



Exploring farmers' acceptance of treated wastewater for irrigation and its diverse impacts: evidence from case studies in the West Bank, Palestine

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Abstract

Global water scarcity has intensified the search for non-conventional water sources, with treated wastewater (TWW) emerging as a promising alternative, particularly in arid and semi-arid regions. In the West Bank's Jenin, Nablus, and Hebron areas, the proliferation of wastewater treatment plants has led to increasing volumes of treated effluent, raising questions about its optimal utilization amid acute water shortages. This study investigates the acceptance and perceived implications of TWW use for irrigation among local farmers. A survey was administered to a sample of 376 farmers using a simple random sampling method. The results indicate strong support for TWW adoption, with 82.7% of respondents expressing willingness to irrigate with treated effluent. The affordability of TWW emerged as the primary driver of acceptance, with 79.5% highlighting lower irrigation costs as a key motivator, while 69.1% acknowledged its potential to reduce dependence on chemical fertilizers. Post-study projections suggest that 80.1% of farmers anticipate increasing TWW usage. Farmers reported high overall satisfaction, especially regarding economic benefits (mean score: 2.67), followed by social (2.39) and environmental (2.17) impacts. These findings emphasize the economic viability and broad acceptance of TWW, positioning it as a sustainable and socially supported strategy for addressing agricultural water demands in water-scarce contexts.

1. INTRODUCTION

Global assessments of the UN's water-related SDGs have highlighted paradoxical trends in local water decisions, worsening long-term water scarcity. Al-Haddad and Aleisa (2024) use the Water-Energy-Food (WEF) nexus framework to assess non-conventional water resources, offering insights into their interconnected dynamics and enhancing resource sustainability.

Using treated wastewater in agriculture represents a progressive approach to sustainable water management, enhancing water resource efficiency while supporting agricultural productivity, economic stability, and environmental sustainability. With global water

scarcity, becoming increasingly pressing, integrating treated wastewater into agricultural practices is crucial for building resilient food systems and advancing sustainable development.

Research conducted worldwide has explored the opportunities and standards for water reuse, assessing various facets of treatment and reuse technologies (Al-Sa'ed et al. 2012; Tzanakakis et al. 2023). The research emphasizes the need to investigate the impacts of water reuse systems on Ecosystem services (ESs) and their consistency with the Global Sustainable Development Goals (SDGs).

Faria et al. (2022) examined social acceptance and views on treated water reuse in Palmas, Brazil, and there was general acceptance of indirect uses but resolute opposition to direct reuse.

Chfadi et al. (2021) explored the general acceptance of treated wastewater reuse in the United Arab Emirates (UAE) and established high acceptance for low-contact purposes and less acceptance for direct or indirect consumption. Al-Saidi (2021) explored the challenge and social attitude towards water reuse, citing the positive effect of water conservation behavior and environmental efficiency. Verhoest et al. (2022) have said that fear and disgust of contamination shape resistance against wastewater reuse at the level of society, outpacing ecological concerns.

De Villar et al. (2023) emphasized prioritizing the retention of all considerations while balancing issues, warning against prioritizing finances, which can have profound ecological consequences.

McLennan et al. (2024) spoke about (i) a review of national regulations compared to the 2020 European Regulation, (ii) the performance of ongoing projects in terms of water quality, and (iii) the role played by European Union Regulation in supporting water reuse in Europe. They concluded that the European regulation would improve consumer confidence through the requirement for minimum standards. It does not, however, include provisions for micropollutants, disinfection by-products, and potential downstream water quality modifications. Additional obstacles include the distance from treated water production to agricultural demand, the lack of economic competitiveness of reclaimed water, and implementing a multi-barrier approach. Al-Rimawi (2014) examined prospects for the reuse of wastewater in Ramallah, reporting on farmers' awareness of treated wastewater but also indicating deficiencies in awareness of treatment methods and controls. Wastewater must be managed properly in order to minimize environmental and public health impacts (Al-Sa'ed et al. 2012; Thaher et al. 2020). Amer (2011) found treated wastewater to be not a cause of soil heavy metal content increment and improved corn yield, while Burnat and Eshtayye (2010) reported issues from unfiltered on-site greywater treatment. Qatawi (2008) researched the social acceptability of treated wastewater reuse in Ramallah and Al-Bireh and found it to

be a valuable resource in times of water shortage.

