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A Model for Cost-Effectiveness Analysis of Wastewater Treatment Facilities Regarding Endocrine Disrupting Compound Removal: A Case Study in the Palestinian West Bank

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Abstract

As water scarcity continues to grow, wastewater reuse emerges as a critical potential water resource for nations in semi-arid areas across the world. This research uses the Middle East as a case study to assess possible options for reusing treated wastewater. Based on a recent water quality study on wastewater treatment plants (WWTPs) in the Palestinian West Bank, this research conducts a Cost-Effectiveness Analysis (CEA) to evaluate the relative advantages of different levels of wastewater treatment. The study compares secondary treatment facilities in the West Bank to select tertiary facilities in Israel in terms of cost per cubic meter of treatment, with a focus on the removal of Endocrine Disrupting Compounds (EDCs), and additional water quality parameters, including total suspended solids (TSS), biological oxygen demand (BOD), total nitrogen (TN), and total phosphorous (TP). After calculating the Cost Effectiveness (CE) ratio, results show that for EDCs, the optimal wastewater solution in the Palestinian Authority is secondary treatment, with the advancement to tertiary infrastructure providing extremely modest water quality benefits at considerable expense. This CEA is valuable for informing decisions on optimal strategies for building new wastewater treatment facilities locally, as well as in other semi-arid regions around the world.

Keywords: Cost-effectiveness analysis (CEA); Endocrine disrupting compounds (EDCs); Wastewater treatment; Water reuse; Water recycling

Introduction

Water is increasingly identified as the next major challenge on the worldwide sustainability agenda [1,2]. Due to both naturally occurring processes as well as human activity, there is a growing amount of stress on available freshwater supplies, especially in semi-arid regions like the Middle East [3,4]. The West Bank is a semi-arid region with an estimated 2016 population of roughly 2.9 million Palestinians [5]. As the population is growing and the availability of freshwater sources is decreasing, wastewater reuse emerges as a critical potential water resource [6-8]. Today, wastewater in the West Bank often goes untreated, which has detrimental ecological and public health impacts for Palestinians and also Israelis, due to cross-boundary waterways [9]. However, the increasingly common efforts to treat and reuse municipal effluents are also accompanied by a growing concern for risk of interaction with contaminated water.

Recent studies show that certain chemicals known as endocrine-disrupting compounds (EDCs) have been found both in raw sewage as well as in treated wastewater [10-12]. EDCs are a broad group of chemicals, including hormones that can have a deleterious effect on various biological systems including male and female reproductive systems as well as on ecosystem health [12-14]. Sources of EDCs are numerous, but water resources are increasingly perceived as a major source of exposure [13,14].

Researchers were first made aware of problems associated with exposure to EDCs by studies done on fish populations located downstream of wastewater treatment sites [15]. Studies on wild fish populations show that exposure to particular hormones can cause feminization [16], intersex condition, and/or lower sperm count [15]. These conditions are negatively correlated with reproductive success and put the future of the fish populations at risk [15]. Numerous studies since then have been done on wildlife and laboratory animals, with results that also associate EDCs with developmental, reproductive, and other health problems [16-18].

Similarly, EDC exposure includes a risk of health problems for humans. Studies have shown a correlation between exposure to EDCs and irregular thyroid function, which can cause dyslexia, mental retardation, and ADHD [13]. Further, EDC exposure has been linked to early onset of menopause, breast cancer, endometriosis, and birth defects [19-21]. Men are also susceptible to reproductive health effects, as tests have shown testicular cancer to be associated with EDC exposure [20] as well as alterations in sperm quality and quantity [16].

Studies confirm that EDC concentrations can be dramatically reduced and effectively eliminated with appropriate wastewater treatment technologies [22,23]. This is particularly important for the Palestinian Authority (PA) where wastewater treatment is limited and release into the environment is common [24,25]. At the present, the PA has three centralized WWTPs, of which only two are fully functioning [26]. Therefore, investment in new wastewater treatment facilities is anticipated across the West Bank in the near future.

Standard WWTPs utilize physical, chemical, and biological processes. Typically, treatment is divided into three general levels: primary, secondary, and tertiary (or advanced) treatment. Solak et al. [14] found that more advanced treatment methods result in higher EDC removal. However, advanced WWTPs are expensive and money is a limiting factor for the PA. Thus, the costs should play a role in deciding which WWTPs are best fit for future projects. Two main factors weigh in for assessing appropriate sewage treatment options: effectiveness of treatment and cost. Therefore, information on costs associated with treatment levels, as well as the effectiveness of EDC removal in different treatment levels is needed in order to make investment decisions for upcoming projects. This study uses Cost-Effectiveness Analysis (CEA) methodology to identify the most cost-effective wastewater treatment level with regards to EDC and nutrient removal.

Methods

Case study selection

Five wastewater treatment plants (WWTPs) were included in the analysis of this study: Tulkarem, Al Bireh, West Nablus, HodHasharon, and Raanana. TulKarem WWTP was selected as an example of primary sewage treatment because it is the only sewage facility in the West Bank that has not progressed beyond primary treatment (aeration pond). The West Bank at present has two fully functioning secondary level WWTPs-Al Bireh, and West Nablus. There are no tertiary level treatment plants operated by the PA, so HodHasharon and Raanana WWTPs in Israel were chosen to provide a comparison between the PA's existing secondary treatment with possible tertiary treatment. The Raanana treatment facility has a similar daily inflow to the Palestinian West Nablus facility, and based on economies of scale, is, therefore, cost comparable.

