organics	Biodegradable organic compounds, primarily consisting of proteins, carbohydrates, and fats, are typically quantified using parameters such as BOD and COD. If released untreated into the environment, their breakdown by microorganisms can result in the consumption of natural oxygen reserves, leading to the emergence of septic conditions.
Pathogens	Pathogenic organisms present in wastewater have the potential to transmit infectious diseases.
Nutrients	Nitrogen, phosphorus, and carbon are important nutrients necessary for growth. However, when released into the aquatic environment, they can foster the proliferation of unwanted aquatic organisms. Excessive discharge of these nutrients onto land can also result in groundwater pollution.
Refractory organics	Conventional wastewater treatment methods often struggle to remove certain organic compounds effectively. Examples of such compounds include surfactants, phenols, and agricultural pesticides.
Heavy metals	HM are commonly introduced into wastewater through commercial and industrial processes. If the wastewater is intended for reuse, it often becomes necessary to eliminate these heavy metals through removal processes.
Dissolved inorganic solids	Inorganic components like calcium, sodium, and sulfate are typically introduced into the initial domestic water supply during its usage. If the wastewater is to be recycled or reused, it might be necessary to eliminate these inorganic constituents through removal methods.

2. Repurposing of Treated Wastewater

TW denotes municipal WW that has undergone treatment to fulfill precise water quality standards to be utilized for beneficial purposes[39]. Global discharge of wastewater leads to pollution. Hence, all nations must prioritize the treatment of such WW and subsequently consider its reuse. Rising demands for household water driven by population expansion, enhanced living conditions, and industrial sector growth will escalate WW generation, thereby encouraging global adoption of TW reuse [40]. Generally, TW is used for several purposes in that major is for agricultural irrigation, groundwater recharge, Urban Non-potable uses and Energy production as shown in Fig 1. The primary issues related to this matter encompass risks to public health and the environment, alongside technical, institutional, social, cultural, and sustainability considerations [41]. Hence, WW treatment and its utilization will be of utmost importance. Reusage of TW have both positive and negative impacts on the society. From a positive point of view, it helps to conserve water and reduces the economic burden in water management, and the negative means most of it affects human health in one or the other way through various exposures. Fig 2 represents the Exposure pathway which shows health concerns from ww irrigated crops [1].

For instance, the WW treatment rate in China defined as the proportion of treated wastewater amount to the total discharged wastewater amount rose to 86% in 2014, marking a 3 - 4-fold increase compared to 1999 [42]. Globally, the use of TW for irrigation has seen an annual increase of 10-29% in Europe, China, and the US, with Australia experiencing a surge of approximately 41%. The primary objective of WW treatment is to provide TW with a safe and acceptable level of risk for both the environment and public health [43]. This is achieved by reducing suspended solids and organic matter, as well as removing chemical and biological contaminants from WW that could pose risks to crops and overall health [42], [44]. Table 3 gives an idea about the municipal ww generation, collection, treatment, and reuse for irrigation in a few countries [39]. It shows that the USA generates more quantity of municipal wastewater and nearly 75% has been treated. Next to the USA, China generates more municipal ww and after treatment, some quantity has been used for irrigation.

Table 3: Municipal ww generation, collection, treatment, and its usage for irrigation in a few countries [39].

Country	Generated Municipal wastewater (10^9 m^3/year)	Collected Municipal wastewater (10^9 m^3/year)	Treated municipal wastewater (10^9 m^3/year)	Treated wastewater used for irrigation (10^9 m^3/year)
Australia	-	-	2	0.28
Brazil	-	-	3.1	0.008
China	48.51	31.14	42.37	1.26
Germany	-	5.287	5.213	5.183
India	-	-	4.416	-
Italy	3.926	-	3.902	0.087
Jordan	-	0.115	0.113	0.103
Pakistan	3.06	-	-	-
South Africa	3.542	2.769	1.919	-
Turkey	4.297	-	3.483	-
UK	4.089	4.048	4.048	-
USA	60.41	47.24	45.35	-
Canada	6.613	5.819	5.632	-
Sweden	0.671	-	0.436	-

