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Assessment of Fresh Water Reallocation by Treated Wastewater for Irrigation

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Abstract

This study investigates the economic feasibility and farmer acceptance of utilizing treated wastewater (TWW) for agricultural irrigation in the Northern Jordan Valley (NJV). Despite its potential to mitigate water scarcity, concerns about soil health, crop yield, and land utilization hinder widespread adoption. The research measures farm profitability and farmers' willingness to embrace TWW through various blending scenarios with traditional surface water sources, incorporating a yield response function to salinity within the profit function. Results reveal that TWW adversely affects salt-sensitive crops like citrus, with net profit declining from US$ 8,666/ha at 0% TWW to US$ 5,152/ha at 100% TWW. Conversely, crops such as date palms and olives maintain stable profitability, with date palms showing minimal variation around US$ 20,370/ha. Economic indicators highlight substantial profit declines for crops like peppers, which drop to US$ 714/ha at 100% TWW. The net value added for citrus decreases from US$ 0.81/m³ to US$ 0.46/m³, while date palms increase from US$ 1.36/m³ to US$ 1.41/m³, indicating resilience to salinity. Farmers' willingness to pay for water varies, exceeding US$ 0.70/m³ for tomatoes and peppers, while olives remain below US$ 0.14/m³. These findings underscore the importance of understanding crop-specific responses to TWW blending and emphasize a holistic approach that considers both economic viability and environmental impacts for sustainable agricultural practices.

Keywords: Agricultural Sustainability; Crop Sensitivity; Economic Feasibility; Irrigation Management; Profitability; Salinity; Treated Wastewater; Yield Response Function.

1. Introduction

Agriculture is the largest consumer of water worldwide, accounting for approximately 70% of global water use [1-3]. Given this significant demand, wastewater reuse presents a promising alternative for sustaining water availability in the agricultural sector. Although the practice of using wastewater for irrigation dates back to ancient times, particularly in arid and semi-arid regions, its adoption remains limited in some areas. This is often due to a perceived abundance of

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water resources or insufficient infrastructure and investment [2, 3]. Arid regions are experiencing an increasing disparity between water supply and demand [4]. Urban water demand continues to rise, with cities frequently receiving priority in freshwater allocations, often to the detriment of irrigated agriculture. In the Middle East and North Africa (MENA) region, agriculture remains the largest water-consuming sector but yields the lowest economic return per unit of water used, posing a significant challenge for sustainably meeting both current and future water requirements [5, 6]. To address this growing gap in irrigation water availability, governments across the MENA region are actively promoting the reuse of treated wastewater (TWW) as a strategic solution [7].

The use of TWW in agriculture presents a viable alternative for reducing freshwater (FW) demand while enhancing soil quality, potentially decreasing or even eliminating the need for fertigation. However, TWW irrigation poses risks of contamination from hazardous substances [8], organic micropollutants, and pathogenic microorganisms [9, 10]. Farmers and stakeholders are particularly concerned about its potential negative impacts on soil health, land use, and crop production [11]. Improper management of TWW irrigation can threaten public health and the environment due to its microbial and toxic components. Although good agricultural practices can help mitigate environmental impacts and contamination, concerns remain regarding soil quality degradation, crop growth limitations, increased salinity, clay dispersion, and pathogen presence [12].

Wastewater reuse has gained recognition as a sustainable solution to water scarcity; however, its adoption is often challenged by public perception, health concerns, and regulatory limitations. While many acknowledge water shortages, there is a general lack of awareness regarding water sources and treatment processes. Public acceptance of water reuse differs across regions. There is strong support in drought-affected areas, but significant hesitation remains for applications involving direct human contact [13]. Addressing these concerns and enhancing public understanding is essential for promoting wastewater reuse, especially in MENA countries, where research and regulations remain limited [14].

Jordan ranks among the most water-deprived countries globally [15], with future predictions indicating a worsening situation due to increasing temperatures, reduced precipitation, and runoff. Currently, Jordan's renewable water resources satisfy about two-thirds of the population's overall water demands, while groundwater extraction exceeds its natural recharge rate. The per capita renewable water resources in Jordan are under 65 cubic meters annually, which is only one-fifth of the United Nations' lowest standard for water scarcity [15]. By 2040, climate change simulations predict a reduction in precipitation by 10 to 15 mm (13-20% less) compared to current levels, with more severe droughts anticipated. In response to these challenges, Jordan has formulated a water substitution and reuse policy that emphasizes the use of TWW as an alternative water source [16].

1.1. Agriculture's Water Consumption

Agriculture consumes approximately 52% of Jordan's total water resources [17] and about 70% of its groundwater, despite contributing only around 4% to the Gross Domestic Product (GDP) [18]. However, agriculture plays a crucial socio-economic role and holds significant political importance. Since 2011, the sector's contribution to the economy has been steadily increasing, partly due to the rise in vegetable and fruit-tree production. Water conservation is a lower priority for farmers in the Northern Jordan Valley (NJV) compared to those in highland areas. The NJV is a vital irrigated zone, contributing approximately 40% to the agricultural GDP [19]. Representing more than 50% of the irrigated area in the region, it significantly constrains farmers' water allocation. The government has boosted and expanded irrigation infrastructures in the NJV, leading farmers to adopt new irrigation and cropping systems, such as plastic houses, drip irrigation, plastic protection, fertilizers, and new seed varieties.

1.2. Reuse of Treated Wastewater

Jordan has been utilizing TWW for agricultural purposes for four decades. According to the "National Water Strategy 2023-2040," all TWW is designated for irrigation use, with the Ministry of Water and Irrigation (MWI) establishing wastewater treatment plants across the country to implement this strategy [20]. Currently, TWW constitutes 30% of Jordan's irrigation water and about 15% of the total water budget [17, 21]. The composition of wastewater in Jordan is somewhat distinct compared to other countries, with higher raw wastewater strength due to lower average domestic water consumption per capita [22, 23]. Additionally, Jordan's wastewater is relatively low in toxic pollutants such as heavy metals and organic micro-pollutants. Nonetheless, existing regulations restrict the direct application of treated effluent for irrigation in agriculture, specifically for fodder crops and fruit trees, prohibiting its use for all types of vegetables [24, 25]. Even though the effluent quality from most treatment plants in Jordan is suitable for restricted irrigation, there is a cultural tendency among farmers and decision-makers to impose even stricter limitations. Policies aim to replace fresh surface water in the NJV's irrigation systems with TWW, permitting agricultural expansion only where such water is available [26, 27]. Plans are underway to increase TWW delivery from 135 to 240 million cubic meters (MCM) and to reallocate withdrawn fresh water (FW) from irrigation to domestic supply.

1.3. Risks and Regulation of Treated Wastewater Use

The attempt to curtail fresh surface water with TWW in Jordan's agricultural practices entails several significant risks: such as employing TWW for irrigation purposes, which raises concerns regarding potential health hazards due to residual pathogens, chemicals, and heavy metals if the treatment process does not sufficiently eliminate these contaminants [28]. To ensure public health and the safe use of TWW in agriculture, the Jordan Standards and Metrology Organization (JSMO) developed and issued the Jordanian Standards 893/2021 [24, 25], as displayed in (Table1), which are based on World Health Organization (WHO) guidelines [29]. These standards and regulations strictly prohibit the use of TWW for irrigating any type of vegetables [25]. The regulation places significant emphasis on water quality parameters from an agronomic perspective, introducing stricter limits on Total Suspended Solids (TSS), recognizing the critical role of TSS in preventing clogging in drip irrigation systems.

The JS 893/2021 standard for wastewater discharge and reuse represents a significant step forward in promoting sustainable water management practices in Jordan. While the stricter regulations on nitrogen and phosphorus levels are crucial for protecting environmental and public health, they also pose considerable challenges in terms of increased treatment costs, economic impacts on agriculture, and the feasibility of compliance, as shown in Table 1.

Table 1. Current Jordanian standards (JS 893/2021) for reclaimed domestic wastewater for irrigation purposes

Parameter	Unit	Jordanian permissible limits for the reuse of reclaimed wastewater for irrigation purposes				
		Class A (Parks, playgrounds, and sides of roads inside the cities)	Class B (Fruit trees, sides of roads outside the cities, and green areas)	Class C (Industrial crops, field crops, and forest crops)	Class D (Cut flowers)	Discharge into streams or water bodies
pH	SU	6.9	6.9	6.9	6.9	6.9
BOD_5	mg/l	30	100	200	15	60
COD	mg/l	100	200	300	50	150
TDS	mg/l	1500	1500	1500	1500	1500
TSS	mg/l	50	100	100	15	60
NO_3-N^-	mg/l	16	16	16	16	20
TN	mg/l	70	70	70	70	70
PO_4^--P	mg/l	10	10	10	10	5
Cl^-	mg/l	500	500	500	500	500
HCO3-	mg/l	400	400	400	400	400
Na^+	mg/l	230	230	230	230	200
Mg^+	mg/l	100	100	100	100	60
Ca^+	mg/l	230	230	230	230	200
SAR	Unitless	9	9	9	9	6
E. coli	MPN/100ml	100	1000	-	1.1	1000

The increasing reuse of TWW has diverse economic ramifications, particularly concerning yield, productivity, and farmers' willingness to invest in this resource. Incorporating TWW may initially offer advantages in augmenting yield and productivity through an alternative irrigation water source [30]. However, the prolonged use of TWW might cause adverse effects on soil quality, potentially leading to reduced agricultural output and subsequently impacting farmers' income. Financial implications are also pertinent, as while TWW may present a cost-effective irrigation alternative compared to FW, there are associated costs with adapting infrastructure to utilize reclaimed water. Such expenses could strain the finances of smaller-scale farmers, potentially limiting their ability to invest in this technology [31].

