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Cost-Benefit Analysis Model for Treated Wastewater Use in Agricultural Irrigation: four Palestinian Case Studies

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ABSTRACT

Worldwide, water scarcity is becoming one of the major limiting factors of economic development and social welfare provisions. Both limited access to and shortage of water sources, affect the agricultural sector, and this is one of the main economic pillars in Palestine, considering the growing demand for food security. Beneficial uses of treated wastewater (TWW) for agricultural purposes, increase irrigated land and enhance agricultural production. This paper aims to present the cost and benefit analysis (CBA) of treated wastewater use in Palestine, focusing on four types of famous crops (fodder, palms, olive and almond trees) and at three different locations of wastewater treatment plants (WWTPs). Results obtained, indicated that use of treated wastewater in agricultural irrigation is economically feasible within Palestinian territories. Use of one million cubic meters (MCM) of TWW in palm cultivation results in financial returns of USD$2 million. Meanwhile; irrigation of fodder, olive and almond trees achieve about USD$1 million per MCM of TWW. The use of TWW from sewage works and facilities erected in Palestinian territories is economically feasible as compared to TWW imported from Israeli wastewater treatment plants.

KEYWORDS : Cost/benefit analysis; economic feasibility; treated wastewater use; agricultural irrigation; wastewater treatment.

1. Introduction

It is becoming clear that developing new water sources will not be enough to meet current challenges of water scarcity; it must be coupled with more efficient use of existing sources of water through water demand management measures, water re-use and by maintaining water quality [1]. Water demand management in the agricultural sector requires the establishment of incentives, regulations and restrictions that will help, guide and coordinate the farmers' behavior for the efficient use of water in irrigation, while encouraging water saving technologies. The survival of the agricultural industry depends on the ability to save water and make water use efficiency as high as possible [2].

Treated wastewater (TWW) is considered a continuous, renewable and reliable water source, year round, as long as people drink and use potable water [3]. TWW as an alternative water source can be used for irrigation, hence reduces demand pressure on the conventional water resources. TWW is independent of winter season, even during drought periods, wastewater is produced constantly [4].

There are economic benefits from using treated wastewater in irrigation. This will increase the irrigated agricultural area and thus increase agricultural production [5]. The agricultural sector contributes significantly to the Palestinian economy. Palestine is characterized by the production of many agricultural crops due to the diversity of climate and terrain. Palestine suffers from water scarcity caused mainly by the lack of control over the Palestinian water resources, among other reasons [6].

Cost-benefit analysis (CBA) is one of the most widely accepted economic tools to support decision-making rational [7]. The method(s) followed in the evaluation process in the CBA is to use market prices to assess the costs and benefits, known as the 'financial analysis'.

2. Agriculture sector challenges in the study areas

The amount of fresh water allocated for agriculture will be reduced drastically to meet the increasing demand for municipal use. The irrigation water shared in Palestinian territories, is threatened by the challenges to subsidize other sectors with each of their water demands, but also to meet the increasing water needs for people in the future [8]. Treated Wastewater Reuse (TWR) in agriculture in semi-arid regions has become a necessity. The re-use of treated wastewater in the Palestinian agricultural sector has promising aspects due to a number of perspectives:

- Sewage is a problem on public health and the environment,
- There is no other unconventional alternate water source in the Palestinian territories, for agriculture (no sea water).
- The cost of TWR is low when compared to the cost of other alternatives. (Such as importing desalinated sea water from the region).
- Wastewater sources are reliable and a relatively constant source of water supply and thus play an important role in reducing uncertainty in the water sector [9].

However, while the TWR is extremely useful for all of these reasons, the use of treated wastewater in Palestine has its own special importance as it will become a constant and controlled water source and will be positively reflected on the national economy development. Therefore, it is necessary to evaluate the possibility of TWR and the different locations for agriculture irrigation [10].

The total arable land in the West Bank and Gaza is about 2.2 million acres and the estimated percentage of area planted is (84.5%), (87% of which are rain-fed agriculture, and 13% irrigated agriculture). In the West Bank, the proportion of agricultural area is 91%, which is equivalent to 1650 thousand acres and in Gaza, the proportion of agricultural area is 9%, which is equivalent to 165 thousand acres [11]. The Palestinian agricultural sector played an important role in the Palestinian national economy, despite the fact that the agricultural sector's share in the Palestinian economy has declined. In the 1970s; the agricultural production ratio fell from 45% to 35% of the gross national product and in the 1980s the drop ranged between 38% to 28% and then in 1993 the percentage dropped to 19% and decreased to 5.5% [12] again in 2010.