Agricultural irrigation stands as the foremost consumer of TW worldwide at present, indicating substantial potential for future opportunities in water reuse across both industrialized and developing nations. [45] was reported that approximately 20 million hectares across nearly 50 countries are irrigated using TW. Apart from the positive side, the usage of TW has also negative impacts on the environment [46]. The primary drawbacks associated with reusing TW include environmental pollution and heightened health risks [45]. Nonetheless, employing effective irrigation management practices can mitigate the adverse impacts of TW to a manageable level, benefiting both the environment and public health [47]. WW reuse may pose health hazards if it is not adequately pre-treated beforehand. Therefore, all risks must be maintained at acceptable levels [48]. Effective management of WW irrigation requires careful consideration of several key elements [49]. These include managing suspended solids, particularly important in micro-irrigation systems where filtration may be necessary; regulating nutrient levels to adjust fertilization practices; assessing salinity to determine leaching requirements and suitable crop patterns; and addressing pathogens through cautious measures and selecting suitable irrigation systems [50], [51].

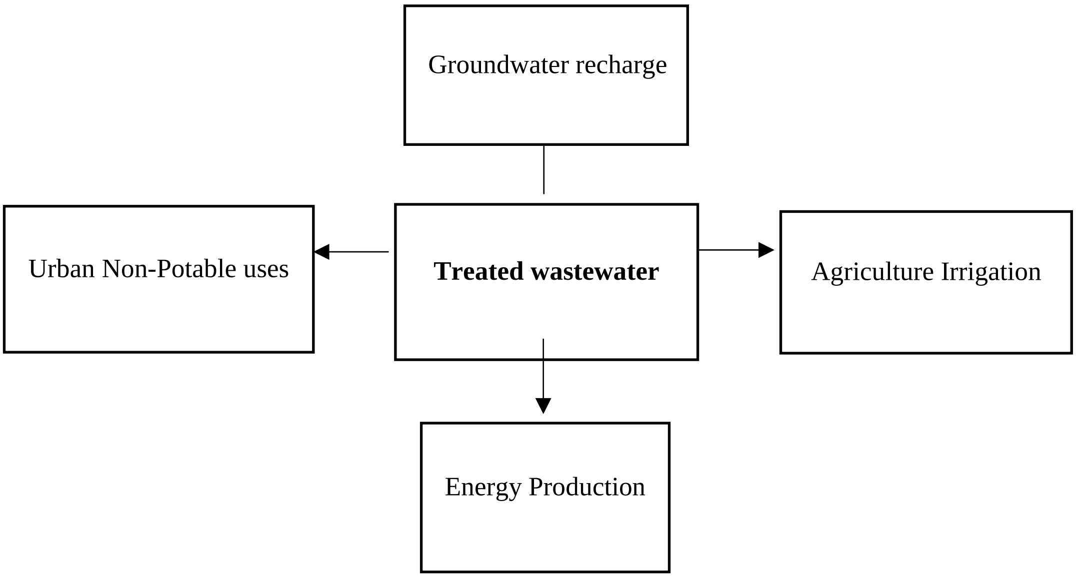

Fig 1: Usage of Treated Wastewater

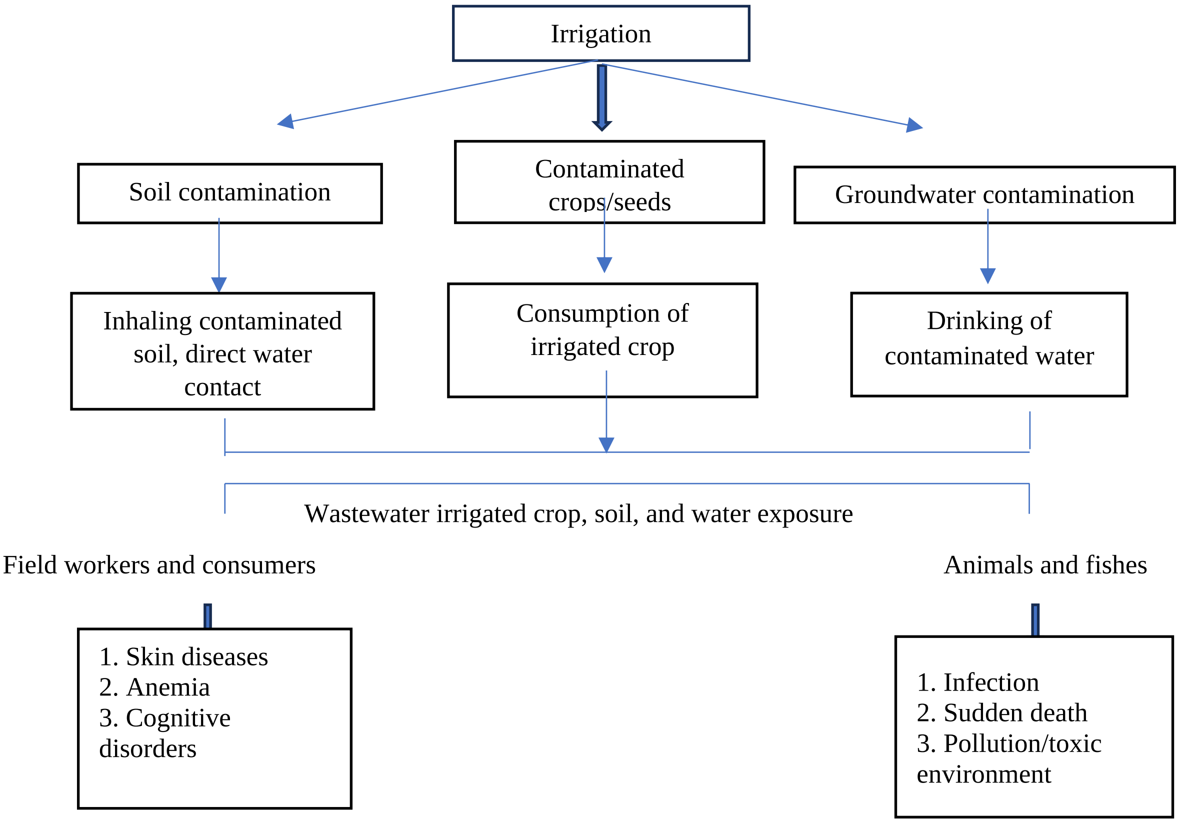

Fig 2. Exposure pathway which shows health concerns from ww irrigated crops [1]

3. The Impact of WW Irrigation on Soil Properties

3.1. Physical Characteristics

The physicochemical and microbiological characteristics of the soil are changed by WW irrigation.[52] It was noted that the organic matter (OM) content of the WW irrigation determines the growth in soil OM, which improves the soil's water retention capacity, hence impacting its compaction resistance and drainage properties [53], [54]. There is disagreement in the scientific literature over how irrigation with WW affects the physical characteristics of soil [55]. Ref [56] observed that irrigation with urban wastewater leads to higher hydraulic conductivity and soil porosity and mentioned that household WW does not have any detrimental effects on hydraulic characteristics.