Abu Madi et al. (2010) assessed the economic and social viability of treated greywater reuse and recommended its use in new buildings and workplaces, coupled with awareness creation. Qaimari (2005) noted the high acceptance of treated water reuse by school children due to limited water availability in Palestinian regions. Further studies (Al-Khatib et al. 2017; Hamdan et al. 2022) examined governance dimensions affecting the reuse of treated wastewater for irrigation in Palestine and demonstrated governance shortcomings that hinder water and sanitation sector reforms.

Treated wastewater can be a new source of non-traditional water used in irrigating agricultural crops and for various human uses. Due to water scarcity all over the globe, there arises an urgent need to intensify wastewater treatment projects and reuse it in agricultural production and in irrigating public gardens and parks.

The effects of wastewater on crops and soils are well known. Tang, D., et al (2024) developed a simple analytical model to estimate crop uptake of solutes. Although crops are not directly exposed to irrigated wastewater, pollutants (and nutrients) may diffuse into the root zone. The results showed that crop contamination is primarily determined by the water balance in the root zone, the diffusion of solutes, and the parameters of biogeochemical interactions. The model contributes to identifying suitable hydrogeological and climatic locations for wastewater irrigation in the hydrological region, determining acceptable levels of irrigation water quality, and assessing crop contamination risks compared to the fertilization value of wastewater. The quantities of wastewater produced are significantly increasing due to human development, but the areas irrigated with wastewater are still very limited. The areas in Tunisia do not exceed 2% of the total irrigated areas, and they have stagnated for almost 40 years, not to mention the enormous damage caused by wastewater. In Tunisia, the adoption of tertiary treatment is being launched everywhere in order to expand the scope of use of wastewater in irrigation following the water shortages and long droughts observed. In many countries, many beaches are closed to swimming due to the pollution caused by this wastewater. But tertiary treatment is expensive and it is strongly recommended to only resort to expensive advanced treatments when necessary,

for each type of crops there is a specific treatment (primary, secondary or tertiary). This water must be used for irrigation in compliance with standards, and it is necessary to understand and analyze the reasons for farmers' reluctance to use this wastewater.

The study focused on the current situation and prospects for the use of treated wastewater for irrigation. Three samples were taken from the northern West Bank Jenin, the central Nablus governorate and the Hebron governorate, which is located in the southern West Bank, which are all considered the largest and most important in the agricultural sector, as they have the largest population density and land area, so studying the extent of social acceptance and the environmental and economic impact of using wastewater by farmers. The objective of this research is to establish the degree of acceptance of the use of TWW by farmers in order to extend its use to other regions.

2. MATERIAL AND METHODS

This study adopted a systematic approach in gathering and examining data on the use of treated wastewater for irrigation. The procedure consisted of the following main components:

2.1 Designing and disseminating the questionnaire

The questionnaire is based on the specific characteristics of the irrigation system in the study area with the aim of assessing the future potential and current state of the use of treated wastewater for irrigation based on social, environmental and economic factors. The questionnaire was composed of three main sections:

- Personal Information: Collecting demographic data of the respondents.
- Farm Readiness: Evaluating farmers' willingness and readiness to use treated wastewater.
- Impact Assessment: Measuring the social, environmental, and economic effects of TWW.

Each category included items ranked on a Likert scale from "I agree" (three marks) to "neutral" (two marks) to "I oppose" (one mark). The survey questionnaire was distributed randomly to residents and employees in the study area to ensure that there was a representative and diverse sample.

A pilot study was conducted on a sample of 25 farmers who were selected randomly to test the study tools. Illiterate and educated farmers were included in this sample. Illiterate farmers were interviewed personally, while educated farmers were sent the questionnaire through electronic media.

2.2 Data sampling and collection

The sample consisted of 376 randomly selected farmers to give results that represent the general West Bank population. Questionnaires were distributed to those farmers in the sample area who were positioned in close proximity to the treatment plants, and their responses were collected, recorded, and analyzed.

