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FINANCIAL AND MANAGERIAL ANALYSIS OF IRRIGATION WITH TREATED WASTEWATER IN ISRAEL

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Abstract

Treated wastewater has become an important water source for irrigation in Israel. Its use benefits the environment by assisting with waste disposal, and agriculture by supplying water and nutrients, but it also carries pollutants that may damage the environment. We refer to wastewater quality as a key issue in agricultural reuse and assess its impacts on environment and groundwater pollution. For this we develop assessment procedures and propose pricing methods that would incorporate the above impacts into the public decision making.

Key Words : Wastewater; Effluents; Economic Assessment; Environmental impacts; Cost-Benefit Analysis.
JEL Classification : C12, O13, Q10, Q25

Introduction

Renewable water resources in Israel are limited and amount to 1,900 MCM (million cubic meter) per annum (312 m^3 per capita)[1]. Domestic water consumption is increasing rapidly at a rate of 2-8 per cent a year[2], reducing the amount of fresh water available for agriculture, and at the same time increasing the output of urban wastewater[3].

Agriculture is the main consumer of freshwater in Israel since of the total annual freshwater withdrawals of 1,700 MCM, agriculture uses 64 per cent. With the increasing water scarcity, treated wastewater is the only practical, reasonably priced alternative for water supply to agriculture, as the high-quality fresh water supply is gradually transferred to urban uses. Directing treated wastewater to agricultural use has additional advantages. Since the alternative is disposal to creeks or to the sea, reuse in irrigation is usually the cheapest option for wastewater disposal[4]. Also, the nutrients in wastewater may provide economies in the use of chemical fertilizers (Haruvy, et. al.)[5].

However, the urban wastewater contains many constituents which potentially pose hazards to health, the environment, crops, soils and groundwater. Most constituents may be reduced to satisfactory levels through advanced treatment processes (Feigin, et. al.[6]), but salinity reduction requires additional relatively expensive processes[7&8]. Thus, unsuitable quality is the main impediment to the use of wastewater for irrigation. The quality of wastewater, i.e., its chemical composition and micro-organism contents, depend on several factors: quality of the source water supplied to households and industry; patterns of in-house water use; the quality of the wastewater produced by households and industrial plants, and the relative proportions from these sources (industrial wastewater might be of quite low quality); and, the timing of wastewater use, i.e., season, day of the week and time of day.

Irrigation with Waste-water

Irrigation with low-quality wastewater may damage

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human health and the environment. Wastewater irrigation affects agriculture through its effects on crop yields, farmers' profits, soil fertilization, and groundwater pollution. Additional problems include damage to irrigation systems, increased water requirements and the need for continuous monitoring and control. Irrigation with wastewater may reduce the yields of economic crops, because of the enhanced salinity levels and the accumulation of salts in the root zone[9]. Also, the excessive nitrogen content in wastewater supplies nutrients to crops at rates different from their needs, and may reduce yield levels or quality (Haruvy, et. al.[10]; Feinerman, et. al.[11]). Wastewater also contains higher concentrations of boron than crops can tolerate, which also damages yields and quality. Such excessive boron concentrations arise from industrial sewage, boron-containing soaps and cleansers, and residuals of dairy herds[12].

Irrigation with wastewater has been found to damage yields, for example, in table olives[13] and grapevines[14], but reclaimed wastewater appeared to be a suitable alternative water resource for irrigation of citrus trees[15]. Wastewater can also damage soils, since wastewater is characterized by a high SAR (Sodium Absorption Ratio) - - SAR represents the ratio between sodium (Na) and calcium and magnesium (Ca + Mg) in water. Irrigation with water of a high SAR (SAR>6, EC<4 dS/m) may sodify the soil surface and deep soil layers, since during irrigation cycles, sodium replaces calcium on the soil clay particles and destabilizes the soil structure. This may reduce soil surface infiltration of water and drainage from the root zone through the lower layers, leading to decreased water infiltration into the soil; increased losses of irrigation and rainwater; increased runoff; and decreased leaching of accumulated salts from the soil root zone. The effect of wastewater irrigation on soils in Israel was analyzed by Tarchitzky, et. al.[16].