This paper explores the economic benefits of treated wastewater reuse in agriculture considering the basis of comparisons of net benefits for TWW reuse in irrigation from WWTPs in the West Bank compared with those in Israel.

3. Methodology

This section explains the methodologies that are applied to estimate the cost and benefit of treated wastewater reuse in irrigation in Wadi Zomer area (Fig. 1). The CBA covers the following scenarios:

Scenario 1: Reuse of treated wastewater generated from the Nablus treatment plant only and leave the remainder discharging across the green line.

Scenario2: Reuse of all TWW generated from the Nablus and Tulkarm treatment plants with zero discharge across the green line,

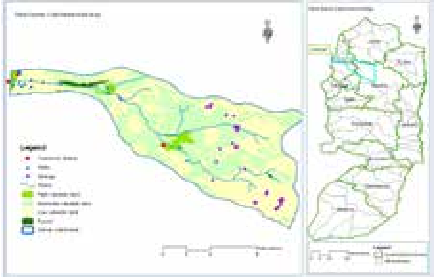

Figure 1 Wadi Zomer catchment area

Scenario3: Reuse of treated wastewater from WWTP inside the green line and pumped back to the Zomer catchment area.

EPANET program was used to design the pumps, conveyance lines and storage tanks for Scenario 3 as shown in Figure (2)

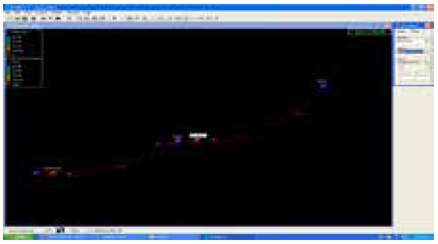

Figure 2. Print of EPANET program

3.1 Wastewater Quantities

Figure 3 below illustrates that the generated amount of waste water to be produced in 2015, is 3.3 million cubic meters for Scenario 1, while the amount of WW Scenario 2 to be produced is 7 million cubic meters and this will be treated in both the Nabulus WWTP and Tulkaram WWTP. However the total quantity is considered to be treated in Israel for Scenario 3. Effluent treated waste water is calculated to be 75% of the total generated quantity, taking into consideration the losses in the trunk lines and losses during treatment operations. The quantity of treated wastewater that will reach agricultural land is assumed to be 75% of the effluent amounts, taking into consideration the leakage and other losses in the conveyance systems, this is equivalent to 56 % of the total generated WW in the area. During the dry season (nine months per year), the total available amount of the treated waste water can be utilized, however; during rainy seasons, there is only a need for 25% of this quantity

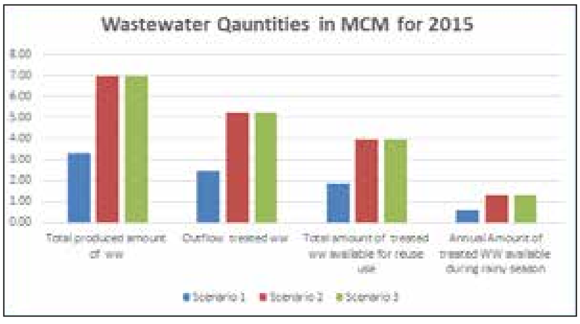

Figure 3 Wastewater Quantities in 2015

In 2035 the amount of wastewater generated and treated in the study area will be almost doubled compared to year 2015. Figure (4) shows that the wastewater generated in the study area in 2035 is calculated to be 8 million cubic meters for Scenario 1, while it is 15 million cubic meters for Scenarios 2 and 3.

