Article

Not peer-reviewed version

An Economic Assessment of Fresh Water Reallocation by Treated Wastewater for Irrigation in Northern Jordan Valley

Mohammed A. Tabieh *, Emad K. Al-Karablieh, Amer Z. Salman, Tala Qtaishat, Nael Thaher, Mohammed Al-Qinna, Nehaya Al-Karablieh, Madi Jaghbir, Ahmad Al-Jamrah, Khaleda Al-Ghazawi, Haitham Aladaileh

Posted Date: 19 August 2024

doi: 10.20944/preprints202408.1260.v1

Keywords: salinity; yield response function; profitability; water values; treated wastewater

Article

An Economic Assessment of Fresh Water Reallocation by Treated Wastewater for Irrigation in Northern Jordan Valley

Mohammed A. Tabieh [1,*], Emad K. Al-Karablieh [1], Amer Z. Salman [1], Tala H. Qtaishat [1], Nael H. Thaher [1], Mohammed Al-Qinna [2], Nehaya Al-Karablieh [3], Madi T. Al-Jaghbir [4], Haitham Aladaileh [5], Khaleda M. Al Ghazawi [6] and Ahmad I. Jamrah [7]

1 Department of Agricultural Economics and Agribusiness Management, School of Agriculture, The University of Jordan, Amman, Jordan
2 Department of Land Management and Environment, Faculty of Natural Resources and Environment, Hashemite University, Zarqa, Jordan
3 Department of Plant Protection, School of Agriculture, The University of Jordan, Amman 11942, Jordan. Hamdi Mango Center for Scientific Research, The University of Jordan, Amman 11942, Jordan
4 Department of Family and Community Medicine, School of Medicine, The University of Jordan, Amman, Jordan
5 Jordan Ministry of Environments, Amman 11942, Jordan
6 Ministry of Planning and International Corporations, Amman, Jordan
7 Department of Civil Engineering, The University of Jordan, Amman 11942, Jordan
* Correspondence: m.tabieh@ju.edu.jo; Tel.: +962-65-355-000

Abstract: The study investigates the economic feasibility and farmer acceptance of utilizing treated wastewater (TWW) for agricultural irrigation, particularly in the Northern Jordan Valley. Despite its potential to mitigate water scarcity, concerns persist regarding its impact on soil health, crop yield, and land utilization, hindering widespread adoption. The research aims to measure farm profitability and farmers' willingness to embrace TWW through various blending scenarios with traditional surface water sources. The yield response function to salinity was incorporated into profit function to simulate crop profitability and water values. Results indicate that the introduction of TWW negatively affects salt-sensitive crops like citrus but positively impacts others such as date palm, olives, tomatoes, and peppers due to increased fertilizer content in irrigation water. Economic performance indicators reveal a gradual decrease in water net productivity for citrus with increasing blending ratios of TWW, with the water value decreasing accordingly. Higher percentages of treated water do not consistently lead to increased productivity, profitability, or net value added, emphasizing the need for careful consideration and understanding of economic risks associated with specific crops and water quality. To mitigate the impact of water salinity on citrus production, growers are advised to improve soil quality, periodically flush the soil with low-salinity water, and use salt-tolerant rootstocks. Regular monitoring of soil and water salinity levels is crucial for informed decision-making. While using TWW, water may offer cost savings.

Keywords: salinity; yield response function; profitability; water values; treated wastewater

1. Introduction

Jordan ranks among the most water-deprived countries globally [1], with future predictions indicating a worsening situation due to increasing temperatures, as well as reduced precipitation and runoffs. Presently, the Jordan's renewable water resources satisfy around two-thirds of the population's overall water demands, and underground water 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 [1]. By 2040, climate-change

 doi:10.20944/preprints202408.1260.v1

simulations predict a reduction in precipitation by 10 to 15 mm (13-20% less) compared to current levels, with more severe droughts anticipated. This has prompted Jordan to formulate a water substitution and reuse policy, focusing on boosting the volume of treated wastewater (TWW) and recognizing TWW as an alternative water source [2].

Jordan's agriculture sector uses about 52% of the nation's total water resources [3] and about 70% of its underground water, despite contributing only around 4% to the Gross Domestic Product (GDP) [4]. 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. In the Jordan Valley, water conservation is less of a priority for farmers compared to those in highland areas, which primarily rely on groundwater. Irrigated agriculture in the Jordan Valley accounts for approximately 40% of the sector's GDP contribution [5]. The Northern Jordan Valley (NJV), representing more than 50% of the irrigated area in the region, is one of the country's key irrigated zones, thus significantly constraining 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

Jordan has been utilizing treated wastewater (TWW) for agricultural purposes since 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 [6]. Currently, TWW constitutes 30% of Jordan's irrigation water and about 15% of the total water budget [3,7]. 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 [8,9]. 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 [10,11]. 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 [12,13] aim to replace fresh surface water in the Jordan Valley's irrigation systems with TWW, permitting agricultural expansion only where such water is available. 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

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 raises concerns regarding potential health hazards due to residual pathogens, chemicals, and heavy metals if the treatment process is insufficient in eliminating these contaminants [14]. To ensure public health and the safe use of treated wastewater (TWW) in agriculture, the Jordan Standards and Metrology Organization (JSMO) developed and issued the Jordanian Standards 893/2021 [10,11] as displayed in (Table 1), which are based on WHO guidelines [15] These standards and regulations strictly prohibit the use of TWW for irrigating any type of vegetables [11]. The regulation places significant emphasis on water quality parameters from an agronomic perspective. It introduces 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

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				Discharge into streams or water bodies
		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)	
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
$NO3^-$	mg/l	16	16	16	16	20
TN	mg/l	70	70	70	70	70
PO_4^-	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

Source: [10].

The increasing reuse of TWW bears diverse economic ramifications, particularly concerning yield, productivity, and farmers' willingness to invest in this resource. Initially, incorporating TWW may offer advantages in augmenting yield and productivity through an alternative irrigation water source [16]. However, the prolonged use of TWW might engender 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 constraining their ability to invest in this technology [17].

The initial benefits of using treated wastewater (TWW) as an irrigation source may decrease over time because of the buildup of salts and contaminants in the soil [16]. 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 soil salinity caused by increased TWW usage 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 jeopardizes their financial stability but also amplifies the financial risks associated with agricultural activities .and may impede farmers' capacity 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 treated wastewater; 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 Jordan Valley, which is considered the country's food basket. The total irrigable area in the Jordan Valley 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 necessitates 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 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 [18] indicates that citrus cultivation dominates the NJV, encompassing 5,894 hectares, representing a substantial 83% of the total citrus cultivation in Jordan. 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, 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 NJV contributes to 10% of the national Grapes yield, with a slightly higher yield of 13.9 tons ha^{-1}. Tomatoes and Pepper display interesting patterns. 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^{-1}. Pepper, with a growth rate of 0.97%, sees a substantial 13% of NJV's area contributing to 17% of the national production, boasting a yield of 51.3 tons/ha.