1.4. Long-Term Effects of Treated Wastewater Use and Agricultural Sustainability

The initial benefits of using TWW as an irrigation source may decrease over time because of the buildup of salts and contaminants in the soil [30]. This accumulation can elevate soil salinity levels, adversely affecting crop growth and productivity. As a result, farmers may experience reduced yields or even crop failures, directly impacting their income and livelihoods. The economic repercussions of decreased yield due to increased TWW usage and resulting soil salinity are substantial. Farmers heavily rely on consistent and robust yields for their income generation. The decline in crop productivity resulting from soil salinization not only threatens their financial stability but also amplifies the financial risks associated with agricultural activities, .and may impede farmers' ability to invest in necessary agricultural inputs or adapt to alternative cultivation methods.

In the near future, developing water resources in the NJV should focus on alternative water sources, such as rainwater harvesting, desalination of brackish water, and the reuse of TWW, increasing the storage of surface-water runoff; artificial recharge, where feasible, and, most importantly, sustaining the existing supply levels. Approximately 70% of Jordan's fruit and vegetable production originates from the NJV, which is considered the country's food basket. The total irrigable area in the NJV is around 36,300 hectares. Farmers receive irrigation water based on the cropping pattern, with citrus trees being the most prevalent in the NJV, where the water allocation for citrus is 40 m^3 per day per ha^{-1}. The primary vegetables grown in the NJV include tomatoes, eggplants, and squash. However, modifying cropping patterns requires both technical assistance and political support. One approach is to maintain a limited number of traditional water-intensive crops that are essential for local consumption and have high market value, such as bananas, while simultaneously transitioning to less water-intensive crops that can better tolerate salt in irrigated water. While the NJV constitutes 6% of Jordan's total cultivated area, its contribution to national agricultural production is more significant at 11%. This suggests that the region exhibits higher productivity on average, indicating potential areas for expansion and enhancement in agricultural practices.

The Department of Statistics (DOS) data indicates that citrus cultivation dominates the NJV, encompassing 5,894 hectares, representing a substantial 83% of the total citrus cultivation in Jordan [18]. The NJV accounts for 88% of the total citrus production, emphasizing its significant contribution to the national yield, which stands at 107,463 tons. In contrast, the date palm cultivation in the NJV occupies a relatively smaller area, standing at 3,228 hectares, contributing to 7% of Jordan's total palm cultivation. However, the growth rate in the NJV is notably high at 15.1%, indicating a burgeoning sector. Similar trends are observed in grapes, where the NJV represents 11% of the total cultivated area, showing a growth rate of 10.6%. The production in the NJV contributes to 10% of the national grapes yield, with a slightly higher yield of 13.9 tons ha^{-1}. Tomatoes and Peppers exhibit noteworthy trend. Despite a negative growth rate, tomatoes cultivation in the NJV covers 5,201 hectares, contributing to 8% of national production, with an impressive yield of 90.5 tons/ha. Pepper, with a growth rate of 0.97%, sees a substantial 13% of the NJV's area contributing to 17% of the national pepper production, boasting a yield of 51.3 tons/ha.

1.5. Shifts in Crop Cultivation and Water Management

Farmers in this region have begun shifting from citrus to other irrigated crops, including date palms and grapes. The area enjoys relatively high rainfall, with over 400 mm in the northern parts and around 300 mm in the southern parts. Citrus irrigation typically occurs from March to November, with limited irrigation outside this period depending on the season’s rainfall. The King Abdullah Canal (KAC) provides the irrigation water, which is divided into two main sections: (1) Northern KAC, 65 km long, fed by freshwater and used for both domestic and irrigation needs; and (2) Southern KAC, 45 km long, fed by blended water and primarily used for irrigation, though 14.5 km of this section is not fully operational. However, approximately 15 to 20 MCM per year of TWW from the Northern region's Wastewater Treatment Plants (WWTPs), mainly Wadi Al Arab, Shalalah, Center Irbid, and later Ramtha, is currently unused as it is being discharged into the Jordan River. Despite the hydraulic infrastructure being in place since 2016 to utilize this water for irrigation in the NJV after blending with freshwater, the quality of the final effluent does not meet the standards and specifications for irrigation water, making it unsuitable for citrus irrigation. Both the Jordan Valley Authority (JVA) and Water Authority of Jordan (WAJ) are working to expedite the process of improving water quality at the Center Irbid WWTP and other Northern WWTPs to enable the use of treated effluents for irrigation in the NJV once they are mixed with sufficient freshwater.

Water salinity can greatly affect citrus production, as citrus trees are highly sensitive to changes in soil and irrigation water salinity [32, 33]. Elevated salinity levels in irrigation water or soil can hinder citrus tree growth and overall yield, causing osmotic stress and alters nutrient uptake. The presence of salts in the water can disrupt the plant's ability to absorb essential nutrients, resulting in stunted growth and smaller fruit. Osmotic stress occurs when the soil's salt concentration exceeds that of the plant's roots, reducing water uptake by the tree, which lead to wilting and decreased fruit production. High salinity can also interfere with the absorption of key nutrients such as potassium, calcium, and magnesium, resulting in nutrient deficiencies that affect fruit quality and size. Water with high salinity is toxic to plants, and presents a salinity hazard. Soils with high total salinity levels are referred to as saline soils. High salt concentrations in the soil can create a "physiological" drought condition, causing plants to wilt because their roots cannot absorb water, despite adequate moisture in the field [34, 35]. The elevated salt content in TWW is typically 1.5–2 times higher than that of Fresh Water (FW). This elevated salt content in TWW can contribute to increased soil salinization, sodication, and structural changes, potentially resulting in reduced yields for salt-sensitive crops [36, 37].

1.6. Impacts of High Salinity Water on Citrus Production

Citrus irrigated with high-salinity water can experience reduced growth and production [33]. Salinity impacts citrus in two main ways: osmotic stress and toxic ion stress. Dissolved salts create an osmotic effect that decreases the availability of free (unbound) water, similar to drought stress [33]. Fruit yields decrease by about 13% for each 1.0 dS/m increase in the electrical conductivity of the saturated-soil extract (ECe) once soil salinity exceeds a threshold ECe of 1.4 dS/m [33]. The primary chemical risks associated with TWW reuse for irrigation are excessive concentrations of salt, heavy metals, nutrients, toxic organic compounds, and organic matter [33]. Concerns about using TWW for irrigation include potential damage to soil quality and crop development, increased salinity, clay dispersion, reduced soil hydraulic conductivity, and the presence of pathogens, posing a public health risk [12]. The elevated presence of heavy metals in wastewater poses potential risks to both humans and animals, as these metals can accumulate in soils and crops. While heavy metals within safe limits in irrigation wastewater may not pose a significant issue, exceeding these limits can result in toxicity [38]. Consequently, diligent monitoring of heavy metals concentrations in water, soils, and crops becomes imperative when employing TWW for irrigation. Excessive levels of these compounds could lead to their accumulation in crops, posing risks to human and animal health.

Several studies in Jordan indicate that farmers are likely to adopt TWW for irrigation if they perceive it as economically beneficial, socially acceptable, environmentally sustainable, and as posing little or no health risks [39-42]. In Jordan, the wastewater treatment systems do not remove nitrogen (N) and phosphorus (P). Typically, the secondary effluents contain 10 to 50 mg/L of total N and 10 mg/L of P. The social acceptance of wastewater reclamation and reuse in agriculture, particularly among farmers, is influenced by local cultural, religious, and socio-economic factors. Additionally, economic and technical factors play a crucial role, including water and wastewater treatment costs, maintenance expenses, the employment of rural labor, and the structure of irrigation networks and crop patterns [43]. Farmers with the option to choose between TWW and other water sources consistently prefer the alternatives, despite higher costs due to social stigma and crop restrictions associated with TWW reuse. Therefore, social marketing and awareness-raising efforts are crucial in reducing opposition to wastewater reuse [6]. A three-year study revealed that nectarines irrigated with TWW exhibited higher quality parameters, antioxidant compounds, and total phenolic content than those irrigated with FW, attributed to the substantial nutrient content in TWW. However, the number of fruits was lower under TWW treatment, but this reduction was offset by the larger weight of individual fruits [44].

This research aims to investigate the potential economic impact of replacing FW with TWW in the NJV. Additionally, it seeks to assess the economic performance and farm profitability resulting from this reallocation or partial blending of the two water sources. Blending TWW with surface water can increase the water supply for farmers in the Northern NJV and enhance overall water availability. This study analyzes the economic impact of this approach by evaluating the effects of increased water salinity on crop productivity. It assesses crop responses to salinity with TWW mixtures at ratios of 10%, 25%, 50%, 75%, and 100%. The analysis involves evaluating crop yields, comparing the financial performance of farms using TWW versus FW, and exploring any differences in production costs.

2. Material and Methods

Assessing the potential economic increment for farm productivity, farm output, reduced chemical costs, and an improved value chain requires a thorough evaluation of the potential increments for gross production, crop yield, and suitability of crop cultivation, as a result of reusing TWW. This economic analysis requires precise information about farm economics, particularly regarding additional costs and returns at the farm level. Farmers, as decision-makers, manage a specific land area, a given water quota, and other restrictions. Creating representative crop budgets and cropping patterns for the study area requires simulating the situation before and after reusing additional TWW for agriculture, along with improvements to the irrigation system, as illustrated in Figure 1.

Figure 1 illustrates the step-by-step methodology of this study. The process begins with defining the research objective, followed by selecting the study area and collecting relevant data on farm economics, water allocation, crop yields, and farmer perceptions. A farm model is developed to simulate various TWW blending scenarios, which are then analyzed for the economic implications of the scenarios, crop yield responses, and farmers' willingness to pay for water. The study further evaluates the environmental and economic impacts before drawing conclusions and providing policy recommendations for sustainable wastewater reuse in agriculture.