2.3 Data processing and analysis

The data collected from the questionnaires were processed using various software programs and statistical techniques, including SPSS Statistics 29, One-Way ANOVA, and Scheffe.

A mixed descriptive-analytical approach (qualitative and quantitative) was followed by collecting the data from the field. With progressive statistical methods, it produced a study about the phenomena by considering all the influences and their concentration on the core subjects.

2.4 Data validation

- Content Validity: Validity of the questionnaire was assured by a review carried out by nine experts in agriculture and wastewater from Palestinian, Jordanian, and Tunisian universities. Their feedback led to the revisions needed.
- Construct Validity: It's validated using the Pearson correlation coefficient to measure the relationship between answers to each question and their corresponding fields, as well as their overall effect on social, environmental, and economic factors.

3. RESULTS AND DISCUSSION

The survey, measurements, and visits to certain farms will be analyzed to better understand the barriers limiting the use of TWW.

3.1 Data interpretation and reliability

Responses were analyzed by converting Likert scale scores into levels:

- To achieve Low: 1.66 and below
- To achieve Medium: 1.67–3.33
- To achieve High: 3.34 and above

Scores were classified into these levels to compare the social, environmental, and economic impacts of wastewater use in agriculture from the farmers' perspective.

Questionnaire reliability was tested with Cronbach's alpha and the half-way partition technique. Table 1 reveals the results, showing high-reliability coefficients for all domains.

The values indicated that the alpha Cronbach coefficients for the social, environmental, and economic impact areas ranged from 0.821 to 0.961, with an overall grade of 0.835, demonstrating high internal consistency.

Table 1. High-reliability coefficients

Aspects	Number of Paragraphs	Alpha Cronbach	Halfway Fragmentation
Social Aspect	11	0.821	0.749
Environmental Aspect	12	0.883	0.875
Economic Aspect	11	0.861	0.842
Overall Grade	34	0.835	0.833

3.2 Global acceptability of using TWW by farmers

The sample includes 376 farmers, of whom the majority - 311 farmers (82.7%) - are willing to use TWW for irrigation, while 65 farmers (17.3%) are not. The adoption of irrigation in these areas is essential due to the extended dry season, which lasts from mid-April to mid-October and coincides with the irrigation period for fruit trees. Additionally, rain-fed agriculture typically produces yields that are about 50% lower than those achieved through irrigation, and the fruit quality is generally inferior.

Government institutions consider farmers' reluctance to use treated wastewater to be due to religious, cultural, psychological, or economic beliefs. However, this study found that farmers' use of treated wastewater is highly accepted. However, there is a lack of pipes relaying the farms and the treatment plants (only 38.4%), and they don't operate at full capacity due to the high costs of connection.

Akpan et al. (2020), nearly 60% of the respondents indicated acceptance of treated greywater for garden use. Al-Khatib et al. (2022) recently documented that 62% of the respondents were accepting greywater for irrigating vegetable crops. In a study by Newcomer et al. (2017), 80% of the respondents accepted treated greywater for vegetable

irrigation. These studies show a general acceptance of applying treated greywater for irrigation purposes, with rates of acceptance inclined to be greater for its potential to conserve resources, protect the environment (Newcomer et al. 2017), and as a nutrient source for crops (Al-Mashaqbeh et al. 2012; Thaher et al. 2020).

Lateef and Egbeyemi (2024) carried out a study aiming to assess the acceptability of reusing hospital-grown treated wastewater (HW) for agricultural irrigation in the peri-urban area of Ibadan, Nigeria, and the willingness of residents to consume crops grown using this water source.

The results revealed that a significant proportion of respondents (56.6%) had limited knowledge of reused wastewater, while about half (52%) viewed reclaimed wastewater favorably. However, the majority (66.1%) expressed reluctance to use reclaimed wastewater for crop irrigation or consumption. Reasons cited for this reluctance included concerns about health risks, lack of trust in WWT processes, psychological factors, and religious beliefs. The study confirmed that urban residents in Ibadan may not readily accept the use of reclaimed wastewater for urban agriculture.