Also, irrigation with wastewater may enhance the contamination of groundwater, mainly with chlorides, nitrogen, heavy metals and organic compounds. Nitrate pollution of groundwater by agriculture emerged as a major conservation issue in the 1990s[17&18]. Levels and costs of pollution with nitrates were analyzed by Hadas, et. al.[19] and Haruvy, et. al. (1997, 1999, 2000)

The process of salinity increase in Israel's Coastal Aquifer was investigated by Mercado[20]. The impact of chlorides increase in groundwater has been analyzed by means of an economic-hydrological model[21]. Other forms of damaging pollution include: organic matter[22]; atrazine[23]; pathogenic organisms, which can be reduced by treatment[24] and heavy metals in low amounts[25&26].

Nevertheless, for irrigation in Israel, using treated wastewater is the best means to facilitate agricultural production under conditions of water scarcity; it uses a water resource that is available in large quantities and that already requires treatment, in order to prevent environmental damage. This paper reviews the prevailing situation and suggests a general framework in which to assess the impacts of irrigation with municipal wastewater on crops, soil and groundwater. These impacts comprise "financial costs" of wastewater treatment and reuse and "real costs" that accrue from the potential hazards. These assessed impacts are used as the basis of recommendations of an appropriate pricing procedure for recycled wastewater used for irrigation.

Methodology Used

The presented methodology includes several steps: examination of the prevailing situation to assess the potential damage from wastewater; estimation of the financial costs of wastewater use and of the potential for damage to crops, soils and groundwater; use of the results obtained as a basis for examination of alternative pricing options.

- **Prevailing situation**

We examined the current quality of wastewater used for irrigation, based on results from two surveys that focused especially on Cl, SAR and B levels. The first survey examined the quality of both source water and effluents (Water Commission[27]). The second survey examined effluent quality (Cl, B) in storage reservoirs during the peaks of the irrigation season (Ministry of Environment[28].

- **Financial Costs**

We estimated the financial costs attributable to treatment, storage and conveyance. Other financial costs refer to costs of adaptation of irrigation systems and increased water requirements because of salinity and evaporation at storage reservoirs.

- **Effects on Crops**

Wastewater usually contains higher salinity levels than source water, and the resulting accumulation of salts in the root zone decreases crop yields. We estimated variations of soil moisture and salinity for citrus growing in Central Israel. The root zone was divided into four layers, in which 40, 30, 20 and 10 per cent, respectively, of the total supplied water was used. Initial salinity levels were 2, 0 and 1 dS/m in irrigation water, rain and soil. Salinity levels following five irrigation and five rain periods were computed. The derived citrus crop yields were computed to estimate the cost of the reduction in crop yields that was due to high salinity.

- **Effects on Soil**

We estimated the damage caused by irrigation with high SAR effluent, as expressed in the creation of an impermeable layer at the soil surface and decreasing hydraulic conductivity in the root zone. Damage was estimated in terms of additional costs of labor and irrigation water, and/or decreased yields.

- **Effect on Groundwater Pollution**

Irrigation with effluent may accelerate the contamination of groundwater, mainly by chlorides, nitrogen, heavy metals and organic compounds. We used a hydrological model to predict the flow of chlorides through the unsaturated zone of the subsoil and into the groundwater below. We assumed that there is a threshold value for chloride concentration in the water supply for domestic consumption, and considered that when the concentration of chlorides in the groundwater reaches this threshold, desalination of groundwater should be initiated. When irrigation is with treated wastewater, it is necessary to initiate desalination earlier than under conditions of irrigation without effluent, and this increases the water supply costs. The damage to groundwater by effluent irrigation is computed in terms of increased capitalized costs that arise from water pumping and transporting, wastewater treatment and earlier initiation of desalinization.

We compared several scenario regarding various water sources, as well as wastewater, and assessed the water supply costs. Some preliminary results were presented by Yaron followed by a detailed scenario presentation by Haruvy. They refer to a given agricultural area (1,211 ha dedicated to citrus growing) and a municipal area (1,052 ha with 120,000 inhabitants), in which the annual agricultural and domestic water consumption is 9.1 and 12.0 MCM, respectively. The initial salinity levels were: aquifer- 250 mg/l, wastewater- 350 mg/l and, rain- 10 mg/l.