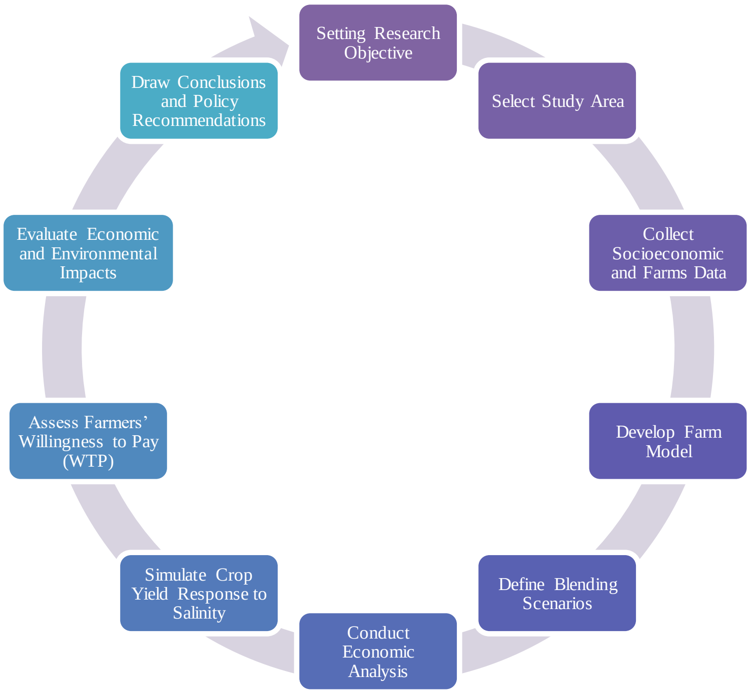

Figure 1. Methodological framework for assessing the economic feasibility reusing TWW for irrigation

2.1. Study Area

The NJV study area extends from 31° 40.8' N to 32° 19.7' N latitude and from 35° 32.7' E to 35° 40' E longitude, with an elevation ranging from -200 m below mean sea level (bmsl) in north to about -300 m bmsl in the south. The total area for the NJV included in this study is more than 182 km^2 as shown in Figure 2.

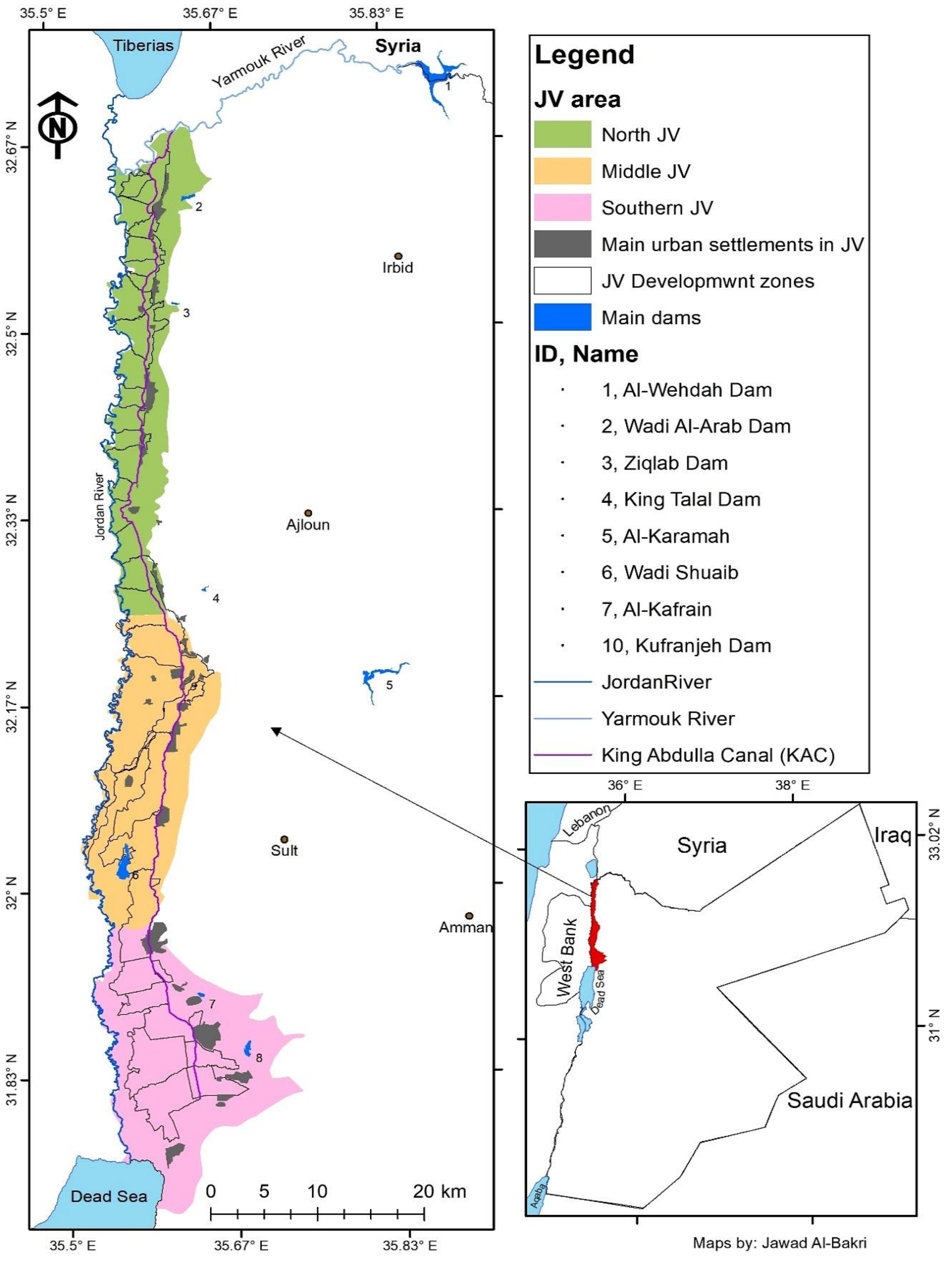

Figure 2. location of the study areas

This study focuses on the northern district of the NJV, where the JVA's water-allocation rules apply as shown in Figure 3.

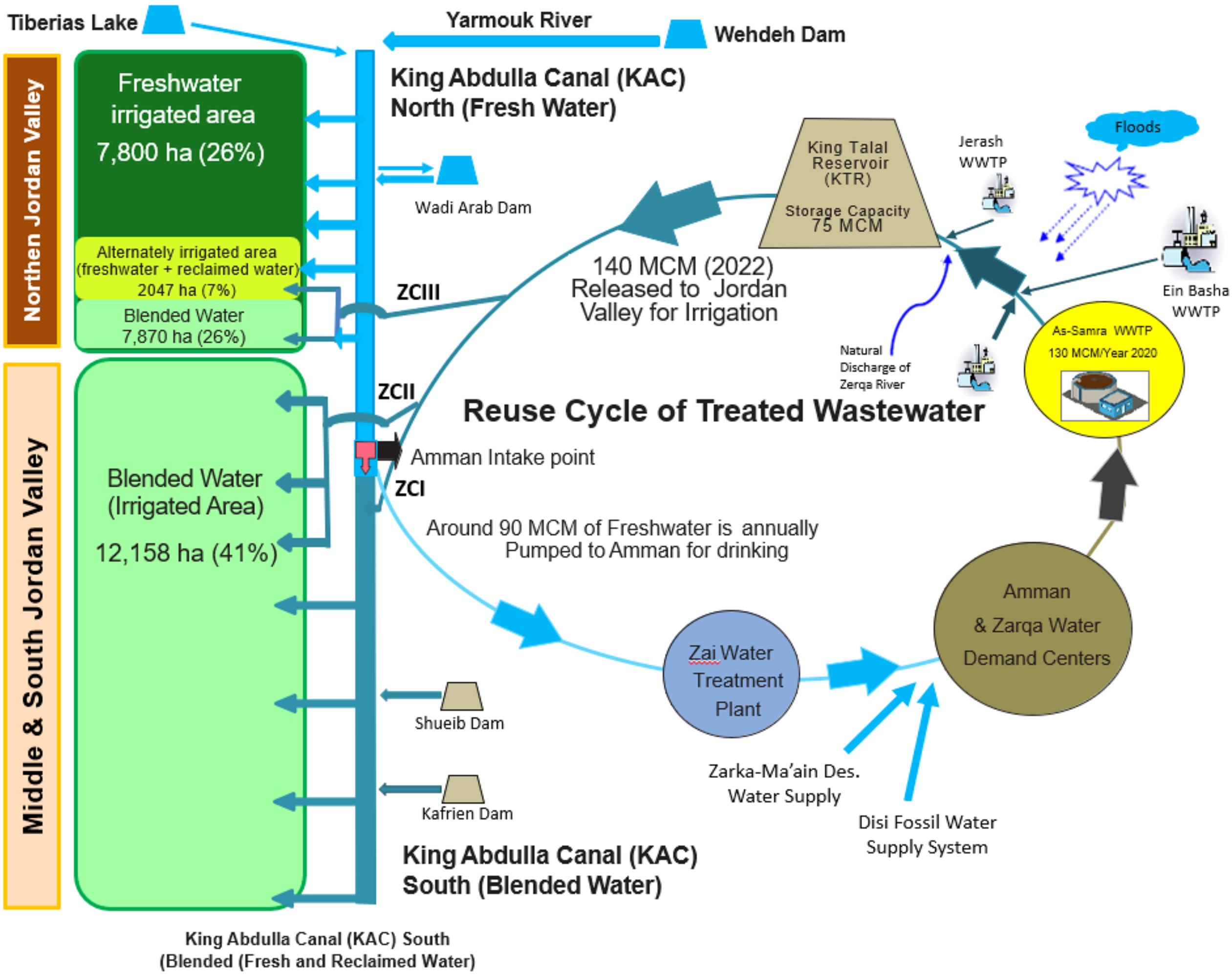

Figure 3. Reuse cycle of treated wastewater

The NJV experiences a warm winter, averaging a minimum temperature of 13°C in January, and a hot summer, with August temperatures peaking at an average of 32°C. The region receives approximately 400 mm of rainfall annually. This warm climate supports significant agricultural activity, making the area a key producer of vegetables (such as tomatoes and okra), bananas, citrus fruits, grapes, and date palms. Soil surveys and maps indicate that the irrigated land is characterized by deep, fine to medium-textured soils with low salinity, which are well-suited for most irrigated crops. Irrigation primarily takes place west of the KAC on farm units developed by the JVA. Additionally, rained cultivation of cereals and olive trees is common on the lands east of the KAC.