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 are not fully operational.

However, approximately 15 to 20 MCM per year of TWW from the Northern region's WWTPs (Wadi Al Arab, Shalalah, Center Irbid, and later Ramtha) are being discharged into the Jordan River and remain unused. This is despite the fact that the hydraulic infrastructure required to utilize this water for irrigation in the NJV, after blending with freshwater, has been in place since 2016. The main issue is that the quality of the final effluent does not meet the standards and specifications for irrigation water, making it unsuitable for citrus irrigation. Both the JVA and 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 [19]. Elevated salinity levels in irrigation water or soil can hinder citrus tree growth and overall yield, causing osmotic stress and altering nutrient uptake. The presence of salts in the water can disrupt the plant's ability to absorb essential nutrients, leading to 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, resulting in wilting and decreased fruit production. High salinity can also interfere with the absorption of key nutrients such as potassium, calcium, and magnesium, leading to nutrient deficiencies that impact the quality and size of the fruit

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 cause a "physiological" drought condition, where plants wilt because their roots cannot absorb the water, even though the field may appear to have adequate moisture [20,21]. The salinity level in treated wastewater (TWW) is typically 1.5–2 times higher than that of fresh water (FW). This elevated salt content in TWW can lead to increased soil salinization, sodication, and structural changes, potentially resulting in reduced yields for salt-sensitive crops [22,23].

Citrus irrigated with high-salinity water can experience reduced growth and production [19]. 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 [19]. 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 [25]. The most critical chemical risks associated with TWW reuse for irrigation include excessive concentrations of salt, heavy metals, nutrients, toxic organic compounds, and organic matter [16,26].

Concerns about using TWW for irrigation encompass potential damage to soil quality and crop development, increased salinity, clay dispersion, reduced soil hydraulic conductivity, and the presence of pathogens in the water, which poses a public health risk [24].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 might not present a significant issue, surpassing these limits can result in toxicity [25]. 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 treated wastewater (TWW) for irrigation if they perceive it as economically beneficial, socially acceptable, environmentally sustainable, and posing little or no health risks. [26–29]. 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 shaped by local cultural, religious, and socio-economic conditions. 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 [30].

Farmers with the option to choose between treated wastewater (TWW) and other water sources consistently prefer the alternatives, despite their higher costs, due to the social stigma and crop restrictions associated with TWW reuse. Therefore, social marketing and awareness-raising efforts are crucial in reducing opposition to wastewater reuse [31].

A three-year study revealed that nectarines irrigated with treated wastewater (TWW) had higher quality parameters, antioxidant compounds, and total phenolic content compared to those irrigated with fresh water (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. [32].

This research aims to investigate the potential economic impact of replacing surface fresh water (FW) with treated wastewater (TWW) in the Northern Jordan Valley (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 treated wastewater (TWW) with surface water can increase the water supply for farmers in the Northern Jordan Valley (NJV) and enhance overall water availability. This study analyzes the economic impact of this approach by evaluating the effects of

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 19 August 2024 doi:10.20944/preprints202408.1260.v1

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 fresh water (FW), and exploring any differences in production costs.

2. Materials and Methods

Assessing the potential economic increment for farm productivity, farm output, reduced chemical costs, and an improved value chain requires concrete and actual 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 in terms of the additional costs and returns at the farm level. Farmers, as decision-makers, have a certain land area, a given water quota, and other restrictions. To create the representative crop budgets and cropping patterns for the study area, simulating the situation before and after re-using additional TWW for agriculture, along with the irrigation system's improvements, is needed.

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's to about -300 m bmsl in the south. The total area for the NJV that is included with this study is more than 182 km^2. This study focuses on the northern district of the Jordan Valley, where the JVA's water-allocation rules apply as shown in Figure 1.

The NJV experiences a warm winter, with January temperatures averaging a minimum of 13°C, 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, rainfed 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 the "blended TWW" and less than 31% is still irrigated with FW. The rest 9% is still alternately irrigated with both waters; the FW and the "blended TWW". It should be stressed that the whole Jordan Valley is envisioned to be, within few years to come, completely irrigated with the "blended TWW"; the objective that would most likely be achieved in near future in light of the increasing TWW amount from As-Samra WWTP in addition to the utilization of the joined effluent of the three WWTPs in the north Jordan Valley, i.e. the Central Irbid, the Shalaleh and Wadi Arab WWTPs. The special significance of wastewater reuse practice in the Jordan Valley lies in the substitution of FW with sufficient "blended TWW". In so doing, the sustainability of agriculture and the free-up of FW for drinking are both secured in the Jordan Valley.

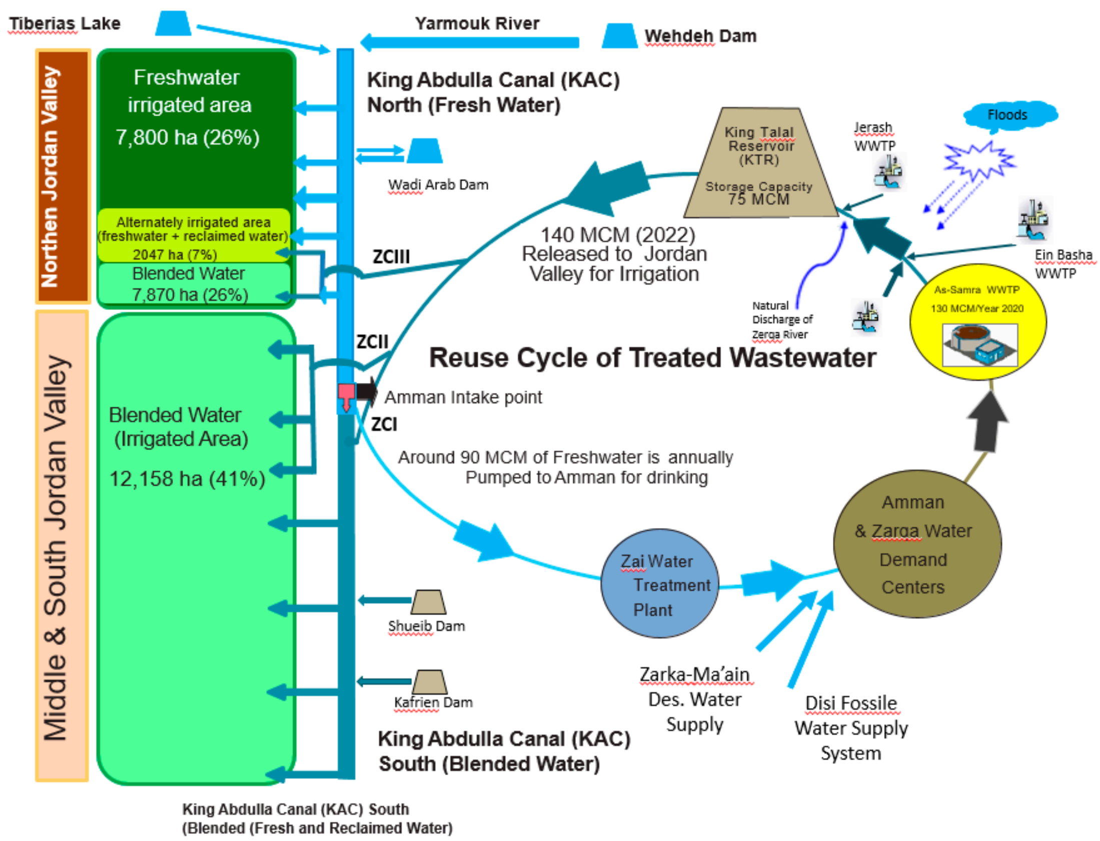

Figure 1. Reuse cycle of treated wastewater.