Studies revealed that the application of wastewater for irrigation led to a rise in soil bulk density, which was ascribed to the build-up of OM[57]. In contrast, a modest decrease in soil bulk density was noted over long periods of WW irrigation. Evaluation of the effects of two different irrigation water qualities on specific physical parameters of fine sandy loam soil was conducted and determined that variations in water quality had no discernible impact on soil retention or bulk density [58]. When irrigation water salinity increased from 1500 to 4000 mg/l, the bulk density values of clay, loamy, and calcareous soils declined while their hydraulic conductivities comparatively increased [59]. It was found that the infiltration of TW and freshwater treatments decreased over time. The study findings regarding the impact of WW irrigation on soil moisture characteristic curves showed that the application of sewage water increased the percentages of all soil moisture contents [53]. These results could be attributed to higher fine particle fractions and OM concentrations. According to Ref [60], TW irrigation raised the water and electrical conductivity of the soil and discovered that using WW for irrigation greatly boosted the soil's ability to hold water. Additionally, prolonged usage of this water gradually raises its maximum water-holding capacity and enhances the physical attributes of most soils.

3.2. Chemical Characteristics

The effects of wastewater irrigation on the chemical qualities of soil, such as pH, salinity, and sodicity, have been the subject of several research [61]. Salinity is assessed using EC and SAR, which correspond to the level of sodium saturation in the soil and infiltration difficulties [62]. Ref [63] determines the effects of employing secondary TW in irrigation. Applying TW did not significantly alter the physicochemical parameters of the soil as compared to freshwater, except EC and SAR, which were marginally higher in TW soil samples. When TW irrigation was used instead of freshwater irrigation, the salinity of the soil increased. Nevertheless, neither a decline in tree productivity nor an increase in leaf Cl or Na concentrations were observed. However, it was noted that prolonged irrigation with TW can have a deleterious effect on the physicochemical characteristics of the soil [64]. It was found that the higher water content increased finer materials and organic content, which improved the capacity for cation exchange [65]. High BOD levels in sewage effluents or treated sewage increased soil OM concentration. According to [66] Raising salt concentrations in irrigation water significantly enhanced soluble sodium in the soil. Long-term irrigation with TW can enhance soil salinity levels.