Currently, about 60% of the irrigated area is irrigated with 'blended TWW,' while less than 31% is irrigated with FW. The remaining 9% is still alternately irrigated with both waters, FW and 'blended TWW.' It should be stressed that the entire NJV is expected to be completely irrigated with 'blended TWW' within the next few years, an objective that is likely to be achieved in the near future in light of the increasing TWW amounts from As-Samra WWTP, in addition to the utilization of the combined effluent from the three WWTPs in northern NJV: the Central Irbid, Shalaleh, and Wadi Arab WWTPs. The special significance of wastewater reuse in the NJV lies in the substitution of FW with sufficient 'blended TWW.' In doing so, the sustainability of agriculture and the availability of FW for drinking water are both secured in the NJV.

2.2. Building a Farm Model

To assess the economic impact of TWW utilization for irrigation in the NJV, we developed comprehensive enterprise budgets for the primary crops cultivated in the region, including citrus, date palms, bananas, and various vegetable crops that can benefit from TWW irrigation. These budgets are based on the most reliable estimates of returns and costs for 2023. The farm model specifically focuses on mature orchard crops, including citrus, grapes, olives, and other fruit trees. In constructing the enterprise budgets, we established two scenarios: the "Business as Usual" (BAU) scenario, which reflects existing farming conditions without TWW, and the "Project" scenario, which incorporates TWW reuse. The latter scenario accounts for expected changes in yield response to salinity, reduced fertilizer costs, and increased water consumption due to the supply augmentation from treated effluents.

For each crop, the budget tables include columns for both scenarios, allowing for a direct comparison of farm income before and after implementing TWW reuse. Total returns (US$/ha) are calculated based on average farm-gate prices (US$/ton) for the main products and by-products, alongside the average yield for each crop (ton/ha). These prices are derived from published data and supplemented by local farmer interviews. Total variable costs (TVC), primarily operational expenses, were obtained through interviews with farmers at the pilot site during the 2022-2023 crop years. TVC encompasses all expenses related to variable inputs necessary for crop production, including fertilizers, seeds, pesticides, water, labor, electricity, and repairs. Additionally, total fixed costs (TFC) were assessed, which include land rent or, if owned by the farmer, quasi-land rent, depreciation of capital assets (such as buildings and machinery), maintenance of irrigation networks, costs associated with plastic houses, amortization of seedlings for fruit trees, and interest on capital investments.

2.3. Building the Scheme Models and Blending Scenarios

The Jordan Valley Authority (JVA) is advancing plans to reallocate surface FW with TWW in the NJV. Although the necessary hydraulic infrastructure is in place, the current quality of TWW does not meet Jordanian irrigation water standards. To rectify this, the Ministry of Water and Irrigation (MWI) is rehabilitating four existing WWTPs to produce treated effluent that complies with these standards, facilitating blending with FW for irrigation.

This study focuses on evaluating the economic impact of reallocating surface FW with TWW, particularly examining how increased salinity levels might influence crop productivity in the NJV. Table 2 presents various TWW blending scenarios (S1-S5) and their corresponding effects on agricultural parameters. The scenarios involve mixing ratios of TWW to FW expressed as percentages, ranging from 0% to 100%. The blending ratios derived from this methodology were recommended in discussions with the MWI as an approach toward a safe blended reuse of TWW, and protecting both soil health and crop productivity for economic viability in the NJV. This approach enables the systematic evaluation of TWW effects on yield, salinity, and income, thereby providing data-driven limits of sustainable irrigation. Considering the existing blending infrastructure and the growing dependence on alternative water supplies, the electrical conductivity (ECw) of FW is consistently set at 1117 µS/cm, while TWW has an EC of 1725 µS/cm.

Table 2. Water quality of irrigation water by blending scenarios

Parameters	Unit	BAU	S_1	S_2	S_3	S_4	S_5
Mixing Ratio (TWW/FW)	Percent	0%	10%	25%	50%	75%	100%
FW salinity	ECw (µS/cm)	1117	1117	1117	1117	1117	1117
TWW salinity	ECw (µS/cm)	1725	1725	1725	1725	1725	1725
ECw irrigation water after mixing	ECw (µS/cm)	1117	1178	1269	1421	1573	1725
Added T-N after mixing	(mg/L)	-	5.97	14.93	29.86	44.78	59.71
Added T-P after mixing	(mg/L)	-	0.94	2.35	4.70	7.04	9.39
Added K+ after mixing	(mg/L)	-	3.20	7.99	15.98	23.97	31.96
Saving cost of fertilizers	US$ /m3	-	0.04	0.07	0.11	0.17	0.21
Decrease in total fertilizer costs	Percent	-	5%	13%	25%	38%	50%

Consequently, the ECw of the irrigation water increases as the proportion of TWW rises. The scenarios detail the agricultural outcomes associated with each blending ratio, including the percentage increase in crop yield due to enhanced water allocation, the proportional rise in water allocation from TWW mixing, and the resultant decrease in fertilizer costs. These parameters offer a comprehensive understanding of the potential agricultural benefits and economic implications of TWW utilization.

TWW serves as a low-strength multi-nutrient fertilizer, containing essential macronutrients such as N, P, and K. Nutrient concentrations in TWW vary based on treatment levels and seasonal conditions. Guidelines indicate that farmers can save up to 60% on fertilization costs by following technical recommendations for using TWW [34, 45]. In the NJV, TWW can meet more than 50% of crop nutrient requirements, though some farmers apply excessive amounts of P and K, not accounting for the nutrients present in TWW. The economic value of the macronutrients in TWW available in the NJV is estimated at around US$ 3.28 million, with nitrogen comprising 23%, phosphorus 20%, and potassium 57% [45, 46]. Assuming an average nitrogen content of 60 ppm and applying 1000 mm annually over two seasons, TWW can provide approximately 600 kg/ha/year of NO_3-N, supplying essential nutrients for crop production along with beneficial micronutrients and organic matter. This analysis offers valuable insights for sustainable water resource management and agricultural practices in the region [47].

2.3.1. Simulating Crop Yield Response to Salinity

To simulate crop yield response to salinity, yield data (ton/ha) were collected from field observations and farmers' interviews, supplemented by the Department of Statistics (DOS) annual report data. Crop yields vary based on production season, agricultural technology, and water quality. Table 3 presents a detailed overview of crop planting, production, and irrigation water requirements in the study area. This data encompasses a range of crops, including citrus, date palms, grapes, olives, bananas, wheat, barley, tomatoes, peppers, squash, and various vegetables.

In the "Planted Area" column, the total area allocated to each crop is specified. The "Cultivated or Bearing Fruit Areas" column distinguishes between actively productive areas and newly planted fruit trees, which, while requiring irrigation, have not yet reached maturity. The "Total Production" column quantifies the overall yield from productive areas in tons, while the "Average Yield" column indicates yield per unit area. The "Net Irrigation Water Requirements" column outlines the amount of water needed for irrigation per unit area, whether productive or not. The "Total Irrigation Water Demand" is calculated by multiplying the net irrigation water requirements by the cultivated area for each crop. This assessment highlights the significant demand for water resources necessary to sustain agricultural activities, emphasizing the critical role of irrigation in enhancing crop yields and ensuring food security. Understanding the total annual irrigation water demand for each crop provides valuable insights into overall water usage within the agricultural sector, essential for effective water resource management and planning.