2.2. Building a Farm Model

Enterprise budgets have been developed and estimated for a majority of the crops grown in the Northern Jordan Valley (NJV), such as citrus, date palm, banana, and various vegetable crops that can utilize treated wastewater (TWW). These enterprise budgets are derived from the most accurate and reliable estimates of returns and costs available in 2023. To represent the orchard and fruit-tree crops that are middle age (the production period and excluding the period of pre-maturity), models are prepared for citrus crops and grapes as well as olives and other fruit trees. In each crop's budget table, columns "without the Project-Business as usual (BAU)" are considered to be representative of the existing situation, and the columns "with the project-reuse of additional TWW" provide the average expected changes, including yield response to salinity, reduced fertilizers costs, increased water consumption as a result of supply augmentation by treated effluents and the resulting farm income before and after the reuse of TWW.

Based on the average farm-gate prices (US$/ton) for the primary product and the by-product as well as the average yield for each crop (ton/ha), the total return (US$/ha) is computed based on the published farm gate prices and the farmers' interviews.

The total variable costs, which are mainly operational costs, are drawn from interviewing farmers at the pilot site during the 2022-2023 crop years. Total variable costs (TVC) include the expenses for all the varying inputs that are used to produce the crops. Examples include the expenses for fertilizers, seeds, pesticides, water, labor, electricity, and repairs. Total Fixed costs (TFC) include land rent or quasi-land rent, in the case that the land is owned by the farmer; the depreciation of capital; buildings; machinery; irrigation networks; plastic houses; the amortization of seedlings in the case of fruit trees; and interest on the capital investment.

2.3. Building the Scheme Models and Blending Scenarios

The JVA is moving forward with plans to reallocate surface FW with TWW in the NJV. While the necessary hydraulic infrastructure is already in place, the current quality of TWW falls short of Jordanian standards for irrigation water. To address this, the MWI is rehabilitating four existing WWTPs to produce treated effluent that meets these standards, enabling its use in NJV irrigation after blending with FW. The optimal mixing ratio is still under investigation. he study focuses on assessing the economic impact of reallocating surface freshwater with treated wastewater in the NJV, with a specific emphasis on how the potential increase in water salinity might affect crop productivity.

Table 2 outlines different TWW blending scenarios (S1-S5) and their corresponding impacts on agricultural parameters. The scenarios involve varying mixing ratios of TWW to FW, expressed as percentages from 0% to 100%. The electrical conductivity (EC_w) of both FW and TWW is consistently set at 1117 µS/cm and 1725 µS/cm, respectively. The resulting EC of irrigation water after blending reflects an increasing trend as the proportion of TWW rises. The table further presents the consequences of these scenarios on agricultural outcomes, including the percentage increase in crop yield as a result of increased allocated water to crops, the proportional increase in water allocation to crops due to mixing with TWW, and the corresponding decrease in fertilizer costs. These parameters provide a comprehensive overview of the potential agricultural benefits and economic implications associated with the utilization of TWW in irrigation. The scenarios delineate a gradient of increasing TWW concentrations and their subsequent effects on key agricultural variables, offering valuable insights for sustainable water resource management and agricultural practices.

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%

Treated wastewater (TWW) contains significant amounts of essential plant macronutrients: nitrogen (N), phosphorus (P), and potassium (K), and can be regarded as a low-strength multi-nutrient fertilizer. The nutrient concentrations in TWW vary depending on the level of wastewater treatment, seasonal changes, and the degree of dilution with rainwater. The guidelines prepared by GTZ [33] for the reuse of TWW show that farmers can save up to 60% of their fertilization costs when applying the technical recommendations. TWW used as irrigation water and soils in Jordan Valley can provide crops with more than 50% of their nutrient requirements. However, farmers in the central and south Jordan Valley apply excessive amounts of P and K, because they do not consider either nutrient in the irrigation water or in the soils. GTZ 2006 [33,34] indicate that the total current monetary value of the macro nutrients NPK in TWW released into the Jordan Valley is estimated to

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 19 August 2024 doi:10.20944/preprints202408.1260.v1

be around US$ 3.28 million of which 23% is N, 20% P and 57% K [20,35]. Assuming an average content of 60 ppm and an application of about 1000 mm per year (for 2 seasons), this results in an influx of about 600 kg/ha/year of NO_3 -N. Therefore, the effluent would supply all the nitrogen and a significant portion of the phosphorus and potassium typically needed for agricultural crop production. Additionally, the effluent contains other valuable micronutrients and organic matter, offering further benefits to crop growth [36].

2.3.1. Simulating Crop Yield Response to Salinity

The crop yield (ton/ha) is collected from field observations. The crop yields vary according to the production season, production technology, and water quality. Crop yields are obtained from farmers' interview and verified by the DOS' annual report data. Table 3 presents a comprehensive overview of crop planting, production, and irrigation water requirements within the study area. The data encompass various crops, including citrus, date palm, grapes, olive, banana, other trees, wheat, barley, other field crops, tomatoes, pepper, squash, and other vegetables.

In the "Planted Area" column, the total area devoted to each crop is delineated, while the "Cultivated or bearing fruit Areas" column specifies the actively utilized cultivation or fruit-bearing, new planted fruit trees are not productive but requires irrigation water and agronomic practices and inputs. The "Total Production" column quantifies the overall yield for each crop of productive areas in tons, with the "Average Yield" column providing the yield per unit of productive area.

The "Net Irrigation Water Requirements" column denotes the amount of water necessary for irrigation per unit area of cultivation either productive or not. The "Total Irrigation Water Demand" calculates the total annual irrigation water demand for each crop by multiplying the net irrigation water requirements by the cultivated area. Furthermore, the assessment of net irrigation water requirements reveals the significant demand for water resources to sustain agricultural activities. This aspect is particularly crucial given the imperative role of irrigation in enhancing crop yields and ensuring food security. The total annual irrigation water demand for each crop provides a comprehensive understanding of the collective water usage within the agricultural sector.