Some studies found that soil salinity rises with TW irrigation but falls after each rainfall. EC in the lower soil strata increased because of irrigation with TW. Furthermore, research revealed that after two years, Al, Fe, and Zn accumulated in the topsoil layer [67]. The HM in TW has a propensity to build up in soil and turn bioavailable. Some research found that extended irrigation with municipal WW resulted in a significant drop in soil pH [67], [68]. In comparison to the control treatment, it was found that the TW irrigation raised the pH level in the top layer of soil. Furthermore, it was shown that the application of ww irrigation resulted in a drop in soil pH and a modest influence on $CaCO_3$ content. The effects of Treated municipal WW in short and long-term irrigation on selected soil properties are shown in below Table 4 [59]. [69]also stated that the majority of the salts in virgin sandy soil were washed off by applying TW for up to 8 years, which resulted in a progressive rise in soil salinity with the length of the irrigation period with TW. Utilizing TW or low-quality water is now part of the extension program to make the most use of available water resources. However, the unregulated use of such water has numerous negative impacts on soils and plants, particularly in long-term use. The hazards are primarily related to water quality and soil factors, rather than crop varieties [70], [71].

Table 4: Effects of Treated municipal WW in short and long-term irrigation on selected soil properties [59].

Parameters	Treated Municipal WW			
	Short term		Long term	
	Clay	Sandy	Clay	Sandy
Pathogens	-	-	-	✓
Nutrients	✓	✓	✓	✓
EC	-	✓	-	✓
SAR	-	-	-	✓
Heavy Metals	-	-	-	✓
pH	✓	✓	✓	✓
Texture	✓	✓	✓	-
Soil biodiversity	✓	✓	✓	-
Porosity	✓	✓	✓	-
Salinization	-	✓	-	✓
Organic matter	✓	✓	✓	✓

Microbiological characteristics, such as enzyme activity, have the potential to be useful as indicators of soil quality because they respond quickly to soil management, fertilization methods, and HM concentrations [72]. The microbial population in the soil plays a significant role in controlling the ecosystem's material cycle. TW contains nutrients, salts, HM, and organic contaminants. All of this could affect enzyme activity in soil. According to the reference [47], [73], there are links between soil enzyme activity and soil organic carbon, phosphorus, and nitrogen levels. It was noted that after the soil was treated with TW, the enzymes' activity was enhanced [74]. TW irrigation promotes soil enzyme activity and biological health, which can contribute to increased plant development and yields [75]. Enzyme activity is positively correlated with soil nutrients, but negatively correlated with salts and negatively correlated with an increase in HM in the soil [47]. The favorable benefit of soil nutrients outweighs the negative consequence of increased HM [76].

Soil fertility is enhanced chemically, physically, and nutritionally when TW is used for plant nourishment and irrigation. TW irrigation may improve crop productivity by supplying nutrients and organic matter to the soil [77]. The use of appropriate management techniques can improve soil health when irrigation is combined with TW. Many researches showed that the soil that got TW irrigation had much higher effective P, total N, and total K content than the land that had received freshwater irrigation. According to Ref [78], soil top layer total N rose after 8 and 20 years of effluent irrigation. It was noted that the activity of microorganisms responsible for the breakdown of organic materials and the release of inorganic nitrogen is negatively impacted by the salinity of soil solutions [69]. Soil watered with sewage effluent has increased accessible P and K content compared to soil irrigated with fresh water [79].

Several research has been conducted to assess the effects of TW irrigation on possibly toxic element levels in soil and crops. TW irrigation resulted in higher concentrations of hazardous substances in the topsoil layer compared to freshwater irrigation [80], [81]. It was noted that prolonged TW irrigation can enhance the quality of the soil and result in a notable increase in OM content. According to Ref [82], the TW irrigation caused the soil's HM content to rise. This increase in accessible HM is a significant barrier since it negatively affects soil properties that may have an impact on soil quality. On the other hand, it could not discover any appreciable differences in the amounts of HM in soils irrigated with freshwater and TW in various years [70]. HM did not affect the soil or the food chain in areas that were irrigated with TW [73]. The effects of prolonged irrigation with low-quality water on certain clayey soils' HM contents were examined in Ref [83]. Ref [84]demonstrated that the HM contents in the soil are not significantly impacted by the varying levels of TW. However, some researchers showed that the extended irrigation with ww polluted with HM significantly enhanced the amount of HM in the soil contingent upon the length of the irrigation period and the amount of HM in the irrigation water. [62], [85].