Table 3. Summary of crop planting, production, and irrigation water requirements of the study area

Crop	Planted Area (ha)	Cultivated or bearing fruit Areas (ha)	------Total Production (ton)	Average Yield (ton/ha)	Net Irrigation Water Requirements (m^3/ha)	Total Irrigation Water Demand, annually (MCM)
Citrus	5,894	4,543	107,463	23.66	7,500	44.206
Date palm	323	202	3,542	17.55	9,580	3.092
Grapes	347	167	4,837	28.92	7,000	2.43
Olive	270	242	762	3.15	4800	1.296
Banana	136	88	4,628	52.58	11,000	1.496
Other trees	227	167	3,294	19.72	6,000	1.363
Wheat	833	797	2,999	3.77	3,500	2.914
Barley	145	120	372	3.11	3000	0.434
Other Field crop	316	290	7,808	26.95	4,000	1.265
Tomatoes	520	520	47,092	90.54	5,050	2.627
Pepper	349	349	14,521	41.66	4,650	1.621
Squash	233	233	8,372	36.00	3,250	0.757
Other Vegetables	1,933	1,933	70,905	36.69	4,200	8.118
Total	**11,525**	**9,649**	**276,595**			**71.619**

Salt tolerance can be quantitatively described by plotting relative yield as a continuous function of soil salinity, measured by the electrical conductivity of the saturated soil extract (ECe). Although this response function typically follows a sigmoidal relationship, Mass [48] and Maas & Hoffman [49] suggested that within the range of soil salinities producing acceptable economic yields, a single linear response function can effectively describe yield responses to salinity concentrations above the threshold. They also assumed that yields do not respond to salinity at concentrations below the threshold. For soil salinities exceeding the threshold of a given crop, the relative yield (Yr) can be estimated for the main crops was simulated response to salinity using Equation 1 [50-52].

$$\widehat{Yr_j} = 100 - b\,(EC_e - a) \tag{1}$$

where $\widehat{Yr_j}$ is the expected as relative crop yield reduction due to salinity for crop $_j$, b is the slope of the curve as yield loss per unit-increase in salinity, a is constant for salinity threshold value, and ECe is the soil electrical conductivity measured by dS/m as a means average root zone salinity of the saturation extract of the soil. The relationship between soil salinity and water salinity (ECe = 1.5 ECw) assumes a 15–20 percent leaching fraction [49-50]. In Table 4, the percentage of crop yield reduction due to increased water salinity is provided for various crops at different blending ratios. This table highlights the relationship between water salinity and crop yield, showing how different crops respond to varying levels of salinity in irrigation water. For instance, citrus crops, which are particularly sensitive to salinity, exhibit a yield reduction of up to 14.2% when exposed to 100% TWW.

Table 4. Percentage of crop yield reduction due to increased water salinity [39, 42-44]

Blending ratio Crops	(a) Threshold (ECe) dS/m	(b) Slope % per dS/m	Percentage of crop yield reduction response to water salinity by increasing blending ratios					
			0%	10%	25%	50%	75%	100%
Citrus	1.5	13.1	2.3%	3.5%	5.3%	8.3%	11.3%	14.2%
Date palm	4	3.6	-	-	-	-	-	-
Grapes	1.5	9.6	1.7%	2.6%	3.9%	6.1%	8.3%	10.4%
Olive	4.5	11	-	-	-	-	-	-
Banana	1.7	10	-	0.7%	2.0%	4.3%	6.6%	8.9%
Other trees	3.65	20.4	-	-	-	-	-	-
Wheat	5.9	3.8	-	-	-	-	-	-
Barley	8	5	-	-	-	-	-	-
Other Field crop	1.5	5.7	1.0%	1.5%	2.3%	3.6%	4.9%	6.2%
Tomatoes	2.5	9.9	-	-	-	-	-	0.9%
Pepper	1.5	14	2.5%	3.7%	5.6%	8.8%	12.0%	15.2%
Squash	3.2	16	-	-	-	-	-	-
Other Vegetables	3.2	16	-	-	1.0%	3.2%	5.4%	7.6%

Soil salinity significantly restricts citrus production in many regions worldwide. Although specific data on fruit yields in response to salinity in Jordan are limited, studies [53-57] indicate that grapefruit, lemons, and oranges are among the most sensitive agricultural crops. Citrus fruit yields decrease by approximately 13% for each 1.0 dS m^{-1} increase in the electrical conductivity of the ECe once soil salinity exceeds a threshold ECe of 1.4 dS m^{-1} [48]. In citriculture, an electrical conductivity (EC) over 3 dS m−1 and a sodium adsorption ratio (SAR) over 9 in saturated soil extract are considered critical for the survival of the cultivation. Additionally, chlorine concentration values above 355 ppm are unsuitable for growing citrus [58]. Citrus growth and fruit yield have been negatively affected under soil salinity of 2 dS m^{-1}, with a 13% decrease in fruit yield observed per each 1 dS m^{-1} salinity increase above 1.4 dS m^{-1}, the threshold value for electrical conductivity in saturated soil extract [59]. Furthermore, threshold salinity levels in the rhizosphere of orange trees cv. Valencia have been reported at ECs of 2.5 to 3.5 dS m^{-1} [60]. In lemon trees of cv. Verna, the toxic threshold for salinity stress syndromes varies with the rootstock used; for sour orange, Cleopatra mandarin, and macrophylla, the threshold values are 1.53, 2.08, and 1.02 dS m^{-1}, respectively [61].

2.3.2. Simulating Crop Gross Margin and Profit Response to Salinity

Enterprise budgets are mainly used to itemize the returns for an enterprise's products and the costs of the inputs required for production activities, to evaluate enterprise efficiency, to estimate the benefits and costs for major changes in production activities, to provide the basis for a total farm plan, and to provide non-farmers with information about the costs incurred to produce crops [62]. Enterprise budgets could serve as a management and decision-making guide for current and prospective entrepreneurs. Working at the farm level, enterprise budgets are desirable to estimate returns and costs for the same farm. However, enterprise budgets reflect the average, or typical, conditions when working on a national or regional level. The profit from individual crops (π_j) are represented in Equation 2.

$$\pi_j = P_j, \left(Y_j, \left(1 - \hat{Y}r_j\right)\right) - P_w, Q_w - \sum_i P_i, X_i - \mathrm{TFC} \tag{2}$$

where, Yj refers to the quantity of product j, $\widehat{Yr}_j$ is the percentage of crop yield reduction due to salinity level, Xi stands for the quantity of inputs i, i = l, 2, ..., n; including the quantity and price of fertilizers, Pj and Pi are the prices of products and inputs, respectively, and Qw, Pw denotes the quantity and price of the water input use based on estimated net irrigation water requirements (IWR), and TFC represent the total fixed costs.

2.3.3. Simulating Water Values Response to Salinity

The importance of valuing irrigation water and to get insight in the value of water to support policy decision making about efficient allocation of water among competing water demand sectors, determining the socio-economic impacts of water allocation decisions and rational investment decision in water infrastructure of water supply and distribution system. To determine the return per cubic meter of irrigation water, one would typically calculate the economic returns generated from agricultural production (e.g., crop yield, revenue from harvested crops) divided by the total volume of water used for irrigation. This calculation provides insight into the economic efficiency of water usage in agriculture and can inform decision-making at both the individual farm and policy levels [63]. One of the common methods to determine the economic value if water is the Residual Imputation Method (RIM) [64].

The RIM assesses the incremental contribution of each input in a production process [63]. When appropriate prices are assigned to all inputs except one, the remaining total value of the product is attributed to the residual input, which, in this case, is water [63, 65, 66]. Residual valuation assumes that if all markets are competitive, except for the water market, the Total Value of production (TV= $P_i . Y_i$) exactly equals the opportunity costs of all inputs. The opportunity costs of non-water inputs are assumed to be their market prices (or estimated shadow prices). The residual value is obtained by subtracting the non-water input costs from the total annual crop revenue, which equals the gross margin. The water-related contribution is calculated by subtracting the water costs from the gross margin. This residual can be interpreted as the maximum amount the farmer could pay for water while still covering the production costs [67].

It represents the at-site value of water. The shadow price (value) of water can be calculated as the residual, which is the difference between the total value of the output (TVP) and the costs of all non-water inputs used in production. This residual, obtained by subtracting non-water input costs from the total annual crop revenue, indicates the maximum amount a farmer could pay for water while still covering production costs, representing the water's at-site value. The water's marginal value (VMPw) is estimated, with average values used in this study as a proxy for the marginal value [68-70].

$$\mathrm{P_w} = ((P_j\,,\ Y_j\left(1 - \hat{Y}r_j\right)) - \textstyle\sum_{\mathrm{i=1}}^{\mathrm{n}} \mathrm{P_i\ X_i})/\mathrm{Q_w} \tag{3}$$

Water values based on the Gross Value Added (GVA): The GVA represents the difference between the gross output of the farm minus intermediate consumption. The resulting water productivity allows for determining the farmers' supply curve of the agricultural products in the short run. The farmer is willing to pay that price of water to avoid losses in the short run and to recover the variable cost. All the fixed cost does not recover and lost. Pw can be interpret as is the shadow price of water, i.e., the net benefit imputed as the value per unit of additional one cubic meter of water input [34]. Therefore, the above Equation 3 is used to estimate the economic value of water for each crop.

Net profitability (NP) is a key measure that reflects the surplus or profit generated from agricultural production after accounting for all costs, both direct and indirect, including depreciation and the opportunity cost of invested capital. This measure serves as a proxy for total pre-tax profit income and provides insight into the economic efficiency of water consumption, as well as farmers' ability to pay for water. When farmers adjust the value they assign to water, it can lead to an equilibrium in the long run, resulting in what is termed "normal profit." In this context, normal profit occurs when total sales revenue equals the total costs incurred, which means that farmers are not earning excess returns beyond covering their expenses. This situation indicates that there are no additional rewards for bearing the risks and uncertainties inherent in agricultural business operations. Despite this, farmers can expect to achieve a normal rate of return on their invested capital.

To estimate the economic value of water for each crop, the equation referenced (Equation 4) is utilized. This equation corresponds to the maximum willingness of irrigators to pay per unit of water for that specific crop, reflecting the economic realities of water use in agricultural practices [62, 71].

$$\mathrm{P_w} = ((P_j\,,\ Y_j\ (1 - \hat{Y}r_j)) - (\textstyle\sum_{\mathrm{i=1}}^{\mathrm{n}} \mathrm{P_i\ X_i} - \mathrm{TFC}))/\mathrm{Q_w} \tag{4}$$

The net irrigation-water requirement (IWR as $\mathrm{Q_w}$) is used instead of the crop's water requirement (CWR) in order to measure the irrigation water's value and to subtract the effective rainfall precipitation's contribution from the irrigation requirements. The IWR was calculated based on the specific crop water requirement (CWR) for the average production of fruit, vegetables, and crop patterns for 2022- 2023. For irrigation purposes, the IWR is determined, which is the sum of the individual IWR according to Equation 5 [72].

$$IWR_j = \textstyle\sum_{t=0}^{T} (kc_{j\,t}\ ,\ ET_0, -P_{eff}) \tag{5}$$

where kc is the crop coefficient of crop j during the growth stage t, and T is the final growth stage. ET0 is the reference evapotranspiration (Penman-Monteith), and *P*eff is the effective precipitation, taken as 80% of the total annual precipitation [73, 74].