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 Productio n (ton)	Average Yield (ton/ha)	Net Irrigation Water Requireme nts (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, Maas and Hoffman [37,38] 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) [39–41].

$$\widehat{Yr}_j = \ 100 - b\ (EC_e - a) \tag{1}$$

Where $\widehat{\boldsymbol{Yr}}_{\boldsymbol{j}}$ 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 ($EC_e = 1.5\ EC_w$) assumes a 15–20 percent leaching fraction [38,39].

Table 4. Percentage of crop yield reduction due to increased water salinity.

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%

Source: [39,42–44].

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 [45–49] 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 saturated-soil extract (ECe) once soil salinity exceeds a threshold ECe of 1.4 dS m^{-1} [37]. 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 [50]. 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 [51]. Furthermore, threshold salinity levels in the rhizosphere

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 19 August 2024 doi:10.20944/preprints202408.1260.v1

of orange trees cv. Valencia have been reported at ECs of 2.5 to 3.5 dS m^{-1} [52]. 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 [53].

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 [54]. 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 ($\boldsymbol{\pi_j}$) are represented in Equation (2).

$$\pi_j = P_j \,.\, (Y_j \,.\, (1 - \hat{Y}r_j)) - P_w . Q_w - \sum_i P_i . X_i - TFC \quad (2)$$

Where, Xi stands for the quantity of inputs i, i = l, 2, ..., n; including the quantity and price of fertilizers, Yj refers to the quantity of product j, 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). $\boldsymbol{\widehat{Yr}_j}$ is the percentage of crop yield reduction due to salinity level.

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 [55]. One of the common methods to determine the economic value if water is the Residual Imputation Method [56].

The Residual Imputation Method (RIM) assesses the incremental contribution of each input in a production process [55]. 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 [55,57,58]. Residual valuation assumes that if all markets are competitive, except for the water market, the total value of production (TV= $P_j . Y_j$) 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 [59].

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 [60–62].

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 19 August 2024 doi:10.20944/preprints202408.1260.v1

$$\mathrm{P_w} = ((P_j\ .\ Y_j\ (1 - \hat{Y}r_j)) - \textstyle\sum_{i=1}^{n} \mathrm{P_i\ X_i})/\mathrm{Q_w} \tag{2}$$

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 [20]. Therefore, the above equation (3) is used to estimate the economic value of water for each crop.

Water values based on the Net Profitability (NP): The net profitability is the measure of the surplus or profit accruing from production after deducting all costs (direct and indirect such as depreciation charges plus opportunity cost of invested capital) and thus a proxy for total pre-tax profit income. The resulting water value is an indication of the economic efficiency of water consumption and a proxy for farmer's ability to pay for water. If the farmers changed this value for water, they would reach an equilibrium in the long run and normal profit. This implies that the sales revenue exactly equals the sum of all input used. In this case, there is no reward to risk and uncertainties in doing business. However, the farmers receive a normal rate of return on invested capital. Therefore, the above equation (4) is used to estimate the economic value of water for each crop. corresponding to the irrigator's maximum willingness to pay per unit of water for that crop [54,63].

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

The net irrigation-water requirement (IWR as $\mathbf{Q_w}$) 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) [64].

$$IWR_j = \textstyle\sum_{t=0}^{T} (kc_{j,t}\ .\ ET_0. - P_{eff}) \tag{4}$$

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 Peff is the effective precipitation, taken as 80% of the total annual precipitation [65,66].

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 Jordan Valley. Wastewater reuse and allocation in the Jordan Valley (including the MJV) is the responsibility of the JVA, which is a regional organization that oversees the development aspects in the Jordan Valley 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

 doi:10.20944/preprints202408.1260.v1

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 Jordan Valley [17].

In Jordan Valley, water services have been heavily subsidized to meet the escalating cost of providing water [67]. The irrigation water tariff in Jordan Valley, 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 percent for all-purpose of water use and only 10% of irrigation water [67–69].

Water in Jordan Valley 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 [70]. 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 percent. 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 FW with TWW

Poor water quality with high salt contents can limit the crops that a farmer is able to grow. Low water quality also reduces the water-use efficiency and, thus, may reduce the yield while increasing the water use. Water quality is multi-dimensional because it includes the concentration of certain chemicals, the salinity level, the concentration of bacteria and organic matter, as well as the temperature. The choice of which water-quality indicators are meaningful depends on the activities for which the water is used. For example, the production of certain crops, such as citrus fruits, depends on salinity levels. If a farmer switches from high-quality to more saline water, it may imply a necessary transition between crops. In cases where the water quality is an input for the production process, one can measure the values by using markets; several methods, such as the contingent valuation method, have been developed to estimate these values by simulating market behavior. That method consists of surveying farmers about their willingness to pay for improved water quality and using those responses to estimate the addition to the economic and societal benefits with higher water quality.

Blending of fresh with wastewater have a significant impact on the crop gross margin, as shown in Table 5. with different situations for the blending ratio of fresh and wastewater (water salinity increased from (ECw (uS/m) = 1117) to (ECw (uS/m) = 1296) shows an insignificant effect on citrus crops and other crops that are sensitive to salinity, such as pepper.

Moderate tolerance and tolerance to salinity crops are benefits form fertilizers content of TWW and shows an increase of gross margin due to saving of fertilizers costs without a decline of crop yield due to increase of water salinity. For the salt-sensitive crops, the additional benefits gained with

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 19 August 2024 doi:10.20944/preprints202408.1260.v1

water blending as reduction of fertilizers costs are not fully compensated by the crop's yield reduction due to salinity.

Salt-tolerant crops or crops with medium tolerance to salinity, such as date palm, barley, Tomatoes, and olives, are not affected by increasing salinity. These crops show a good performance when increasing the mixing ratio of FW to treated wastewater; this result might be due to many reasons, such as the water's nutrient content, the decreasing cost of fertilizer, and the increasing per-unit yield due to receiving the full net-irrigation water demand.

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

Table 6 provides net profit values (US$/ha) for various crops across different blending scenarios. The blending scenarios range from 0% TWW(S_BAU) to 100% TWW(S_5), with incremental increases in the proportion of TWW used for irrigation. The net profit values represent the financial return per unit area of cultivation for each crop under each blending scenario. These values are essential for evaluating the economic viability of crop production under different water management strategies.

Analysis of the data reveals how net profit varies among different crops in response to changes in the blending ratio of FW to treated wastewater. For example, crops such as citrus, Grapes, and banana demonstrate a gradual decline in net profit as the proportion of TWW increases. This decline may be attributed to factors such as reduced crop quality or marketability associated with the use of TWW for irrigation.