1. **Scenario 1**: the town uses local aquifer water and agriculture uses treated effluents;
2. **Scenario 2**: the town consumes local aquifer water, imported aquifer water (with a salinity level of 176 mg/l) and National Carrier water (with a salinity of 220 mg/l). Agriculture uses local aquifer water as well as the other two water sources;
3. **Scenario 3**: the town consumes local aquifer water and National Carrier water.

The patterns of time variation in salinity levels in the aquifer and in the town, for each scenario are presented in **Figures 1 and 2**.

- **Wastewater Pricing**

There are two basic principles that can serve as a basis for pricing wastewater so as to reflect the distribution of the burden among the producers (municipalities), users (farmers) of wastewater, and the society (the government). They are the compensation principle (Kaldor-Hicks) and the "polluter pays" principle. The compensation principle (Kaldor-Hicks) answers the

FIGURE 1
AQUIFER SALINITY LEVELS THROUGH TIME UNDER DIFFERENT SCENARIOS (Cl mg/l)

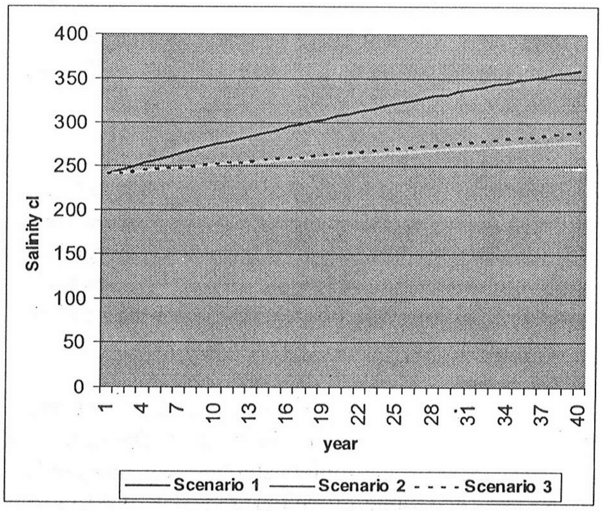
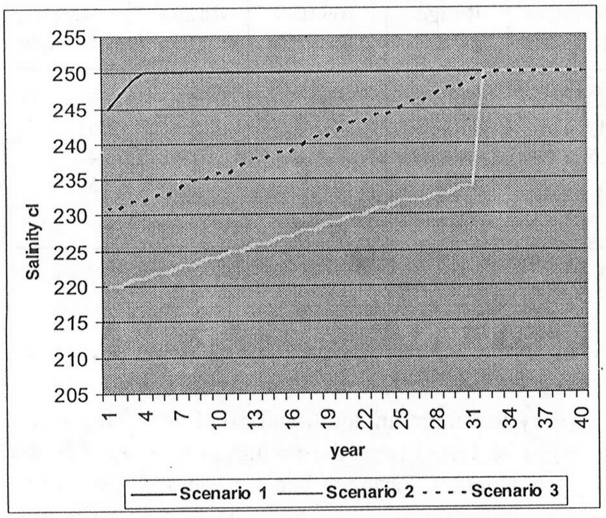


FIGURE 2
TOWN WATER SALINITY LEVELS THROUGH TIME UNDER DIFFERENT SCENARIOS (Cl mg/l)



question of which projects should society support. According to this principle, projects should be supported if the social benefits exceed the social cost, and should be financed independently of whether private benefits exceed private costs. The society (government) should prefer projects in which the gainers can compensate the losers, so that everyone can be better off.

According to the "polluter pays" principle, the entity that is responsible for polluting the environment should bear the costs of the pollution. With regard to wastewater, this means that the urban users, who are responsible for lowering the wastewater quality, should compensate the farmers for the costs of the transition from high-quality fresh water to wastewater. The compensation to farmers that arises from the transition to effluent should cover the need for new installations, losses caused by the reduced water quality, reduced yields, increased requirements for irrigation, leaching, etc. Based on these principles we suggested methods for pricing the wastewater supplied to farmers.