3. Results and Discussion

Due to the increasing problem with water shortages in the NJV, the utilization of wastewater, which was once not an attractive option, has gained prominence. TWW plays a major role in narrowing the gap between supply and demand for the agricultural sector, especially in the NJV. Wastewater reuse and allocation in the NJV (including the MJV) is the responsibility of the JVA, which is a regional organization that oversees the development aspects in the NJV including water, agriculture, and other services. Farmers in the MJV receive irrigation water based on a weekly quota that is organized either by the JVA directly or through the Water Users Association (WUA) that operates under the supervision of the JVA. The weekly irrigation water quota is designed based on the crop type, where farmers who grow crops such as citrus fruit or bananas receive a larger water quota than farmers growing vegetables.

When the indirect (mixed) wastewater reuse program was initially introduced in the MJV, a significant obstacle emerged as farmers experienced damage to their citrus fruit plantations, leading them to replace them with alternative crops. This setback coincided with the inadequate quality of effluent from the As-Samra wastewater treatment plant. Consequently, MJV farmers directly linked the utilization of wastewater for irrigation with the loss of their traditional farming practices. The transition from citrus fruit plantations to vegetable crops also resulted in a decrease in the water allocation provided by the JVA. Despite notable enhancements in the effluent quality from the upgraded As-Samra plant, a negative perception of wastewater reuse persists among farmers throughout the NJV [31].

In NJV, water services have been heavily subsidized to meet the escalating cost of providing water [75]. The irrigation water tariff in NJV, which is an increasing block water tariff, the TWW which is priced at fixed rate of 0.014 US$/m^3. But with rising economic pressures, increasing fuel prices, and demands for financial resources, calls for full cost recovery are gaining momentum. Decision-makers are thus torn between the pressures to meet water authorities' demands for expansion and maintenance, and public pressure to restrict water prices, particularly for poor people. Water pricing is one of the measures to potentially establish effective demand management to use water efficiently and sustainably. Appropriate and adequate operation and maintenance of water systems is necessary to enable them to meet the current and future requirements for distributing water.

The average tariff billed per cubic meter of irrigation water in 2022 ranged between (0.011 to 0.022 US$/m^3), with a total average of 0.017 US$/m^3. Based on billed water volume, the average operation and maintenance costs per cubic meter billed are about US$ 0.17 per m^3. The average revenue per cubic meter billed of irrigation water for all-purpose is only US$ 0.042 per cubic meter. The JVA is not able to cover its basic operating costs; its revenues fall far short. The decline of JVA's capacity to pay for its operating expenditures has been especially pronounced since 2008. The operating margin is highly negative and shows that currently the total revenues, including pumping revenues, which were not charged to WAJ, do not even cover staff costs. The operating cost coverage ratio is less than 30% for all-purpose of water use and only 10% of irrigation water [75-77].

Water in NJV is charged according to the principle of price discrimination and quota system. In 2004, the JVA revised the quota system to better supply of water and crop water requirements [78]. The new quotas correspond to 3,600, 7,650 and 12,550 m^3/haJD for vegetables, citrus and bananas, respectively, i.e., a cut by about 20 to 30%. On a regional scale, this generated total FW savings in the northern and middle directorates of approximately 20 MCM. The water saved was subsequently reallocated to domestic use in Amman with about 53 MCM in 2010. Quotas are set according to water availability and demand patterns. Given that competition for water has increased, the quota system is reviewed on a regular basis, according to water availability.

3.1. Crop Economic Performance by Reallocation of Fresh Water with Treated Wastewater

The quality of irrigation water plays a crucial role in determining the economic performance of crops. High salinity levels can significantly limit the types of crops that farmers can cultivate, adversely affecting both water-use efficiency and overall yield while increasing water consumption. Water quality is multidimensional, encompassing factors such as chemical concentrations, salinity, bacterial content, organic matter, and temperature. The specific water quality indicators that matter most depend on the agricultural activities being performed. For instance, the cultivation of sensitive crops like citrus fruits is heavily influenced by salinity levels. A transition from high-quality freshwater to more saline water often necessitates a shift in crop selection to varieties that are more tolerant of salt. To measure the economic value of water quality, methods such as contingent valuation can be employed. This approach surveys farmers about their willingness to pay for improved water quality, enabling the estimation of the economic and societal benefits associated with higher-quality water.

The blending of freshwater with treated wastewater has a significant impact on the gross margins of various crops, as illustrated in Table 5. As salinity increases from an electrical conductivity (ECw) of 1117 uS/m to 1296 uS/m, the gross margins for citrus crops decline markedly. For example, the gross margin for citrus drops from 10,066 US$/ha at 0% TWW to 6,538 US$/ha at 100% TWW, reflecting the detrimental effects of increasing salinity on these crops. Similarly, sensitive crops like peppers also show reduced profitability under higher salinity conditions. Conversely, crops that possess moderate to high salinity tolerance, such as date palms, barley, tomatoes, and olives, exhibit improved economic performance when irrigated with TWW. These crops benefit from the nutrient content of TWW, which can lead to increased gross margins due to reduced fertilizer costs without a corresponding decline in yield. For instance, date palms maintain or enhance their gross margins as the blending ratio of freshwater to treated wastewater increases, thanks to the additional nutrients and lower fertilizer expenses.

Table 5. Gross margin (US$/ha) by blending scenarios

Scenarios	S_BAU (0%)	S_1 (10%)	S_2 (25%)	S_3 (50%)	S_4 (75%)	S_5 (100%)
Citrus	10,066	9,688	9,128	8,232	7,378	6,538
Palm	23,954	24,010	24,094	24,248	24,388	24,528
Grapes	20,300	19,880	19,264	18,284	17,318	16,394
Olive	1,162	1,176	1,190	1,218	1,232	1,260
Banana	29,848	29,386	28,392	26,782	25,214	23,688
Other trees	7,266	7,280	7,308	7,364	7,420	7,476
Wheat	854	854	868	896	924	938
Barley	924	924	924	938	952	966
Other Field crop	8,652	8,526	8,344	8,050	7,756	7,462
Tomatoes	8,932	8,988	9,086	9,226	9,366	9,184
Pepper	12,208	11,648	10,836	9,520	8,274	7,084
Squash	3,206	3,290	3,430	3,654	3,878	4,102
Other Vegetables	9,856	9,926	9,632	8,946	8,260	7,616

These values illustrate the varying impacts of TWW blending on crop profitability, highlighting the necessity for strategic crop selection and irrigation management. As evidenced, salt-sensitive crops experience declines in gross margins due to increased salinity, while salt-tolerant crops can thrive, making it crucial for farmers to adapt their practices accordingly to optimize economic returns in the face of water quality challenges. Figure 4 shows the Net Value Added (US$/m³) by Blending Scenarios highlight the critical role of strategic crop selection and irrigation management in mitigating the economic impacts of water salinity. As evidenced, salt-sensitive crops exhibit a notable decline in gross margins as salinity increases, reflecting reduced productivity and profitability under high TWW blending ratios. Conversely, salt-tolerant crops maintain stable or even enhanced economic returns, demonstrating their adaptability to saline irrigation conditions.

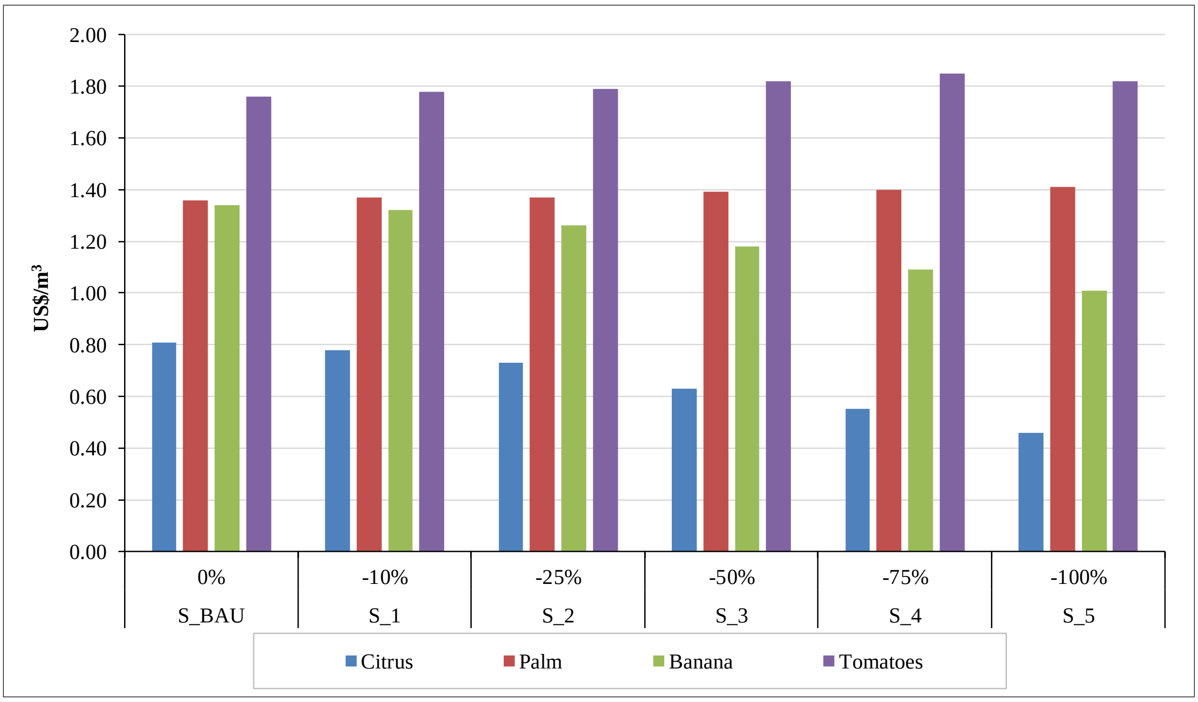

Figure 4. Net value added (US$/m³) by blending scenarios

Table 6 summarizes the net profit values (US$/ha) for various crops across a range of blending scenarios, from 0% TWW to 100% TWW. These scenarios reflect incremental increases in the proportion of TWW used for irrigation, providing a framework to evaluate the financial returns per hectare for each crop under varying water management strategies.