Conversely, some crops, like date palm, olive, wheat, barley, and other field crops, exhibit relatively stable net profit values across different blending scenarios. This suggests that these crops are less sensitive to changes in water quality or may have lower input costs associated with irrigation. Furthermore, certain crops, such as pepper, squash, and other vegetables, experience a significant decrease in net profit with increasing proportions of treated wastewater. This indicates that these crops may be particularly sensitive to changes in water quality or may require adjustments in cultivation practices to maintain profitability.

Overall, the findings from Table 6 provide valuable insights into the economic implications of blending FW with TWW for crop production. These insights can inform decision-making processes related to water resource management, crop selection, and agricultural profitability in water-limited regions. The net profit analysis presented in Table 6 offers valuable insights into the economic implications of blending FW with TWW for crop production. The data reveal varying trends among different crops, with some showing a gradual decline in net profit as the proportion of TWW increases, while others maintain relatively stable profitability levels.

These findings emphasize the importance of considering both water quality and economic viability when implementing water management strategies in agriculture. While some crops may be more resilient to changes in water quality, others may require careful consideration and potential adjustments to maintain profitability.

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

Table 7 shows the value added of water by increasing the bleeding percentage of TWW. The average water value for surface water is the highest for peppers, minor vegetable crops, annual field crops (fodders), with more (US$ 2.1/m^3). The net value added for citrus is US$ 0.81/m^3, and this value added is decreased to about US$ 046/m^3 by relaying on TWW. On the contrary, Date palm, Tomatoes, cereals and olives showing an increase of water value added by increasing of the blending ration of TWW.

Different crops respond differently to varying blending ratios of TWW and FW. For instance, crops like citrus, banana, Grapes, and pepper show a decreasing trend in net value added as the proportion of TWW increases, indicating that they might be sensitive to salinity in treated wastewater. On the other hand, crops like palm, olives, and some vegetables show a relatively stable or increasing trend in net value added across blending scenarios, suggesting they are tolerant to increase salinity of irrigation water.

The net value added for crops reflects not only the water quality but also the nutrient content provided by the irrigation water. TWW often contains elevated levels of nutrients, such as nitrogen and phosphorus, which can benefit crop growth. The varying responses of different crops to blending scenarios may be related to their differing nutrient requirements and abilities to utilize nutrients from the irrigation water. The net value added reflects the overall economic benefit (or loss) associated with using blended water for irrigation. Crops with higher net value added under specific blending scenarios may indicate that they are less affected by the potential negative impacts of treated wastewater, such as salinity, residual contaminants, or pathogens. Understanding the water quality requirements of different crops is essential for optimizing blending ratios to maximize economic returns while ensuring crop productivity and quality. Higher net values indicate greater economic benefits, which could incentivize farmers to adopt water reuse practices. However, socio-economic factors such as market demand, consumer preferences, and regulatory policies also play crucial roles in determining the viability and acceptance of crops grown with blended water.

Table 7. Net Value Added (US$ per 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

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.

The farmers' greatest ability to pay for water was for Tomatoes, Pepper, Date Palm with more than US$ more than 0.7/m^3. The lowest was for olives and cereal crops and did not exceed US$ 0.14/m^3. Furthermore, by increasing the blending ratio, the results illustrate a decreasing FAP for citrus crops from 0.63 US$/m^3 to 0.28 US$/m^3.

Sensitive crops like citrus and peppers display extreme decline in net profit as the percentage of treated water increases. This suggests a higher sensitivity to the water quality or composition of water for these crops. Certain crops might show an optimum percentage of treated water for maximizing net profit. For instance, date Palm, Tomatoes and other fruits exhibit a gradual increase in profit, indicating that a certain mixed ratio might provide the best balance between water cost savings and maintaining profitability.

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

Some crops like wheat, barley, and other field crops maintain a relatively consistent net profit across different water mix percentages, indicating a potential resilience to changes in water quality.

Identifying the reasons behind the extreme fluctuations in net profit for certain crops when exposed to higher percentages of treated water could offer insights into the crop's sensitivity to water quality and its economic implications. Evaluating the trade-offs between water cost savings and crop profitability. Even if certain crops exhibit decreased profitability with higher treated water percentages, the overall cost-benefit analysis considering water expenses might still favor their cultivation. Considering the long-term effects on soil quality and the economic implications of potential soil degradation due to increased usage of treated water.

Considering the economic aspects of water usage and crop selection. Even though certain crops might have reduced water productivity with treated water, they could still be economically viable due to other factors like market demand or yield. Assessing the environmental impact of using treated water on different crops and soils. This includes examining the potential accumulation of contaminants in crops or changes in soil quality over time.

4. Conclusions

Using a blend of TWW and fresh surface water for irrigation has emerged as a valuable resource in addressing water scarcity, particularly in the underutilized TWW of NJV. Using this TWW for irrigation, post proper treatment, offers economic and environmental advantages. It conserves substantial amounts of FW for domestic use and can potentially reduce or eliminate the necessity for expensive chemical fertilizers in soil. However, the impact of TW irrigation on crops remains inconclusive, potentially due to variations in wastewater properties, crop varieties, plant adaptability to nutrient-deficient settings, and sensitivity to environmental conditions.

The negative impact of TW can be reduced significantly by selecting a proper crop types and varieties, irrigation system, an appropriate cropping pattern with appropriate and effective irrigation management, as well as continuous examination of water, soil, and plant quality, and by taking careful and precautionary actions against pathogens.

This study tries to develop an economic framework that is a tool to help water agencies and other water-sector professionals to assist water managers with identifying and estimating the full range of benefits and costs associated with water-reuse. With water scarcity in the Jordan Valley, the options are either augmenting the water supply by utilizing non-conventional water resources, such as blending FW with treated wastewater, or controlling and reducing the demand. Because the fresh-water supply is well developed in the form of dams on the JV and it is expected to decrease in the future due to climate change and competition with domestic demand, the choices to improve water productivity include reducing the demand by changing cropping patterns or reducing the irrigated area within each farm unit. Both options are unrealistic in light of the country's increased demand for food. Therefore, improved irrigation efficiency must be investigated at all levels.

The economic-performance indicators show that citrus is negatively affected by introducing TWW in the NJV. Other crops, such as date palm, olives, Tomatoes, and peppers, are positively influenced by reusing treated wastewater. The gross margin, net profit per hectare analysis shows an insignificant effect on citrus crops and other crops that are sensitive to salinity, such as pepper and other vegetables, with a slight reduction of farm income. Salt-tolerant crops or crops with medium tolerance to salinity, such as date palm, barley, Tomatoes, and olives, are not affected by increasing salinity. These crops have a good performance when increasing the mixing ratio of FW to treated wastewater. This result might be due to many reasons, such as the water's nutrient content, a decreased fertilizer cost, or an increased per-unit yield from receiving the full net-irrigation water demand. For the salt-sensitive crops, the additional benefits and cost reduction gained with water blending are compensated by the crop-yield reduction due to salinity.