Research Findings

Survey Results

In 1994, The Water Commission conducted a survey to collect data on the quality of both the source water supplied to municipalities and the wastewater they produced. These data facilitated the evaluation of the pollutants added within the boundaries of the municipalities. The results suggested that in the upper quartile (25 per cent of the survey data), the addition of wastewater increased the concentration of pollutants as follows: SAR (Sodium Absorption Ratio) – from 3.18 to 18.04; sodium – from 158 to 581 mg/l; boron – from 0.54 to 1.54 mg/l; and chlorides – from 160 to 939 mg/l. For comparison, in Israel, the current limit of chlorides, expressed as chlorine, in drinking water is 250 mg/l, and it is expected to be reduced to 150 mg/l; the limit in Europe is 100 mg/l. A "normal" increase of concentration of chlorides in municipal wastewater, over their concentration in the source supply water is considered to be between 80-100 mg/l). The survey data show that domestic use increased the concentrations of pollutants **(Table 1)**.

TABLE 1
ADDITIONS OF POLLUTANTS TO SEWAGE AS COMPARED TO SOURCE WATER IN CHOSEN LOCATIONS : 1994

Pollutant	Chlorides mg/l	Sodium mg/l	SAR	Boron mg/l
Minimum	1.1	32	0.19	0.13
Maximum	939	581	18.04	1.54
Average	137	124	2.82	0.48
Standard deviation	146	95	2.68	0.25
1st quartile	63	71	1.65	0.34
Median	98	92	2.13	0.45
3rd quartile	160	158	3.18	0.54

Source: Based on **Water Commission Survey**: 1994 (1995)

In 1997, the Ministry of Environment conducted another survey, to examine the effluent quality in storage reservoirs during the peak of the 1997 irrigation season (July – August) **(Table 2)**. The survey results showed that 47 per cent of the total stored volume of effluents contained chloride concentrations between 300 and 500 mg/l; and that in 9 per cent it was as high as 500-800 mg/l. Also, 44 per cent of the total stored effluent volume contained boron concentrations between 0.6 and 1.61 mg/l (the "safe" limit is 0.5 mg/l). No SAR values were cited in this survey.

TABLE 2
EFFLUENT QUALITY IN STORAGE RESERVOIRS : 1997

TSS		BOD		EC		Cl		B	
Range mg/l	Relative Ratio %	Range mg/l	Relative Ratio %	Range mg/l	Relative Ratio %	Range mg/l	Relative Ratio %	Range mg/l	Relative Ratio %
30-	28	20-	18	1.5-	30	250-	30	0.25-	2
30-50	5	20-50	18	1.5-2	40	250-300	23	0.25-0.50	51
50-75	16	50-75	25	2-2.5	25	300-400	37	0.50-0.75	42
75-100	23	75-100	18	2.5+	5	400+	10	0.75-1.00	5
100+	28	100+	21						

Source: Based on **Ministry of Environment Survey**: 1997 (1998)

The following points arose from examination of these and other survey data. The annual average in-house water use is 100 m^3 per person, of which a considerable portion contains concentrations of chemicals, which may be detrimental to agricultural yields and may impair soil conservation. If not treated appropriately, such wastewater will cause groundwater contamination with chlorides, nitrates, sodium, boron, organic compounds, etc. The only existing regulations with respect to effluent quality are public health-oriented, and even these are not properly enforced. For example, the values of two basic effluent-quality parameters, BOD (Biological Oxygen Demand) and TSS (Total Suspended Solids), considerably exceeded their regulation levels (BOD – 20 and TSS – 30 mg/l). These surveys did not include values of microbiological aspects, which are usually treated through disinfection processes.

Especially lacking among the survey data are systematic quality comparisons between the source fresh water supplied to municipalities, and the outgoing wastewater they produce. Such comparisons are necessary in order to quantify the addition of pollutants by users within the municipal boundaries and, possibly, to identify the heavy polluters. The data suggest that rigorously organized monitoring and control of water, including with proper quality sampling is required, and that it should cover the supply/use chain from the supply of fresh water to households and industrial plants, through to the use of wastewater in irrigation.