4. Impact of Wastewater Irrigation on Plants

WW is regarded as a reliable source of water that has a high nutrient capacity [86] and Crop productivity can be significantly increased by reusing it for crop irrigation [82], [87]. However, wastewater use for crop irrigation requires careful control because of the probable inclusion of undesired elements in the sludge, such as HM and pollutants[67], [88]. A study was carried out to investigate the impact of TW irrigation, fresh water, and surface and subsurface drip irrigation on okra conduction and growth metrics. The findings showed that TW had a favorable impact on the production characteristics and growth metrics of okra. Furthermore, when compared to freshwater, the results showed that okra's maximum agronomic performance was achieved with TW [89]. The utilization of wastewater for irrigation over two years resulted in a marginal increase in biomass [90]. TW is advantageous because of its high nutrient requirements, which support soil fertility maintenance and improve plant development and yield [91]. The presence of NH_4^+ and NO_3^-, two main types of nitrogen that are well-known for their capacity to increase the number of meristematic cells, maybe the cause of this result[86], [92]. TW led to a rise in hm across the majority of plant samples, notably for Zn, Cu, and Mn [68]. But for some plants, like corn and alfalfa, only the presence of Fe was able to overcome the crucial threshold for both irrigation techniques [93]. A notable rise in the yield of fruity vegetables was observed with TW. The yields of tomato, kidney bean, cucumber, and eggplant were 15%, 7%, 24%, and 61% higher respectively when irrigated with TW compared to freshwater [94]. When comparing TW irrigation to groundwater irrigation, there was a positive impact on the development and yield of tomato, eggplant, and cucumber, indicating that TW irrigation can likely take the role of groundwater irrigation [52]. TW can be a safe alternative source for irrigating leafy and root crops.

Numerous studies have found that using treated wastewater for irrigation does not negatively affect plants, groundwater, or the food chain [59], [93], [95]. Increasing levels of metals in the environment have a significant impact on plant development and metabolism, resulting in substantial crop output losses. Field experiments revealed no significant accumulation of heavy metals in tomatoes and cabbage irrigated with treated wastewater. Other vegetable plants, however, exhibited notable accumulation of heavy metals [96]. Furthermore, studies have shown that irrigating plants with different kinds of TW greatly raised the quantities of measured elements in vegetables, especially leafy species, such as Cu, Ni, Fe, etc[95]. Researchers looked into how TW affected carrot and cucumber productivity and quality and they came to the conclusion that, when compared to freshwater irrigation, plants that got TW irrigation had higher levels of macro-micronutrients in their stems, leaves, and fruits [84], [97]. Heavy metals have numerous direct and indirect negative impacts on plant growth. Despite its toxicity, Nickel is regarded as an essential element because of its great biological activity. However, due to their extreme negative impacts on both humans and plants, as well as their high mobility in the soil environment, Cd and Pb are considered the most dangerous metal ions. There is substantial evidence demonstrating that high concentrations of Cd or Pb significantly hinder plant growth and disrupt physiological processes by modifying metabolism. Fruit organs are less prone to accumulate trace elements than leafy or root vegetables, as HM concentrates more in the latter [67], [70], [98].

Crops absorb a considerable part of HM from the soil through their roots. The type of soil-forming rocks, organic matter content, soil pH, absorption capacity, presence of minerals like $CaCO_3$ and oxides, anthropogenic influences, and other chemical and physical properties of the soil are the main factors influencing the transport of heavy metals from the soil layers to crop roots [59]. The study showed that although the quality of soil microorganisms was affected by TW irrigation, very little E. coli was discovered in the soil and none at all in the harvested maize or onions. Thus, more research is needed to determine the advantages and limitations of reusing TW in crop irrigation [99]. Irrigating vegetables with TW can lower health risks to humans if appropriate vegetables and their consumable parts are carefully chosen. The dangers connected with using WW in agriculture can be reduced by managing WW properly, which includes choosing appropriate crops and irrigation techniques as well as keeping an eye on the amounts and distribution of metallic trace elements in the soil and plants [45], [100].