In addition to climatic constraints and mainly the presence of a long dry season requiring irrigation, the survey revealed other motivations such as (i) increased yields and incomes, (ii) reduced production costs, and (iii) sensitivity to environmental preservation, especially for farmers with a certain level of education.

3.3 Prospects for increasing crop yields with TWW

Regarding the effect of wastewater on yields and fruit quality, most farmers, 208 (55.3%), believe that treated wastewater improves crop quality and yield. There are 113 farmers (30.1%) who are in doubt about its effect, and 55 farmers (14.6%) claim no effect on crop quality or yield (Table 2).

Table 2. Perceptions on the Effect of TWW on Crop Quality and Production Increases

Variable	Answer	Number of farmers	Percent%
Is there an impact of the use of treated wastewater in agriculture on crop quality and increased production	Yes	208	55.3
	No answer	113	30.1
	No	55	14.6
	Total	376	100

Most farmers opined that the application of treated wastewater in agriculture has resulted in increased production, with most reporting a positive impact without affecting the quality of crops. In particular, 162 farmers (43.1%) opined this way. The second category, 21 farmers (5.6%), perceived that treated wastewater enhanced soil cohesiveness and production quality. Eight farmers (2.1%) said it changed the taste of crops. Moreover, six farmers (1.6%) indicated low production and health issues each. Finally, five farmers (1.3%) indicated that the TWW caused pollution. These problems, however, were attributed not to the quality of the treated wastewater, which is good according to Palestinian standards, but to its abuse. It is also worth considering whether the use of treated wastewater is gradually becoming integrated into farmers' irrigation practices and whether this signals the emergence of a broader commitment to sustainable water management. Nevertheless, concerns regarding the sanitary safety and quality of agricultural products irrigated with treated wastewater remain subject to debate. Potential consumer apprehension about contaminants may lead to reduced market demand, thereby posing economic risks for farmers.

3.4 Long-term use and amounts of TWW used for irrigation

The most dominant cluster of farmers is 123 (32.7%), who have irrigated with treated wastewater for 2-5 years. Farmers who have been irrigating for less than a year and those who have never irrigated both account for 115 farmers (30.6%), in second place. In contrast, just 23 farmers (6.1%) have irrigated with treated wastewater for more than five years. These findings concur with Odone et al. (2024), who carried out a two-year field experiment of irrigating processing tomato crops with tertiary-treated wastewater with an innovative fertigation system in the northern and southern regions of Italy. With those already present in the irrigation water being considered, this system was designed to provide precise amounts

of nutrients. The study contrasted three water sources: freshwater with chemical fertilizer, tertiary-treated wastewater with chemical fertilizer, and tertiary-treated wastewater with no added fertilizers. The one treatment that failed to supply sufficient nutrients for the tomatoes was tertiary-treated wastewater without added fertilizers. No adverse effect on soil or plant health was observed, and tomatoes watered with treated wastewater had growth and yield similar to those watered with freshwater, but without differences in fruit quality. This is a benefit to the application of TWW for irrigation. Averages, standard deviations, and relative weights were calculated to assess the socio-economic and environmental effects of wastewater treatment for irrigation. In a study of the behavior of macronutrients in agricultural soils during the recharge of treated wastewater (TWW) through AgMAR, focusing on the effects of mineral formation during the recharge process, nutrient retention from treated wastewater was found to enhance nutrient availability to plants. However, the precipitation of some forms, such as $MnHPO_4$ and $Ca_3(PO_4)_2$, may clog soil pores, impeding recharge pathways. These findings support the reuse of treated wastewater as a sustainable method for supplementing agricultural nutrients and ensuring safe groundwater recharge, while also providing a safe solution for disposal in wastewater treatment plants (Kumar and Yadav, 2025).

The TWW quantities used can explain the degree of motivation farmers have for using wastewater. Four groups of farms were taken according to their size and the amount of wastewater used. Table 3 indicates that most groups use less than 50 thousand liters of TWW per month for irrigation, with 183 farmers (48.7%). The second-largest group, consisting of 122 farmers (32.4%), uses between 51 and 100 thousand liters monthly. Only 18 farmers (4.8%) use or will use more than 300 thousand liters per month.