Financial Costs

Secondary treatment costs amount to \$0.26 m^{-3}, and tertiary treatment an additional \$0.18 m^{-3}. These costs should be levied from the polluter, represented by the city population. Farmers face storage and conveyance costs amounting to \$0.16 m^{-3}. The storage costs arise because effluents must be stored during non-irrigation periods. There are additional costs to farmers, amounting to \$0.10 m^{-3}. These results are presented in **Table 3**. These costs are average costs for Israel.

Effects on Crops

According to our analysis, yield losses increase with increasing soil salinity in the root zone, and depend on crop sensitivity. It is recommended that the need for leaching the soil be evaluated by sampling soil from the various land plots. Since salinity levels can be decreased by increasing the leaching fraction, the reduction in profits through crop losses should be balanced against the additional water cost, to determine the lowest overall costs.

Effects on Soil

Creation of a layer having reduced permeability at the soil surface may impair germination, but this can be mitigated by the application of additional irrigation for germination. Estimated costs, including labor costs and reduced revenue, amount to \$14.80 per ha or \$0.03 m^{-3}. Damage caused by increased runoff, and expressed in a yield loss (10-15 per cent) has been estimated at \$0.045 m^{-3}. Decreased hydraulic conductivity can be prevented by additional leaching (10-20 per cent), at a cost of \$0.052 m^{-3}.

TABLE 3
ANNUAL COST TO FARMERS ($/m^{-3}) IN TRANSITION TO IRRIGATION WITH WASTEWATER AVERAGE FOR ISRAEL : 1997

Item	Sub-item	Annual Cost $/m^{-3}
Secondary Treatment Cost		0.262
Storage and Conveyance	Conveyance to Storage	0.022
	Storage	0.070
	Conveyance to Fields	0.070
Total Storage and Conveyance		0.162
Additional Cost and Damages		
Additional Storage Cost	10% losses due to evaporation	0.012
	Change of quality	n.a.
Irrigation System	Monitoring and quality control	0.012
	Filtration chlorinating chemicals	0.025
	Accelerated depreciation	0.005
	Maintenance	0.002
Leaching Irrigation	10% of irrigation water	0.012
	Soil salinity tests	0.006
Misc. (elimination of most vegetable crops, additional labor, etc.)		0.026
Total Additional Cost and Damages		0.100

Source: Yaron, et. al., 1999a

Effect on Groundwater Pollution

We calculated the water supply costs for the three scenarios presented in the methodology section. The total discounted costs for 40 years are presented in **Table 4**. In Scenario 1, agriculture uses relatively less expensively treated effluent but desalinization for domestic use of groundwater for domestic water consumption should begin earlier, which increases the costs of water for the urban population.

Although treatment costs that include desalinization are higher when irrigation is with treated wastewater, the total water supply costs are lower, because of the lower costs of wastewater to farmers. Nevertheless, the salinity levels in the groundwater are relatively high, and this should also be included in the account, in the form of derived environmental damage.

Principles for Wastewater Pricing

The costs accrued to farmers through the transition

TABLE 4
COSTS OF WATER SUPPLY FOR RELEVANT SCENARIOS : ANNUAL CAPITAL RETURN
(US$ million)

Scenario	Current Desalinization Cost	Discounted Desalinization Cost	Supply Cost to Town	Supply Cost to Agriculture	Total Supply Cost	Total Discounted Supply Cost
Scenario 1	5.61	1.01	26.82	16.17	42.99	15.00
Scenario 2	0.09	0.01	25.84	20.88	46.72	17.00
Scenario 3	0.04	0.003	28.35	20.87	49.23	17.95

Note: Annual capital return was computed over a period of 40 years at an annual interest rate of 5%.

to irrigation with effluent arise from the installation of new elements and adjustments of the water supply system, and are presented in **Table 3**. Costs of disposal are presented in **Table 5**.