Table 6. Net profit (US$/ha) by blending scenarios

Scenarios	S_BAU (0%)	S_1 (10%)	S_2 (25%)	S_3 (50%)	S_4 (75%)	S_5 (100%)
Citrus	8,666	8,288	7,742	6,846	5,978	5,152
Palm	20,370	20,426	20,510	20,650	20,790	20,944
Grapes	18,228	17,808	17,192	16,212	15,246	14,322
Olive	462	476	490	518	532	560
Banana	23,814	23,352	22,358	20,748	19,180	17,654
Other trees	6,146	6,160	6,188	6,244	6,300	6,356
Wheat	518	532	546	574	588	616
Barley	770	770	770	784	798	812
Other Field crop	7,518	7,392	7,210	6,916	6,622	6,328
Tomatoes	6,482	6,538	6,622	6,762	6,902	6,734
Pepper	5,838	5,292	4,466	3,164	1,904	714
Squash	2,170	2,254	2,394	2,618	2,842	3,066
Other Vegetables	9,100	9,170	8,876	8,190	7,504	6,860

The data reveal distinct patterns in how net profit is affected by changes in the blending ratio of FW and TWW. For crops such as citrus, grapes, and bananas, there is a notable decline in net profit as the proportion of TWW increases. For instance, the net profit for citrus drops from US$ 8,666/ha at 0% TWW to US$ 5,152/ha at 100% TWW. This decline may be attributed to reduced crop quality and marketability associated with the use of TWW, highlighting the sensitivity of these crops to water quality changes. In contrast, crops like date palms, olives, wheat, and barley exhibit relatively stable net profit values across different blending scenarios. For example, the net profit for date palms shows minimal variation, remaining around 20,370 US$/ha at 0% TWW and slightly increasing to 20,790 US$/ha at 75% TWW. This stability suggests that these crops are less sensitive to changes in water quality or have lower associated input costs for irrigation. However, certain crops, including peppers and squash, experience significant decreases in net profit with increasing proportions of treated wastewater. The net profit for peppers declines sharply from 5,838 US$/ha at 0% TWW to 714 US$/ha at 100% TWW, indicating a high sensitivity to changes in water quality. This highlights the need for careful management and potential adjustments in cultivation practices for these sensitive crops to maintain profitability. Overall, the findings from the net profit analysis underscore the importance of considering both water quality and economic viability when implementing water management strategies in agriculture. While some crops demonstrate resilience to varying water quality, others require more meticulous approaches to ensure profitability. This analysis can inform decision-making processes related to crop selection, water resource management, and agricultural sustainability in regions facing water limitations. Table 7 shows the value added of water by increasing the bleeding percentage of TWW.

Table 7. Net value added (US$/m^3) by blending scenarios

Scenarios	S_BAU (0%)	S_1 (10%)	S_2 (25%)	S_3 (50%)	S_4 (75%)	S_5 (100%)
Citrus	0.81	0.78	0.73	0.63	0.55	0.46
Palm	1.36	1.37	1.37	1.39	1.40	1.41
Grapes	0.59	0.56	0.53	0.49	0.46	0.42
Olive	0.15	0.15	0.15	0.15	0.17	0.17
Banana	1.34	1.32	1.26	1.18	1.09	1.01
Other trees	0.60	0.60	0.62	0.62	0.63	0.63
Wheat	0.21	0.22	0.22	0.22	0.24	0.24
Barley	0.21	0.21	0.21	0.22	0.22	0.22
Other Field crop	1.83	1.81	1.76	1.69	1.64	1.57
Tomatoes	1.76	1.78	1.79	1.82	1.85	1.82
Pepper	2.62	2.51	2.32	2.04	1.78	1.53
Squash	0.98	1.01	1.05	1.12	1.19	1.26
Other Vegetables	2.35	2.37	2.30	2.13	1.97	1.81

In Table 7, the net value added (in US$/m^3) is presented for different crops under varying blending scenarios of TWW and FW. The results indicate that surface water has the highest average value for crops such as peppers, minor vegetable crops, and annual field crops, with a peak net value of 2.1 US$/m^3. Conversely, citrus crops display a notable decline in net value added as the proportion of TWW increases, starting at 0.81 US$/m³ at 0% TWW and decreasing to 0.46 US$/m³ at 100% TWW. This trend highlights the sensitivity of citrus to the salinity levels commonly found in treated wastewater. In contrast, crops such as date palms, tomatoes, and olives show varying responses to increased blending ratios. For example, date palms exhibit a consistent increase in net value added from 1.36 US$/m³ to 1.41 US$/m³, suggesting a resilience to salinity and a beneficial response to nutrient content in TWW.

Different crops respond uniquely to varying blending ratios of TWW and FW. Sensitive crops like citrus, bananas, grapes, and peppers reveal a decreasing trend in net value added as the TWW proportion increases, indicating their susceptibility to the quality of irrigation water. On the other hand, crops such as palms, olives, and certain vegetables demonstrate stable or increasing trends in net value added across different blending scenarios. Figure 5 shows the Net Profit (US$/ha) by Blending Scenarios illustrates the distinct economic responses of various crops to increasing TWW proportions in irrigation water. The results highlight the differentiated impact of water quality on crop profitability, underscoring the importance of crop selection in salinity-prone environments. Salt-sensitive crops—such as citrus, bananas, grapes, and peppers—exhibit a declining trend in net profit per hectare as the proportion of TWW increases, suggesting their vulnerability to salinity and water quality changes. This decline reflects reduced yields, potential physiological stress, and increased management costs associated with mitigating salt-related damage.

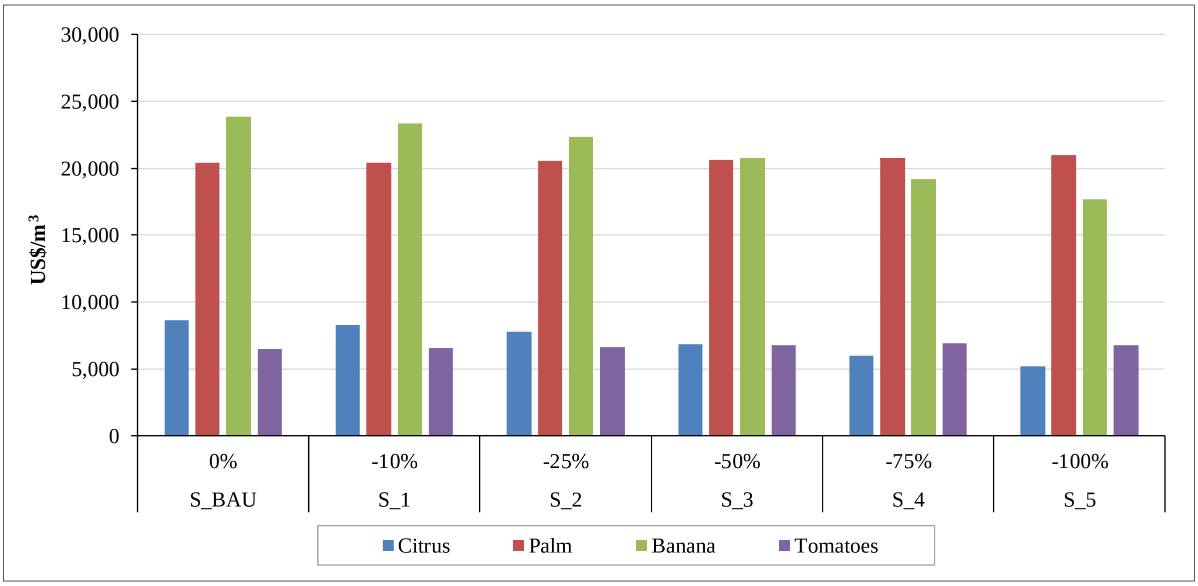

Figure 5. Net profit (US$/ha) by blending scenarios

This resilience suggests that these crops are better suited to tolerate the increased salinity associated with TWW. The differences in responses can be attributed to the specific nutrient requirements of each crop and their ability to utilize nutrients present in the irrigation water. The net value added serves as an indicator of the overall economic benefit or loss associated with using blended water for irrigation, emphasizing the importance of understanding crop-specific water quality needs for optimizing blending ratios. The farmers' ability to pay (FAP) for water and the water profitability of one additional cubic meter of water by reusing wastewater by crop in the NJV is shown in Table 8.