Table 3. Monthly Usage and Percentage of TWW used by Farmers (Current and Projected)

Variable	Volume of TWW used/Month	Number of farmers	Percent % of use TWW
Current and projected amount of TWW for irrigation on your farm per month	≤ 50 thousand liters	183	48.7
	51-100 thousand liters	122	32.4
	101-300 thousand liters	53	14.1
	> 300 thousand liters	18	4.8
	Total	376	100

Reusing wastewater for crop irrigation becomes necessary due to freshwater scarcity and groundwater depletion. So, the environmental, social and economic impacts of wastewater treatment on irrigating crops were considered in the questionnaire.

3.5 Socio-economic and environmental impacts of treated wastewater use

To evaluate the socio-economic and environmental effects of the use of treated wastewater in irrigation, averages, standard deviations, and relative weights were computed. The findings indicated a considerable overall impact, an average score of 2.40 (80%). The economic dimension gained the best score, an average score of 2.67 (89%), with strong approval. Social was second with a mean score of 2.39 (79.7%), then came the environmental, with a mean of 2.17 (72.3%).

3.6 Social implications of irrigation with TWW

With regard to social impact, the use of wastewater in agriculture can affect the health of vulnerable populations, thereby increasing health problems and social suffering. The greywater is not potable, and therefore would be more appropriate for irrigation (Thaher et al. 2020; Al-Khatib et al. 2022). If wastewater is used for irrigation, it may affect the quality of agricultural products and reduce their value in markets. So, what was the social impact of the use of treated wastewater in irrigation? To answer the question, computational averages, standard deviations, and relative weights of the level of social effects resulting from the use of treated wastewater in irrigation were extracted. The social impacts of the use of treated wastewater scored between 1.53 and 2.76, with a general average score of 2.39, which represents a high level of agreement at 79.7%.

This indicates that the reuse of wastewater in agriculture results in major social impacts that are mainly linked to public health issues. The reuse of wastewater may pose hazards to the communities around it if not properly treated, as

it may contain toxic chemicals and diseases. Insufficiently treated wastewater may also lead to social disturbance and protests as citizens stage demonstrations against its use in agriculture. Slabbert et al. (2024) suggested a procedure for creating a national communication approach for water reuse in South Africa to be prepared through stakeholder input. The communications plan informs and creates literacy on water reuse and seeks to eradicate the numerous perceptions that exist about it.

The strategy is adaptive and may be vital to deal with intricate views regarding water reuse.

Previous studies (Hamdan et al. 2022; Al-Khatib et al. 2022) have seen residents of the West Bank acknowledge the severe scarcity of water in Palestine and view properly treated wastewater, according to international criteria, as a valuable agricultural asset. Surprisingly, 62% of people were ready to use greywater for irrigating vegetables, a strategy validated by operations at the Al-Bireh station, where treated wastewater was successfully used in cultivating a variety of crops, including vegetables, roses, citrus, olives, and other fruit trees (Nofal, 2011).

3.7 Environmental impact of using treated wastewater in irrigation

The environmental impacts of wastewater use in agriculture depend on several factors, including wastewater treatment; if wastewater is effectively treated before it is used in agriculture, this may reduce negative environmental impacts. So, the level of environmental impacts from the use of treated wastewater in irrigation was asked? To answer the question, computational averages, standard deviations, and relative weights of the level of environmental impacts resulting from the use of treated wastewater in irrigation were extracted

The overall mean environmental effect rating was 2.71, equivalent to 72.3% agreement with the component's outcome. Such a high rating may be due to various factors concerning the

ecological impacts of using treated wastewater for irrigation.

Ibrahim (2019) attempted to determine the suitability of wastewater quality from selected wastewater treatment plants in Jordan for irrigation purposes based on a weighted arithmetic water quality index (WQI) approach according to the Jordanian standards for reclaimed domestic wastewater. Fifteen physical, chemical, and microbiological parameters were selected to calculate the WQI. According to the WQI scale classification, most of the selected wastewater treatment plants were not fully compliant with the Jordanian standards for reclaimed domestic wastewater regarding the direct reuse of treated wastewater for irrigation purposes. The results of this study benefit water managers and policymakers in taking sound actions regarding water resources and agricultural management in Jordan.