TABLE 5
COSTS OF EFFLUENT DISPOSAL ($/m³)

	Conveying Distance (km)			
	0 km	2 km	10 km	30 km
~~Disposal to Creeks~~ (Upgrading Cost)	0.182			
Disposal to Sea (Without Upgrading)		0.010	0.037	0.100
Disposal to sea With Upgrading		0.192	0.220	0.282

Source: Yaron, et. al., 1999a

In **Table 6** we present the "building blocks" for approaches to effluent pricing based on the compensation principle or the "polluter pays" principle. The costs in **Table 6** are schematic. In specific cases, the actual values could differ, according to the specific conditions. The price of wastewater to farmers can be determined in one of the following ways. The first begins with direct negotiations between the producers of wastewater (municipalities) and the farmers in the area. If no agreement is reached between the parties, the Water Commissioner should determine the price. In the case of wastewater produced by public or governmental institutions, the Water Commissioner should determine the prices.

TABLE 6
BUILDING BLOCKS FOR APPROACHES TO EFFLUENT PRICING FOR USE IN IRRIGATION ($/m³)

1.	Price of good quality water to agriculture	0.182
2.	Cost of supply of good quality water	0.240
3.	Cost of effluent conveyance and storage	0.162
4.	Cost of secondary wastewater treatment	0.250
5.	Additional cost and damages to farmers	0.100
6.	Cost of zero base disposal level	0.010-0.182

Notes :
1) Price of good quality water is weighted average price (spring 1997).
2) Cost of supply of good quality water is average cost of Mekorot Company (1997 budget); without elimination of high-cost water plants which supply water to peripheral regions.
3) Cost of effluent conveyance is according to annual capital return, $0.115 m⁻³ is recommended cost to farmers.
4) Cost of upgrading to tertiary effluent level is $0.182 m⁻³
5) Additional cost to farmer arises from transition to effluent irrigation
6) Cost of disposal only, treatment cost excluded

The price agreed upon or dictated by the Water Commissioner should comply with two major criteria: it should be "reasonable" and "fair" in consideration of the building blocks, previously enumerated; and it should be "efficient", in the sense that it should balance, as far as possible, supply of demand. A basic price will be determined with respect to a predetermined volume of wastewater, and this price will comply with the above criteria. Upward or downward block deviations from this price (block differential prices) will be defined, according to the excess of demand or supply of wastewater in the region. The possibility of interconnecting several wastewater reservoirs within a reasonable distance of one another should be considered; it would enable excess wastewater in one or more reservoirs to be transferred to others which face excess demand.

We present three alternative options for wastewater pricing (**Table 7**) as follows:

TABLE 7
ALTERNATIVES FOR LEVYING PRICES

Alternative	$/m-3
Alternative A	
Good quality water price for farmers	0.182
Less	
Additional cost and damages to farmers (Effluent supply excluded)	-0.100
Effluent Price to Farmer	0.082
Alternative B	
Cost of good quality water supply	0.240
Less	
Additional cost and damages to farmers (Effluent supply excluded)	-0.140
Effluent Price to Farmer	**0.100**
Alternative C	
Cost of effluent disposal to farms land (According to annual capital return)	0.162
Less	
"Zero base" effluent disposal	-0.075
Effluent Price to Farmer	**0.087**

Alternatives A and B are based on the compensation principle, with the price and cost, respectively, of good quality water reduced so as to compensate for the additional costs and damage sustained by the farmers. Alternative C is based on the "polluter pays", principle by deducting the cost of alternative means of wastewater disposal. The alternatives in **Table 7** may serve as schemes, and as a basis for the elaboration of pricing systems (or prices) of wastewater to farmers, by a body in which representatives of the official institutions such as the Water Commission, Farmers Organizations, Mekorot (National Water Company in Israel) and the Ministry of Finance, should be involved.

Conclusions

Reusing wastewater is a necessity in the Israeli water management situation. The main benefits include sustaining agricultural production and maintaining environmental quality. In addition to the visible financial costs, there are other real costs expressed in impacts on crop yields, soils and groundwater. We have presented ways to assess these costs, which will serve as basis for determining water prices to farmers.

All these scenarios relate to secondary treatment, which seems to be the most common. Additional water treatment almost doubles the costs but does not get rid of salinity unless it is followed by relatively expensive desalinization processes. We have identified and analyzed the multivariate aspects of wastewater irrigation, using a generalized point of view that can be applied to other countries facing the need of wastewater irrigation.. Nevertheless, the specific conditions under which these tools are applied need to be explored and specified in order to implement the results for specific sites in Israel or in other countries.

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