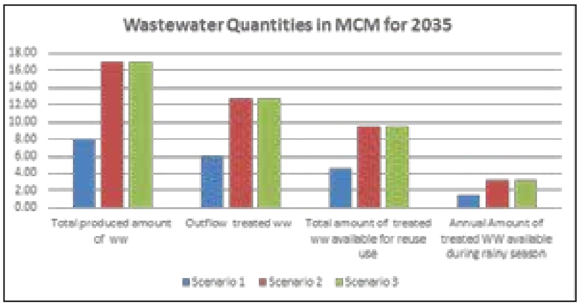

Figure 4 Wastewater Quantities in 2035

3.2 Agricultural land area

According to the type of soil and its physical and chemical characteristics, the agricultural land areas are classified into three types, the first one is a high-value type, which is used in vegetable cultivation. Palestinian specifications and standards prevents the use of treated wastewater for vegetable irrigation and only allowed to be used to irrigate trees and livestock feed. The second is a medium agricultural value type, which occupies an area of 6,400 dunums and the third is a low-value type, which occupies an area of 78,319 dunums.

Treated wastewater can be used to irrigate medium and low agricultural land types, based on the Palestinian standards. The following crop types, fodder, palms, olive and almond trees, have been studied to be irrigated by TWW.

Figure (5) shows that there is adequate agricultural land area for the total quantity of treated wastewater generated in the study area and there will be no need to transfer any amount of TWW to other areas or Israel.

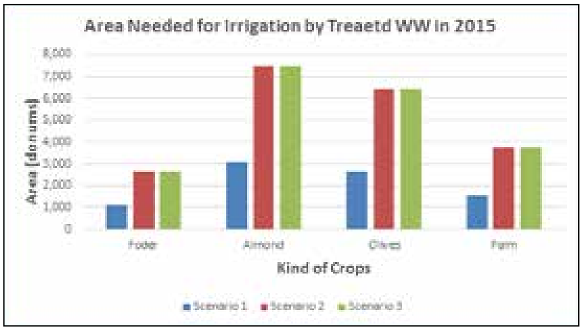

Figure 5 Agriculture land needed for reuse TWW in 2015

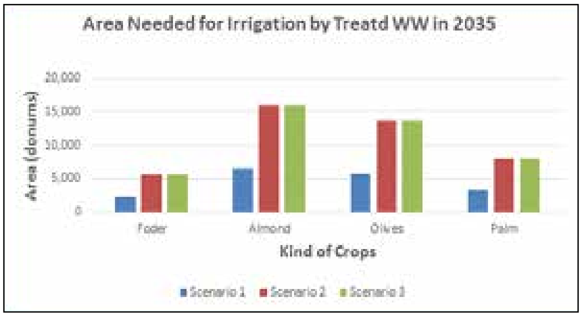

Figure 6 Agriculture land needed for reuse TWW in 2035

Figure 7 below shows that in year 2035 and in case 'feed' is selected to be grown, the maximum land needed is 59% of the medium value land. In case 'palm' is selected, the maximum land needed is 110% of the medium value land, which translates to 64 dunum in 2035, to use all the produced treated wastewater quantities within the study area and this area can be used from low-value land.

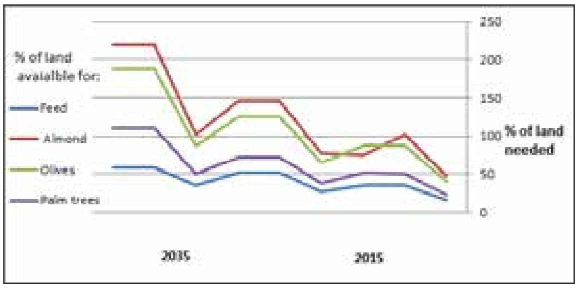

Figure 7 Agriculture land needed vs. available for TWW reuse in 2015 and 2035

3.3. Production values of irrigated crops

Production values of irrigated crops are estimated by multiplying the total dunums of land to be irrigated by the production value of one dunum cultivated. Based on data obtained from the Ministry of Agriculture [20], the production value of land cultivated with animal fodder is USD$2000/dunum, the production value of land cultivated with almonds is USD $1428/dunum, the production value of land cultivated with olive trees is USD$1131/dunum and the production value of land cultivated with palm trees is USD$5143/dunum.

4. Results and Discussion

This section represents the results of costs and benefits analysis of wastewater treatment reuse in agricultural irrigation in the Zomer catchment area. The analysis covers the costs and benefits for seasonal reservoirs, TWW conveyance lines, pumps and drip irrigation systems. The analysis covers the period from 2015 to 2035.