5. Impact on Public health due to WW irrigation

The biggest harm to a soil's ecosystem and health while utilizing TW for irrigation is thought to be the infections[101]. Proper WW treatment and disinfection eliminates or deactivates the majority of microorganisms. Nonetheless, certain pathogen concentrations in TW might still be high enough to cause infection [102]. Public health concerns should be addressed, particularly if the water contains HM and organic materials. The organic chemicals in treated water that are left behind after treatment have the potential to contaminate soil and endanger human health [103]. Numerous writers have documented that some newly discovered pollutants remain in TW and can penetrate agricultural lands via irrigation, building up in the soil and roots before moving on to edible plant parts like fruits and leaves[104].

Crops may absorb water-borne microcontaminants if pathogens in traditional wastewater treatment facilities are not entirely eradicated. These pollutants have the potential to build up in fruits and vegetables and then enter the food chain, where they could have detrimental impacts on both people and animals [104], [105]. Furthermore, groundwater becomes contaminated as a result of these pollutants. Therefore, some precautions must be taken while using treated water for irrigation to lower these chemical dangers. Various human health risks, types of risks, and exposure pathways associated with ww irrigation are shown in below Table 5 [59]. The exposure used to determine diseases connected with ww irrigation from the chosen literature is shown in below Table 6. Most of the time field workers and farmers are at health risk as they are directly in contact with irrigation water and soil. The presence of microorganisms that represent a concern to human health in TW is contingent upon its quality, which is determined by the treatments administered. Moreover, this may increase the risk of bacterial, viral, and parasite illnesses in crops that are watered with this water. Sometimes microbes and pathogens present in the TW may lead to various diseases such as cholera, dysentery, gastroenteritis, etc. Microbiological tests must be conducted before using TW for irrigation to minimize the various health risks associated with it [73], [105].

Table 5: Major Types of risk and health risks from ww irrigation [59]

Sl No	Type of Risk	Health risk	Who is at risk?	Exposure pathway
1	Occupational risks	Skin allergies, Nail problems, Parasitic, Bacterial, and Viral Infections.	Field Workers	Direct contact with irrigation water and soil
2	Consumption related risks	Bacterial and Viral infections	Consumers	Eating contaminated raw vegetables
3	Environmental risks	Various infections and Respiratory problems	People nearby fields especially children	Soil particles intake Aerosols

Table 6: Exposure used to determine diseases connected with ww irrigation from chosen literature.

Author	Location	Health risk	Route of Exposure	Type of Wastewater
[106]	Hyderabad, India	Intestinal infection	Occupational exposure	Partially treated and untreated ww
[107]	Musi River, India	Skin allergies	Exposure to contaminated sources	Partially TW
[108]	Bangkok, Thailand	Diarrhea	Direct exposure	Untreated WW
[109]	Vietnam	Parasitic infection	Consuming vegetables	Partially treated and untreated WW
[110]	Sweden	Gastroenteritis	Direct ingestion of greywater during maintenance	Treated greywater
[111]	Mexico	Diarrhea	Groundwater contamination, exposure to aerosols	Untreated WW

6. Conclusion

Reusing TW for irrigation has emerged as an important resource and an appealing solution to water scarcity, especially in nations where wastewater production is high. After proper treatment, using this massive WW as an irrigation source has advantages for the ecology and the economy as it might save a significant amount of freshwater and reduce or even eliminate the need to fertilize the soil with costly chemical fertilizers. The varying outcomes of TW irrigation on crops can be ascribed to various factors, including the characteristics of the WW, the kind of crops, plant species, their capacity to flourish in environments lacking in nutrients, and their susceptibility to environmental and climatic fluctuations. Long-term irrigation with TW may hurt soil physicochemical qualities and increase soil microbial activity. Therefore, to reduce any detrimental consequences, specific criteria for WW management and reuse should be followed. More research is required to ascertain the drawbacks and advantages of irrigating crops using TW.

Due to these concerns outlined in the review, a concise examination of the dangers linked to exposure to untreated WW, as well as advanced techniques for its treatment and further explore the potential for reusing TW in agricultural practices is needed.

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