3.8 Farmer's benefit when TWW is used for irrigation

The "economic aspect" had the highest score, at a mean score of 2.67 (89.0%), indicating strong consensus. This might be attributed to the low price of TWW by comparison to other kinds of water. The average production is about 12, 15, and 12 tons per hectare, respectively, for apricot, grapes, and pomegranate, while the yield for non-irrigated agriculture is about 7, 10, and 8 tons per hectare, respectively (Ministry of Agriculture reports and farm visit). Also, no fertilizers are used when TWW is used. Overall, while treatment is expensive, irrigation with treated wastewater can conserve freshwater supplies, not to mention that the discharge of wastewater into the natural environment also has a cost. Respectively 44% and 60% of the Jordanian and Tunisian farmers who accept treated-sewage crops (18.3% and 28.5% of the total, respectively) report potential economic return effects as the grounds for their choices. These results are consistent with Abu Madi (2008) and Lahlou et al. (2001), which highlight economic advantages of wastewater reuse, e.g., savings in disease and environmental pollution in Bengaluru in India. Interventions, where possible, would be tailored to the specific cost, risk, and benefit perception of the target group (Kollmann et al., 2023).

Even if the household surveys reveal that, respectively, 89% and 100% of the Jordanian and Tunisian farmers who reject raw-sewage crops (97.1% and 99.3% of the total,

respectively) report that perceived health impacts are the reason.

The sensitivity of populations to the environment can be a driver of the use of WWT, and it can depend on the education level.

3.9 Impact of the education level on environmental and socio-economic water reuse factors.

The level of education significantly influences awareness and knowledge of the social, environmental, and economic benefits of using treated water for irrigation. As the level of education increases, the level of environmental protection, economic benefit, and capacity-building knowledge can be enhanced.

The economic implications of wastewater utilization in agriculture can be significant due to high costs and heterogeneous effects on the market and society. However, statistical analysis revealed no significant differences ($\alpha \leq 0.05$) in the perceptions of social, environmental, and economic impacts among study participants by level of education.

To confirm this, averages, standard deviations, and a One-Way ANOVA test were employed to compare the perceived effects of individuals with varying levels of education. Table 4 shows the differences in mean scores for the effects of treated wastewater use by level of education and the number of respondents per level of education.

One-way ANOVA tests were conducted in order to test the significance of the variation, as shown in Table 5. The results show statistically significant variation at the $\alpha \leq 0.05$ level in the total impacts of utilizing treated WW in agriculture, largely due to variation in education levels. The p-value for total impacts calculated is 0.001, lower than 0.05, indicating statistical significance.

In addition, the study sample average scores for the social, environmental, and economic impacts of treated wastewater use differed significantly, where p-values amounted to 0.007, 0.004, and 0.001, respectively, all being less than 0.05, revealing statistical significance.

In favor of these findings, research carried out by Thaher (2020) identified that the educational level influences acceptance of wastewater treatment stations, with 73% of the uneducated being satisfied compared to 58.8% of educated individuals who were dissatisfied. The same

Table 4. Respondent statistics on perceived social, environmental, and economic impacts of using treated wastewater in agriculture by education level.

Aspects	Educational level	Number	Arithmetic average	Standard deviation
Social aspect	Initial	29	2.26	0.39
	Secondary	113	2.37	0.34
	Undergraduate	140	2.39	0.28
	Postgraduate	94	2.47	0.23
	Total	376	2.39	0.30
Environmental aspect	Initial	29	1.95	0.41
	Secondary	113	2.16	0.39
	Undergraduate	140	2.22	0.37
	Postgraduate	94	2.18	0.36
	Total	376	2.17	0.38
Economic aspect	Initial	29	2.42	0.36
	Secondary	113	2.59	0.44
	Undergraduate	140	2.72	0.28
	Postgraduate	94	2.77	0.21
	Total	376	2.67	0.35
Total effects	Initial	29	2.20	0.25
	Secondary	113	2.36	0.27
	Undergraduate	140	2.44	0.16
	Postgraduate	94	2.46	0.17
	Total	376	2.40	0.22

Table 5. One-Way ANOVA test results on impacts of treated wastewater use in agriculture by education level.