4.1 Investment Costs

The investment costs for the treated wastewater reuse conveyance system including the pumping facilities, conveyance lines, storage facilities and irrigation systems is estimated for year 2015.

4.1.1 Capital Expenditures (CAPEX)

4.1.1.1 Seasonal Reservoirs

Two reservoirs are needed for scenarios 1 & 2 with storage capacities of 33000 m3 and 61650 m3 to store water from two days' worth of capture of treated waste water quantities in 2035. The capital expenditures for the storage reservoirs is estimated at USD$120/m^3 [13].

4.1.1.2 Conveyance Lines

For Scenario 1 and 2, a steel pipe with diameter of 250 mm is required as a conveyance line from WWTP to irrigated area. The estimated capital cost per meter is USD$100 which includes supply, excavation, bedding, backfilling, fitting, pipe installation, reinstatement, cleaning and testing [14].

The length of line required for Scenario 1 from the Nablus treatment plant to the Nablus irrigated area is estimated to be 4 km and to the Tulkarm irrigated area is 4.5 km. For Scenario 2, the length of lines needed from the Tulkarm treatment plant to the upstream irrigated area is estimated to be 10 km and to the Tulkarm irrigated area is 8 km. For scenario 3, two diameters are needed; 500 mm and 750 mm for a total length of 25 km. The estimated capital per meter run is USD$500 and USD$700 respectively, which include the cost of supply, excavation, bedding, backfilling, fitting, pipe installation, re-instatement, cleaning and testing

4.1.1.3. Drip Irrigation schemes

The CAPEX for the drip irrigation systems is set at USD$200/dunum [15]. The total area of irrigated land is determined by dividing the volume of treated wastewater available for irrigation by the volume of water required to irrigate one dunum of land of a specific crop. The total water demand for the crops (feed, almond, olives and palm trees) to be irrigated with treated wastewater is 600-1700 m^3/dunum/year [16].

Table 1: Net Present Value for the cost of construction of drip irrigation network needed per crop type

CROP TYPE	SCENARIO 1 $	SCENARIO 2 $	SCENARIO 3 $
Fodder	621,885	750,368	750,368
Almond	1,762,009	2,126,042	2,126,042
Olives	1,510,293	1,822,322	1,822,322
Palm	881,004	1,063,021	1,063,021

Table 1: Drip irrigation network cost

4.1.1. 4. Pumping Facilities

For Scenario 1, there is no need for pumping facilities as the identified agricultural area can be irrigated by gravity from the Nablus Treatment Plant.

For Scenario 2, about half of the treated wastewater, needs to be pumped from the Tulkarem WWTP to the upstream agricultural areas. To capture the treated WW in 2035, two sets of pumps are needed to pump 4 million cubic meters to a level 240 m above sea level.

For Scenario 3, treated wastewater need to be pumped from Israel to Nablus and Tulkarem agricultural area in two stages. Three sets of pumps are needed to pump 11.25 million cubic meters to a level 240 m above sea level as first stage. 5.75 million cubic meters will be pumped from 240 to 540 m above sea level in the second stage,

According to the design prepared by adopting EPANET program [17] the following components are needed:

Booster Pumps (3 x 1000 m^3/hr @ 240 TDH), Booster Pumps (3 x 500 m^3/hr @ 300 TDH) with two pumps at operation and one stand by. The cost of which are USD$7 million and USD$5 million including civil, mechanical and electrical work in addition to the construction of two water balance reservoirs with a capacity of 15000 m^3

transmission pipeline DN 750 mm, transmission pipeline DN 500 mm,

The above mentioned prices were obtained from suppliers and contractors [18].

CAPITAL EXPENDITURES (CAPEX)	SCENARIO 1	SCENARIO 2	SCENARIO 3
Storage Reservoirs	3.96	7.4	
Conveyance Systems	0.85	1.8	15.5
Pumping Stations/ Boosters including the Balance Reservoirs		3	12
Total Capital Costs (M USD)	4.81	12.2	27.5

Table2: Estimated Capital Costs for the Conveyance Systems of the Three Scenarios

4.2. Operational Expenditures (OPEX)

The annual operational expenditures (OPEX) for the water facilities are assumed to be 5% for the boosters, 2% for the conveyance lines and storage reservoirs of the CAPEX with an assumed annual increase of 1% of these costs [19]. The annual operational expenditures reflects the annual running costs for the conveyance schemes. Table 3 below shows the NPV calculation for the O&M expenditures for the three scenarios.