The average net value added for surface water is the highest for bananas, Tomatoes, Date Palm, and peppers, with more than US$ 1.0/m^3. The net value added for citrus crops is US$ 0.63/m3, and the values decrease to about US$ 0.28/m^3 by increasing the blending ratio. Therefore, the current practice of banana and date palm producers is economically rational by installing RO unit to irrigate banana, since water value is near twice of JD 0.78 m^{-3} of the brackish water desalination costs of one cubic meter of about US$ 0.4 per cubic meter with a standard deviation of US$ 0.18 per cubic meter The estimated values of water represent the maximum price that farmers might be willing to pay for water under the current market conditions

Date palm, Grapes, olives, and bananas show an increasing added water value when blending water with treated wastewater. The farmers' ability to pay for water is the greatest for bananas, Tomatoes, and peppers, with more than US$ more than 1.4/m^3. The lowest is for olives and citrus crops, and the amount does not exceed US$ 0.38/ m^3. Furthermore, by increasing the blending ratio, the results illustrate an increasing FAP for olives and a decreasing FAP for citrus crops.

To mitigate the impact of water salinity on citrus production, growers can take several measures to minimize salt buildup in the root zone such as improve soil quality by adding organic matter and gypsum to enhance soil structure and drainage, periodically flush the soil with large amounts of low-salinity water during winter to leach out accumulated salts from the root zone, using citrus rootstocks that are more salt-tolerant when establishing new orchards. Regularly test soil and water to monitor salinity levels and make informed decisions regarding necessary amendments and irrigation practices. However, Water prices relative to agricultural water value are very low in the Jordan Valley, farmers pay a water price of US$ 0.018/m^3, this provides no incentive for efficient water use in the Jordan Valley

Higher percentages of treated water may not always correlate with increased productivity, profitability, or net value added. Understanding the economic risks associated with specific crops and their sensitivity to water quality is crucial for informed decision-making. While using treated water can potentially save costs, it's essential to balance these savings against the impact on crop productivity and economic returns. Understanding the reasons behind the sensitivity of certain crops to treated water, especially those showing significant negative impacts, requires deeper investigation. This analysis can guide better crop selection and water management strategies. While reusing wastewater for irrigation offers potential cost savings, its impact varies widely across different crops. Balancing economic benefits with potential productivity and profitability reductions is crucial in deciding the optimal usage of treated water in agricultural practices. Further studies are necessary to make informed decisions about water resource management and crop selection for sustainable and economically viable farming in the region.

Author Contributions: Conceptualization, M. T., and M. Q.; Model design and data collection, M. T., E. K., and A. S.; Formal analysis, E. K., and M. J.; Methodology, T. Q. and E. K.; Resources, M. T.; Software, E. K and A. S.; Writing – original draft, E. K.; K.A; H. A; T. Q. and A. J; Writing – review & editing, N. K., N. T., and A. J. All authors drafted and revised the manuscript. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Acknowledgments: The authors are grateful to both the Ministry of Water and Irrigation and the Ministry of Agriculture in Jordan for providing us with the data used in the article. This research was financially supported by Deanship of Academic Research at The University of Jordan and the Jordanian Higher Council for Science and Technology (HCST) under CYCLOLIVE PRIMA II project.

Data Availability Statement: The data presented in this study are available upon request from the authors with reasonable justifications

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Hlavaty, H. Water Management Initiative: Review of Water Scarcity Ranking Methodologies; United States Agency for International Development. Prepared by Tetra Tech Water Management Initiative: Jordan, 2018.
2. MWI. Water Substitution and Reuse Policy; Ministry of Water and Irrigation: Amman, Jordan, 2016.
3. MWI. Annual Report 2020; Ministery of Water and Irrigation: Amman, Jordan, 2020.
4. DOS. Interactive Database, 2020, Departement of Statisitics, Amman, Jordan. Available online: https://dosweb.dos.gov.jo/ (accessed on 7 March 2024).
5. CBJ. Monthly Statistical Bulletin; Central Bank of Jordan: Amman, Jordan, 2018; Volume 54, p. 66.
6. MWI. National Water Strategy 2016-2025; Ministry of Water and Irrigation: Amman, Jordan, 2016.
7. MWI. Water Budget for the Year 2020; Directorate of Strategic Planning, Ministry of Water and Irrigation: Amman, Jordan, 2021.
8. Abdulla, F.; Alfarra, A.; Abu Qdais, H.; Sonneveld, B. Evaluation of wastewater treatment plants in Jordan and suitability for reuse. Acad. J. Env. Sci. 2016, 4, 111-117, doi:10.15413/ajes.2016.0305
9. Abdulla, F.; Farahat, S. Impact of climate change on the performance of wastewater treatment plant: Case study central Irbid WWTP (Jordan). Procedia Manuf. 2020, 44, 205-212, doi:https://www.sciencedirect.com/science/article/pii/S2351978920308106.
10. JSMO. Jordanian Standards 893/2021 (Water – Reclaimed Domestic Wastewater): Technical Regulation. ; Jordan Standards and Metrology Organization, Amman, Jordan: 2021.
11. Official Gazette. Regulation No (Z/1). Revised Instructions and Conditions for the Use of Wastewater, Treated Wastewater, Saline and Brackish Water for agricultural purposes. According to the Article (15/C) of the Agricultural Law No (13) for the year 2015 and its amendments. Date 01/02/20. 2021, 5696, 377.
12. MWI. Water Reallocation Policy 2016.
13. MWI. Water Substitution and Reuse Policy. 2016.