Aspects	Source of variation	Sum of squares	Degrees of liberty	Average boxes	Calculated p-value	Level of statistical connotation
Social aspect	Inter -group	1.19	3	0.40		
	In -group	32.17	372	0.09	4.59	**0.004
	Total	33.36	375			
Environmental aspect	Inter -group	1.73	3	0.58		
	In -group	52.79	372	0.14	4.06	**0.007
	Total	54.52	375			
Economic aspect	Inter -group	3.92	3	1.31		
	In -group	40.96	372	0.11	11.85	**0.001
	Total	44.88	375			
Total effects	Inter-group	1.82	3	0.61		
	In-group	16.11	372	0.04	14.01	**0.001
	Total	17.93	375			

**Statistically significant at an indicative level (0.01).

findings were observed in similar research (Deek et al., 2010; Arafat, 2012), where significant differences in favor of individuals with higher education levels indicated that more scientific knowledge enhances acceptance of treated wastewater. These findings align with our study, which shows that higher levels of education are positively correlated with greater acceptance of using treated wastewater.

The Scheffe test was utilized in detecting the sources of variation in study respondents' mean scores by their level of education on the social, environmental, and economic benefits of using treated wastewater in agriculture. Results are in Table 6 and indicate the following bilateral comparisons:

- *Social Impacts*

Differences in mean scores relating to the social impacts of treated wastewater utilization are linked to the level of education. Specifically, there were significant differences between the primary and postgraduate levels of education, with the latter group finding greater social benefits.

- Environmental Impacts

The study shows that the mean score for environmental impacts also varies by level of education. Farmers with lower education levels reported less impact in comparison to those who possess postgraduate degrees.

- Economic Impacts

Mean scores for economic impacts also vary based on the level of education. Farmers with tertiary or postgraduate education reported more economic advantages in comparison to those with primary or secondary education only.

- Overall Impact

The overall perceived impact of treated wastewater use in agriculture varies by education level.

Farmers with tertiary or postgraduate education rated the overall impacts higher than those with secondary or primary education only.

Educational and social factors can help explain the differences in perceived social effects of wastewater use in agriculture among individuals with varying education levels:

- **Environmental and Technological Awareness:** Individuals with university and postgraduate education often have a deeper understanding of environmental and technological issues related to wastewater treatment. This knowledge leads to more sustainable and effective agricultural practices.
- **Analysis and Economic Planning:** Higher education equips individuals with skills to analyse economic data and plan agricultural projects using wastewater, allowing for accurate assessment of benefits and costs to make informed decisions.
- **Innovation and Technological Development:** Advanced education can foster innovation in wastewater treatment techniques and their agricultural applications, resulting in more effective and sustainable solutions to environmental and economic challenges.

- **Participation in Decision-Making:** Educated individuals often influence economic and political decisions concerning agriculture and water resource management, shaping policies and investments that reflect societal interests and environmental preservation.

- **Education and Public Awareness:** Higher education promotes disseminating knowledge about the effective use of wastewater in agriculture, encouraging sustainable practices.

The study supports Abu Madi et al.'s (2004) findings, highlighting wastewater reuse's economic benefits on the West Bank, including enhanced water resources, agricultural value, and environmental protection. Other studies (Al-Rimawi, 2014; Dabous, 2012; Faria & Naval, 2022; Verhoest et al., 2022) noted that insufficient commitment to health, environmental, and medical precautions, along with weak oversight and lack of coordination among regulatory bodies, undermines the safe reuse of treated wastewater in agricultural irrigation in Brazil, Italy, most European countries, Palestine and neighboring countries. Amaris et al. (2020) applied discrete choice models to predict, for the first time, socio-economic groups' greywater preferences over quality attributes like color and odor, and various household uses. It was established that on-site greywater systems were less acceptable when water quality was low. These findings determine the role of education, economy, and environment in deciding the use of wastewater in agriculture in Santiago, Chile. Similarly, Burnat (2009) indicated that treatment plants for greywater at household levels produce beneficial impacts on water and food production, household income, self-provisioning, and plant growth while reducing soil and air pollution and increasing regional aesthetics.