O & M NPV (USD)	SCENARIO 1	SCENARIO 2	SCENARIO 3
Storage Reservoirs	175,744	328,322	0
Conveyance Lines	37,985	79,884	687,888
Booster PS	0	426,607	1,706,428
Total O&M NPV ($)	213,729	834,813	2,394,316

Table3: Net Present Value for Operation and Maintenance Expenditures

4.3. Unit Costs

The unit costs are calculated by taking the total net present value per each crop (Capex + Opex), divided by the available TWW per each scenario. Table 4 shows that the unit costs per each crop for scenario 3 is higher than Scenario 2 and Scenario. Also it shows that unit cost for the almonds is the highest and that the cost of fodder is the lowest.

UNIT COSTS (USD$/m^3)	SCENARIO 1	SCENARIO 2	SCENARIO 3
Fodder	1.26	3.06	6.81
Almond	1.51	3.37	7.12
Olives	1.45	3.30	7.05
Palm	1.31	3.13	6.88

Table 4 cubic meter cost for each type of agricultural types and scenario

4.4. Benefit from using treated wastewater for irrigation crops

There are many benefits that will result from using treated wastewater in agriculture including the environmental, social and health benefits. The direct benefit discussed here is the increase in the production of agriculture due the increase of available water for irrigation.

Table 5 represents the production value per each crop and scenario. The production value for palm trees is higher than others crops for the three scenarios.

CROP PRODUCTION (USD$/m^3)	SCENARIO 1	SCENARIO 2	SCENARIO 3
Fodder	4.63	3.6	3.6
Almond	8.86	6.78	6.78
Olives	6.36	4.95	4.95
Palm	16.87	13.12	13.12

Table 5: Crop production for the three scenarios

The net benefit per cubic meter of TWW is the cost per each crop is the crop production minus the cost per each cubic meter of treated wastewater. Table 6 shows that Scenario 1 is the best option in terms of economic and financial returns to farmers and palm cultivation is the best type of crops.

NET BENEFIT (USD$/m^3)	SCENARIO 1	SCENARIO 2	SCENARIO 3
Fodder	3.38	0.54	-3.21
Almond	7.35	3.41	-0.34
Olives	4.91	1.65	-2.1
Palm	15.56	9.99	6.24

Table 6: Benefits from using TWW in agriculture (Millions USD)

Figure 8 below represents the net production value per crop for each scenario. It shows that the net production value for both Scenarios 1 and 2 is positive, while it is negative for Scenario 3, which mean that the value of production will not cover the capital and operational costs for conveyance systems in Scenario 3.

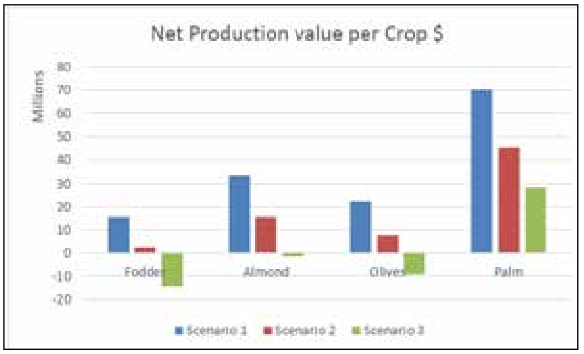

Figure 8: Net Production value per Crop and Scenario in millions USD.

5. Conclusion and Recommendations

The paper presents several answers to decision-makers questions concerning the reuse of TWW in irrigation considering different scenarios for the location of the WWTP and different types of crops. Cost benefit analysis for the different scenarios shows that treating wastewater and reuse inside the West Bank is more cost effective and has a higher positive financial impact and return of more than 150% comparing with treating Palestinian wastewater inside Israel and pumping it back for reuse in the West Bank. Concerning agricultural crops, palm cultivation is the best feasible scenario compared with the other three crops, meanwhile animal fodder is the least feasible scenario. The generated wastewater in Palestine is expected to be 200 million cubic meters in 2035 and that the re-use of treated waste water will provide benefits ranging from 200 to 1000 million USD per year, depending on the crops type and the components of the reuse system.

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