14. Hashem, M.S.; Qi, X. Treated wastewater irrigation—A review. Water 2021, 13, 1527, doi:https://doi.org/10.3390/w13111527.
15. WHO. Guidelines for the safe use of wastewater excreta and greywater; World Health Organization: 2006; Volume 1: Policy and Regulatory Aspects.
16. Alkhaza'leh, H.; Abu-Awwad, A.; Alqinna, M. Effect of irrigation with treated wastewater on potatoes' yields, soil chemical, physical and microbial properties. Jordan J. Earth Environ. Sci. 2023, 14.
17. Hosney, H.; Tawfik, M.H.; Duker, A.; van der Steen, P. Prospects for treated wastewater reuse in agriculture in low-and middle-income countries: Systematic analysis and decision-making trees for diverse management approaches. Environ. Dev. 2023, 46, 100849, doi:https://doi.org/10.1016/j.envdev.2023.100849.
18. DOS. Interactive Database, 2024, Departement of Statisitics, Amman, Jordan. Available online: https://dosweb.dos.gov.jo/ (accessed on 7 March 2024).
19. Levy, Y.; Syvertsen, J. Irrigation water quality and salinity effects in citrus trees. In Horticultural Reviews, Janick, J., Ed.; John Wiley and Sons, Inc.: New Jersey, United States, 2003; pp. 37-82.
20. Abdel-Jabbar, S.; Vallentin, A.; Boening-Zilkens, M. Guidelines for Reclaimed Water Irrigation in the Jordan Valley: Practical Recommendations for Farmers and Extension Workers; Jordan Valley Authority (JVA) and Deutsche Geselischaft für Technische Zusammenarbeit (GTZ): Jordan, 2006.
21. Abobatta, W.F. Plant responses and tolerance to combined salt and drought stress. In Salt and Drought Stress Tolerance in Plants: Signaling Networks and Adaptive Mechanisms, Hasanuzzaman, M., Tanveer, M., Eds.; Springer Cham: 2020; pp. 17-52.
22. Chen, W.; Lu, S.; Jiao, W.; Wang, M.; Chang, A.C. Reclaimed water: A safe irrigation water source? Environ. Dev. 2013, 8, 74-83, doi:https://doi.org/10.1016/j.envdev.2013.04.003.
23. Carr, G. Water reuse for irrigated agriculture in Jordan: soil sustainability, perceptions and management. Water, life and civilisation: climate, environment and society in the Jordan valley; Cambridge University Press: Cambridge, 2011; pp. 415-428.
24. Urbano, V.R.; Mendonça, T.G.; Bastos, R.G.; Souza, C.F. Effects of treated wastewater irrigation on soil properties and lettuce yield. Agric. Water Manage. 2017, 181, 108-115, doi:https://doi.org/10.1016/j.agwat.2016.12.001.
25. Abdu, N.; Abdulkadir, A.; Agbenin, J.O.; Buerkert, A. Vertical distribution of heavy metals in wastewater-irrigated vegetable garden soils of three West African cities. Nutr. Cycling Agroecosyst. 2011, 89, 387-397, doi:https://link.springer.com/content/pdf/10.1007/s10705-010-9403-3.
26. Abu Madi, M.; Braadbaart, O.; Al-Sa'ed, R.; Alaerts, G. Willingness of farmers to pay for reclaimed wastewater in Jordan and Tunisia. Water Supply 2003, 3, 115-122, doi:https://doi.org/10.2166/ws.2003.0052.
27. Choukr-Allah, R. Wastewater treatment and reuse. In Arab environment: water: sustainable management of a scarce resource; Arab Forum for Environment and Development (AFED): Beirut, Lebanon, 2010; pp. 107-124.
28. Qadir, M.; Wichelns, D.; Raschid-Sally, L.; McCornick, P.G.; Drechsel, P.; Bahri, A.; Minhas, P.S. The challenges of wastewater irrigation in developing countries. Agric. Water Manage. 2010, 97, 561-568, doi:https://doi.org/10.1016/j.agwat.2008.11.004.
29. Emad, A.-K.; Badi, L.; Halasheh, M.; Sobh, A.; Baz, I.A.; Zoubi, R.A.; Asalamat, H.; Burwell, K.; Götzenberger, J.; Pogade, F.; et al. Decentralized Wastewater Management in Jordan; Federal Ministry of Economic Cooperation and Development: Bonn, Germany: Amman, Jordan, 2019.
30. Salgot, M.; Vergés, C.; Angelakis, A.N. Risk assessment in wastewater recycling and reuse. Water Supply 2003, 3, 301-309, doi:https://doi.org/10.2166/ws.2003.0076.
31. Tawfik, M.H.; Al-Zawaidah, H.; Hoogesteger, J.; Al-Zu'Bi, M.; Hellegers, P.; Mateo-Sagasta, J.; Elmahdi, A. Shifting Waters: The Challenges of Transitioning from Freshwater to Treated Wastewater Irrigation in the Northern Jordan Valley. Water 2023, 15, 1315, doi:10.3390/w15071315.
32. Pedrero, F.; Camposeo, S.; Pace, B.; Cefola, M.; Vivaldi, G.A. Use of reclaimed wastewater on fruit quality of nectarine in Southern Italy. Agric. Water Manage. 2018, 203, 186-192, doi:https://doi.org/10.1016/j.agwat.2018.01.029.
33. Abdel-Jabbar, S.; Vallentin, A.; Boening-Zilkens, M. Guidelines for Reclaimed Water Irrigation in the Jordan Valley: Practical Recommendations for Farmers and Extension Workers; Jordan Valley Authority (JVA), Deutsche Geselischaft für Technische Zusammenarbeit (GTZ) 2006.
34. Vallentin, A. Agricultural Use of Reclaimed Water-Experiences in Jordan. Water Practice and Technology 2006, 1, wpt2006040.

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 19 August 2024 doi:10.20944/preprints202408.1260.v1