Results indicated an important overall impact with a mean of 2.40 (80%). Economic impact was most valued at 2.67 (89%), which indicated widespread acceptance. The social impact scored the next value of 2.39 (79.7%), and the environmental impact scored 2.17 (72.3%). Even if the acceptability of irrigation with TWW is almost very obvious, the long-term effects on the soil remain to be examined.

3.10 Long-term environmental and agricultural implications of wastewater use

No adverse effects on the population or animals were observed. According to measurements conducted by the Ministry of Agriculture (see

Table 7), the soil in the Nablus area shows the following nutrients composition. Soil samples were collected from beneath almond trees at a depth of 0–30 cm, both before the use of wastewater in 2021 and after the application of wastewater in 2024. The soil in this area is classified as clay loam.

WWT has an inlet and outlet average electrical conductivity of about 1.6 and 1.4 dS/m respectively. In soil, an increase is generally observed for all parameters. In the case of electrical conductivity (EC), regular monitoring must be carried out because with this rate of increase, a soil salinization can be observed, resulting in the abandonment of several crops sensitive to salinity and even any other agriculture activity. The level of the water table is about 25 m and it must be monitored in turn because in the event of the presence of an impermeable layer, a water table can be formed in the long term.

The environmental effect of applying treated wastewater in agriculture can be regarded as moderate if proper precautions are observed during treatment and application. This is consistent with a study done by Mancuso et al. (2023), which indicated benefits in long-term monitoring of Nature-based Solutions (NBS). Their study provided recommendations on how to improve water quality, including Class A standards. It established the applicability of reclaimed water to meet crops' water and nutrient needs and nitrogen removal rate estimates for upcoming lagoon systems. Also, the introduction of advanced (tertiary) treatments can broaden the scope of use of wastewater even under market gardening.

In (Darabee, et. al 2022) study, the main objective is to accelerate the disinfection process of contaminated water using solar energy when adding hybrid nano-liquid mixtures. Five hybrid nano-liquid mixtures containing different amounts of aluminum oxide (Al₂O₃) and titanium oxide (TiO₂) nanoparticles were used, focusing on how they affect the disinfection of contaminated water using solar energy. It was found that the addition of a hybrid nano-liquid mixture of any composition accelerated the disinfection process. In addition, the optimal concentration of the hybrid nanofluid mixture to reduce the total coliform count was found to be 250 mL of Al₂O₃ and 250 mL of TiO₂, while the optimal concentration to reduce the number of E. coli was 400 mL of Al₂O₃ and 100 mL of TiO₂. Finally, it can be concluded that among all the

hybrid mixtures used, the hybrid nanofluid with a volume concentration of 250 mL of Al₂O₃ and 250 mL of TiO₂ is the most efficient in the solar water disinfection process.

4. CONCLUSIONS

This study explored wastewater's quality, components, and disposal methods and assessed its potential for use in irrigation after treatment, comparing findings with global standards. It investigated the societal acceptance of treated wastewater for crop irrigation and public parks in the study area.

The overall impact on the use of treated wastewater based on social, environmental, and economic considerations was strongly valued and averaged 2.40 (80.0%). Financial was the highest (2.67), followed by social (2.39) and environmental (2.17). Overwhelmingly, 82.7% of farmers consent to use treated wastewater in agriculture, while 55.3% of farmers believe treated wastewater positively impacts crop quality and yield, and 43.1% of farmers believe treated wastewater improves agricultural yield. No significant variations in land size or agriculture effects were noted, but education significantly influenced perceptions, with higher education being linked to more favorable attitudes. The organization of training workshops on wastewater uses helps to make better use of wastewater.

The search for the necessary funds to connect wastewater treatment plants to irrigate areas must begin. Some aspects require special attention, such as monitoring the evolution of soil salinity and health parameters. Also, the compost component requires consideration and is also a potential source of fertilization, but particular attention must be paid to the health aspects.

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