Table 8. The farmers' ability to pay for water (US$/m³)

Scenarios	S_BAU (0%)	S_1 (10%)	S_2 (25%)	S_3 (50%)	S_4 (75%)	S_5 (100%)
Citrus	0.63	0.59	0.53	0.45	0.36	0.28
Palm	0.98	0.99	0.99	1.02	1.04	1.05
Grapes	0.28	0.27	0.24	0.20	0.15	0.13
Olive	0.00	0.00	0.01	0.01	0.01	0.03
Banana	0.78	0.77	0.71	0.63	0.55	0.46
Other trees	0.42	0.42	0.42	0.43	0.43	0.45
Wheat	0.13	0.13	0.13	0.14	0.14	0.14
Barley	0.15	0.17	0.17	0.17	0.17	0.18
Other Field crop	1.55	1.53	1.48	1.41	1.34	1.29
Tomatoes	1.29	1.29	1.32	1.34	1.37	1.33
Pepper	1.26	1.13	0.97	0.69	0.41	0.15
Squash	0.67	0.70	0.74	0.80	0.87	0.94
Other Vegetables	2.17	2.18	2.11	1.95	1.79	1.64

Table 8 delves into farmers' ability to pay for water, showcasing how this metric varies across different crops. The data reveals that farmers show the highest willingness to pay for water associated with tomatoes, peppers, and date palms, with values exceeding 0.70 US$/m³. In contrast, the ability to pay for olives and cereal crops is significantly lower, not surpassing 0.14 US$/m³. Moreover, as the blending ratio increases, the ability to pay for citrus crops declines sharply from 0.63 US$/m³ at 0% TWW to 0.28 US$/m³ at 100% TWW, reflecting their vulnerability to the quality of TWW. This decline in ability to pay is consistent with the observed decreases in net value added for sensitive crops, suggesting that certain crops may have an optimal TWW blending percentage that maximizes profitability.

The analysis further highlights the resilience of crops such as wheat, barley, and other field crops, which maintain relatively consistent net profitability across different water mix percentages. This potential resilience indicates that these crops may be less affected by changes in water quality compared to more sensitive varieties. Understanding the underlying reasons for the extreme fluctuations in net profit for certain crops exposed to higher percentages of TWW can provide valuable insights into their sensitivity to water quality and the associated economic implications. Evaluating the trade-offs between water cost savings and crop profitability is essential for informed decision-making. Even if some crops demonstrate decreased profitability with increased TWW percentages, a comprehensive cost-benefit analysis—including factors like water expenses, market demand, and yield—might still favor their cultivation. Additionally, long-term effects on soil quality due to increased use of treated water must be considered, as potential degradation could influence future agricultural productivity.

Our findings align with studies such as Haddadin et al. [79], which estimated water values for different horticultural crops in Jordan, showing significant variability based on crop type and irrigation system. Additionally, the AFD study [80] using the Seasonal Agricultural Water Allocation System (SAWAS) model found shadow prices for water between 0.34 US/m³ for blended water and 0.55 US/m³ for fresh water from the King Abdullah Canal (KAC), which aligns with our findings regarding farmers' water valuation.

Furthermore, the ISSP study [69, 81] estimated farmers' ability to pay for irrigation water using the Residual Valuation Approach. Our results confirm their findings that cash crops, such as cucumbers, have the highest water value (3.19 US/m³), while field crops like wheat and barley have significantly lower values (0.16 US/m³ and 0.07 US/m³, respectively). Additionally, Wolff et al. [82] assessed the economic value of water in Jordan, concluding that agricultural water values were much lower than those in the domestic sector (5.5-7 US/m³), reinforcing the economic rationale for differentiated water pricing. These comparisons provide a comprehensive contextual analysis of our findings, strengthening the validity of our results and their implications for water management policies in Jordan.

The study highlights the significant impact of TWW irrigation on crop productivity and economic feasibility, emphasizing the importance of crop selection when integrating TWW into irrigation strategies. Salt-sensitive crops, such as citrus and peppers, exhibit a substantial decline in net profit as the proportion of TWW increases, whereas salt-tolerant crops like date palms and olives maintain stable profitability. The economic return per cubic meter of water varies significantly across different crops, with citrus and peppers experiencing reduced net value added under high TWW conditions, while date palms and tomatoes demonstrate resilience and even improved economic returns due to the nutrient content in TWW. These findings underscore the necessity for tailored irrigation policies that optimize water use efficiency while sustaining profitability.

Farmers' willingness to pay for irrigation water is closely linked to economic viability and crop sensitivity to water quality. High-value crops, such as tomatoes and peppers, demonstrate a higher ability to pay, whereas lower-value crops, including olives and cereals, necessitate access to lower-cost water sources like TWW to remain viable. As TWW proportions increase, the willingness to pay for water declines, particularly for citrus farmers, indicating the economic strain associated with increased salinity. To ensure economic sustainability, differentiated pricing strategies for irrigation water should be considered, aligning water costs with crop profitability. A tiered pricing model could incentivize efficient water use and encourage the cultivation of salt-tolerant crops in regions where freshwater resources are scarce.

Long-term sustainability concerns arise due to the progressive accumulation of salinity in soils irrigated with TWW. Over time, salinity buildup threatens soil structure, leading to clay dispersion and modification, which impair water infiltration and root development. Furthermore, the presence of microbial contaminants necessitates stringent monitoring to prevent potential risks to agricultural productivity and public health. Regular soil and water quality assessments are essential to mitigate these risks, and adaptive irrigation strategies should be employed to manage salinity dynamically. The use of soil amendments, such as gypsum and organic matter, can aid in maintaining soil structure and mitigating the adverse effects of long-term TWW application.

The findings of this study emphasize the need for strategic policy interventions to optimize TWW use in agriculture. Crop-specific water allocation policies should be developed to regulate the proportion of TWW used for different crops, ensuring that salt-sensitive crops receive blended water while salt-tolerant crops can utilize higher proportions of TWW. Investments in wastewater treatment infrastructure and blending stations are crucial for improving water quality and enabling dynamic mixing based on crop requirements. Additionally, farmer awareness and training programs should be implemented to educate agricultural stakeholders on best practices for irrigation, soil management, and salinity control. Providing incentives for adopting water-saving technologies, such as precision irrigation and soil amendments, can further enhance the economic and environmental sustainability of wastewater reuse.

Finally, it is imperative to assess the environmental impacts of using treated water on different crops and soils. This includes examining the potential accumulation of contaminants in crops and the changes in soil quality over time, which could affect both crop yield and safety. Overall, the insights gained from Tables 7 and 8 emphasize the necessity of a holistic approach to evaluating economic and environmental factors in water reuse practices and crop selection, ensuring that agricultural systems remain sustainable and productive in the long term.

4. Conclusions

The findings of this study underscore the significant potential of integrating TWW with fresh surface water for irrigation in the NJV, particularly in addressing the pressing issue of water scarcity. This approach not only conserves valuable freshwater resources but also offers economic benefits by reducing reliance on chemical fertilizers. The study highlights that TWW can be a sustainable alternative for irrigation in the Northern Jordan Valley if properly managed. While some crops suffer from increased salinity, salt-tolerant crops can thrive, offering economic benefits. Strategic irrigation practices, adjusted blending ratios, and targeted policies will be essential to maximize the economic viability and environmental sustainability of wastewater reuse. However, the effectiveness and impact of TWW on different crops are influenced by various factors, necessitating careful management.

- The use of TWW in irrigation can conserve substantial amounts of freshwater, which is crucial in the NJV where water resources are increasingly limited. The potential reduction in chemical fertilizer costs can further enhance the economic viability of this practice.
- The impact of TWW on crop productivity varies significantly. For instance, citrus crops experience a decline in net value added, decreasing from US\$ 0.63/m³ at 0% TWW to US\$ 0.28/m³ at 100% TWW, indicating their sensitivity to increased salinity. In contrast, crops such as date palms and tomatoes show enhanced profitability, with their net value added remaining stable or increasing under higher TWW blending ratios.
- Effective management practices, including the selection of salt-tolerant crop varieties and the implementation of appropriate irrigation techniques, can mitigate the negative effects of TWW. Regular monitoring of water quality, soil health, and crop performance is essential to ensure sustainable agricultural practices.
- Increase public awareness and education on proper wastewater management to foster acceptance, promote sustainable agriculture, and safeguard public health.
- Regular monitoring of sodium levels, microbial activity, and crop health is essential to prevent long-term soil degradation (salinity, sodicity, structural decline) and plant issues (toxicity, physiological stress).
- Economic performance indicators highlight that while salt-sensitive crops like peppers may experience a slight reduction in farm income due to salinity, salt-tolerant crops such as date palms and barley thrive with TWW, showing resilience and maintaining profitability. For example, date palms can achieve net value added of over US\$ 1.40/m³ when blended appropriately.
- Future research should focus on optimizing irrigation efficiency and developing innovative water reuse strategies to enhance agricultural productivity. Exploring the long-term effects of TWW on soil quality and crop yield will be vital for ensuring the sustainability of this practice in the face of increasing food demand in the region. Additionally, establishing clear guidelines for crop selection based on salinity tolerance will help maximize the economic benefits of using TWW.

5. Declarations

5.1. Author Contributions

Conceptualization, M.T. and E.K.; methodology, E.K.; software, A.S.; validation, A.J., T.Z., and M.J.; formal analysis, N.K. and E.K.; investigation, T.Q.; resources, A.J.; data curation, N.K.; writing—original draft preparation, E.K.; writing—review and editing, M.T. and T.Z.; visualization, A.S. and N.T.; supervision, M.J.; project administration, E.K.; funding acquisition, A.J. All authors have read and agreed to the published version of the manuscript.

5.2. Data Availability Statement

The data presented in this study are available in the article.

5.3. Funding

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5.5. Institutional Review Board Statement

Not applicable.

5.6. Informed Consent Statement

Not applicable.

5.7. Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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