35. Vallentin, A.A.-J., S.; Srouji, F. . Guidelines for Brackish Water Irrigation in the Jordan Valley; Jordan Valley Authority (JVA) and Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ): Jordan, 2003.
36. Pescod, M. Wastewater treatment and use in agriculture-FAO irrigation and drainage paper 47. Food and Agriculture Organization of the United Nations, Rome 1992.
37. Maas, E. Salinity and citriculture. Tree Physiol. 1993, 12, 195-216, doi:https://doi.org/10.1093/treephys/12.2.195.
38. Maas, E.V.; Hoffman, G.J. Crop salt tolerance—current assessment. J. Irrig. Drain. Div. 1977, 103, 115-134, doi:https://doi.org/10.1061/JRCEA4.0001137.
39. Ayers, R.S.; Westcot, D.W. Water quality for agriculture; Food and Agriculture Organization of the United Nations Rome, 1985; Volume 29.
40. Grieve, C.M.; Grattan, S.R.; Maas, E.V. Plant salt tolerance. In ASCE manual and reports on engineering practice; American Society of Civil Engineers: Reston, 2012; Volume 71, pp. 405-459.
41. Maas, E. Testing crops for salinity tolerance. In Proceedings of the Workshop on adaptation of plants to soil stresses, University of Nebraska Lincoln, NE, 1993; pp. 234-247.
42. El-Otmani, M.; Chouaibi, A.; Azrof, C.; Bouchaou, L.; Choukr-Allah, R. Response of clementine candarin to water-saving strategies under water scarcity conditions. Water 2020, 12, doi:https://doi.org/10.3390/w12092439.
43. Grattan, S.R.; Díaz, F.J.; Pedrero, F.; Vivaldi, G.A. Assessing the suitability of saline wastewaters for irrigation of Citrus spp.: Emphasis on boron and specific-ion interactions. Agric. Water Manage. 2015, 157, 48-58, doi:https://doi.org/10.1016/j.agwat.2015.01.002.
44. Van Genuchten, M.T.; Gupta, S. A reassessment of the crop tolerance response function. J. Indian Soc. Soil Sci. 1993, 41, 730-737, doi:https://www.pc-progress.com/Documents/RVGenugten/P1295.pdf.
45. Vila Verde, D.D.S.; Mendes, M.I.D.S.; Nobre, L.V.D.C.; Souza, A.D.S.; Dos Santos, K.C.F.; Soares Filho, W.D.S. In vitro tolerance of citrus rootstocks under saline stress. Plant Cell, Tissue and Organ Culture (PCTOC) 2024, 156, doi:10.1007/s11240-023-02627-y.
46. Panigrahi, P. Impact of deficit irrigation on citrus production under a sub-humid climate: a case study. Water Supply 2023, 23, 1177-1188, doi:10.2166/ws.2023.074.
47. Oubelkacem, A.; Scardigno, A.; Choukr-Allah, R. Treated Wastewater Reuse on Citrus in Morocco: Assessing the Economic Feasibility of Irrigation and Nutrient Management Strategies. Integrated Environmental Assessment and Management 2020, 16, 898-909, doi:10.1002/ieam.4314.
48. Bilal, H.M.; Zulfiqar, R.; Adnan, M.; Umer, M.S.; Islam, H.; Zaheer, H.; Abbas, W.M.; Haider, F.; Ahmad, I. Impact of salinity on citrus production; A review. Int. J. Appl. Res 2020, 6, 173-176.
49. Levy, Y.; Syvertsen, J. Irrigation water quality and salinity effects in citrus trees. Horticultural Reviews 2004, 30, 37-82.
50. Simpson, C.R.; Nelson, S.D.; Melgar, J.C.; Jifon, J.; King, S.R.; Schuster, G.; Volder, A. Growth response of grafted and ungrafted citrus trees to saline irrigation. Sci. Hortic. 2014, 169, 199-205, doi:https://doi.org/10.1016/j.scienta.2014.02.020.
51. Murkute, A.A.; Sharma, S.; Singh, S. Citrus in terms of soil and water salinity: A review. J. Sci. Ind. Res. 2005, 64, 393-402, doi:https://nopr.niscpr.res.in/handle/123456789/5137.
52. Al-Yassin, A. Influence of salinity on citrus: a review paper. J. Cent. Eur. Agric. 2004, 5, 263-272, doi:https://hrcak.srce.hr/16803.
53. Cerda, A.; Nieves, M.; Guillen, M.G. Salt tolerance of lemon trees as affected by rootstock. Irrig. Sci. 1990, 11, 245-249, doi:https://doi.org/10.1007/BF00190540.
54. Greaser, G.; Harper, J. Agricultural alternatives: Enterprise budget analysis, Penn State College of Agricultural Sciences, Cooperative Extenstion. 1994.
55. Young, R.A.; Loomis, J.B. Determining the economic value of water: concepts and methods; Routledge: 2014.
56. Menezes, F.M.; Capodeferro, M.W.; Smiderle, J.J.; Guimarães, P.E. Estimating efficient water prices in the Sao Marcos River Basin: a residual imputation approach. J. Water Resour. Plan. Manag. 2022, 148, 06022001, doi:https://doi.org/10.1061/(asce)wr.1943-5452.0001538.
57. Hellegers, P.; Davidson, B. Determining the disaggregated economic value of irrigation water in the Musi sub-basin in India. Agric. Water Manage. 2010, 97, 933-938, doi:https://doi.org/10.1016/j.agwat.2010.01.026.

58. Speelman, S.; Farolfi, S.; Perret, S.; D'Haese, L.; D'Haese, M. Irrigation Water Value at Small-scale Schemes: Evidence from the North West Province, South Africa. Int. J. Water Resour. Dev. 2008, 24, 621-633, doi:https://doi.org/10.1080/07900620802224536.
59. Scheierling, S.; Treguer, D.O.; Booker, J.F. Water productivity in agriculture: Looking for water in the agricultural productivity and efficiency literature. Water Econ. Policy 2016, 02, 1650007, doi:https://doi.org/10.1142/S2382624X16500077.
60. Kiprop, J.K.; Lagat, J.; Mshenga, P.; Macharia, A. Determining the economic value of irrigation water in Kerio Valley Basin (Kenya) by residual value method. J. Econ. Sustainable Dev. 2015, 6, 102-108, doi:https://www.iiste.org/Journals/index.php/JEDS/article/view/21470.
61. Ashfaq, M.; Jabeen, S.; Baig, I.A. Estimation of the economic value of irrigation water. J. Agric. Social Sci. 2005, 1, 270-272.
62. Tabieh, M.; Al-Karablieh, E.; Salman, A.; Al-Qudah, H.; Al-Rimawi, A.; Qtaishat, T. Farmers’ Ability to Pay for Irrigation Water in the Jordan Valley. J. Water Resource Prot. 2015, 7, 1157-1173, doi:http://dx.doi.org/10.4236/jwarp.2015.715095.
63. Al-Karablieh, E.K.; Salman, A.Z.; Al-Omari, A.S.; Wolff, H.-P.; Al-Assa'd, T.A.; Hunaiti, D.A.; Subah, A.M. Estimation of the economic value of irrigation water in Jordan. J. Agric. Sci. Technol. B2 2012, 2, 487.
64. Allen, R.G.; Pereira, L.S.; Raes, D.; Smith, M. Crop evapotranspiration-Guidelines for computing crop water requirements-FAO Irrigation and drainage paper 56. Fao, Rome 1998, 300, D05109.
65. FAO. CropWat 0.8, Food and Agriculture Organization, Land and Water Division.: 2021.
66. Al-Bakri, J.T.; Shawash, S.; Ghanim, A.; Abdelkhaleq, R. Geospatial techniques for improved water management in Jordan. Water 2016, 8, 132, doi:https://doi.org/10.3390/w8040132.
67. Van Den Berg, C.; Agha Al Nimer, S.K.H.; Fileccia, T.; Gonzalez, L.M.; Wahseh, S. The cost of irrigation water in the Jordan Valley (English). Water Partnership Program (WPP); World Bank Group: Washington, D.C., 2016.
68. Al-Assa'd, T.A.; Al-Karablieh, E.K.; Salman, A.Z.; Wolff, H.-P. Recognizing the Economic Value of Domestic Water in Jordan as a Way for Appropriate Setting of Water Pricing. In Proceedings of the 1st Water and Environment International Conference, 26-29 October, 2011, Marrakech, Morocco, 2011.
69. Wolff, H.P.; Al-Karablieh, E.; Al-Assa'd, T.; Subah, A.; Salman, A.Z. Jordan water demand management study: on behalf of the Jordanian Ministry of Water and Irrigation in cooperation with the French Development Agency (AFD). Water Supply 2012, 12, 38-44, doi:10.2166/ws.2011.114.
70. Salman, A.; Al-Karablieh, E.; Haddadin, M. Limits of pricing policy in curtailing household water consumption under scarcity conditions. Water Policy 2008, 10, 295-304, doi:https://doi.org/10.2166/wp.2008.040.