Cost parameters and calculations

This analysis chose to incorporate two different types of costs: (1) the operational and maintenance costs and (2) the start-up costs of each WWTP. Operational costs were comprised of electricity, maintenance and upkeep, and current employee wages. Establishment costs included payment for land, building materials, municipal piping, electricity for the building, employee wages (engineers, contractors, construction), permits, and financing the complete project (any interest paid). Financial data were collected from the chief operator of each treatment plant. The daily inflow of each facility differed, as did the start-up and operational costs. Therefore, in order to relate the costs of different WWTPs to one another, a comparable unit price was utilized across technologies and plant size. This unit is the cost of treatment per cubic meter of water.

In the analysis, two varying financial scenarios were examined when computing the unit cost. In Scenario One, the calculation neglected the initial startup costs and focused only on the yearly operational costs. The reality is that in the past, and for the foreseeable future, international donors have been willing to pay for the establishment costs of WWTPs in the PA. Therefore, Scenario One calculated the unit price from the Palestinian government's perspective, in which operational costs are the only salient expenses, and initial costs are excluded. Scenario Two offers the full picture and is more applicable worldwide to stakeholders who have an interest in assessing the entire cost of a project. The estimates in Scenario Two are relevant for contexts where the WWTPs are financed by the local government and/or by taxpayers. In Scenario Two, the initial costs were amortized using a basic equation calculating the present value start-up costs for specific WWTPs.

$$\text{Cost}_{\text{present value}} = A/i[1-1/(1+i)^{T} \qquad (1)$$

Where: A is the payment Amount per period (New Israeli Shekel), i is the interest rate (percent), and T is the total number of payments (years) [27].

The cost unit was calculated in New Israeli Shekel (NIS) per cubic meter and then converted to United States Dollars (USD) using the March 2016 value of 3.9 NIS to 1 USD. Using the startup costs, an interest rate of 4% [27], and the life expectancy of the treatment plant as 25 years, the value of A was calculated for the above equation.

Effectiveness parameters and calculations

The effectiveness measure used in this study was EDC and nutrient removal. The EDCs referred to in these results are natural estrogens, estrone and estriol, and the other parameters are total suspended solids (TSS), biological oxygen demand(BOD), total nitrogen(TN), and total phosphorous(TP).

All secondary and tertiary WWTPs in this study were a part of a larger Israeli-Palestinian research project, which monitored the presence and fate of EDCs throughout wastewater treatment processes [28]. Estriol and estrone data from Dotan et al [28] were used to calculate removal percentages in the WWTPs. Data for removal percentages of TSS, BOD, TN, and TP were taken from the monthly reports of the monitoring systems at the WWTPs. Odeh W [29] provided estriol data for the primary treatment facility, Tulkarem WWTP, but not for estrone and the WWTP does not monitor its nutrient levels. Therefore, data from the literature [30] were taken for estrone removal, and nutrient removal is not included in this study for primary treatment.

The following calculation was used to quantify removal effectiveness:

$$\text{Removal Percent} = [C_i - C_f]/C_i * 100 \qquad (2)$$

Where: C_i is the initial concentration of the contaminant and C_f is the final concentration of the contaminant. Multiplying the number by 100% shows the percent removal.

Cost-effectiveness analysis

In order to evaluate the wastewater treatment options for Palestinians in the West Bank, a CEA was carried out. CEA is a technique that relates the costs of a program to its key outcomes of benefits [31]. This study looks at the cost of wastewater treatment in relation to the effectiveness of contaminant removal. The costs and the effectiveness values are brought together to make the CE ratio. The cost of treatment (USD per cubic meter) is the numerator and the effectiveness (removal amount, ranging from 0-1) is the denominator.

$$C/E = \text{Cost}/\text{Effectiveness} \qquad (3)$$

Where: C is the cost and E are the chosen measure of effectiveness.

The optimal solution is one with low cost and high effectiveness. The best CE ratio is the smallest number because it means the lowest price for the highest removal.

After the CE ratio was computed, a sensitivity analysis was performed in order to take the uncertainty of predicted impacts and monetization into consideration for the overall recommendation. This study used the extreme case sensitivity analysis to compute worst- and best- case scenarios [32]. The cost per treatment of cubic meter of water stays constant at each plant; so therefore, the extreme cases were taken as the best and worst removal levels. Thus, the highest and lowest removal percentages were selected for each plant, and then the CE ratio was recalculated for each condition. The results show the CE ratios in best and worst case scenarios.

Results

Costs

The differences between the two financing scenarios are highlighted in Table 1. In Scenario One, startup costs were excluded, reflecting the current reality in the PA, where initial costs of WWTPs are funded by foreign aid. In Scenario Two, startup costs were included, making the study adaptable to other locals where funding for infrastructure is not supported by foreign aid, in addition to representing the possible future of Palestinian WWTPs. In Scenario One, the average prices for secondary and tertiary treatment were $0.21/m^3 and $0.43/m^3, respectively. In Scenario Two, the price of secondary treatment averaged to $0.49/m^3 and the one tertiary treatment plant calculations amounted to $0.62/m^3.

Effectiveness

Table 2 shows the results of the removal effectiveness for the different WWTPs. As expected, the data show an increase in EDC removal linked with an upgraded treatment level. For estrone, the difference in removal between primary and secondary is quite significant, moving from 7% to 97%. The discrepancy between secondary and tertiary is much smaller, increasing from 97% to 99%. The same benefits associated with the more advanced treatment of EDCs proved true also for TSS, BOD, TN, and TP.

Cost effectiveness ratio

Table 3 shows the CE ratios calculated for (a) Scenario One and (b) Scenario Two for both EDCs as well as for TSS, BOD, TN and TP. The lower the CE ratio value, the more attractive the option is because it signifies a higher effectiveness for a lower cost. In Scenario One, the secondary treatment facilities had significantly lower CE values in all categories in comparison to tertiary treatment. In Scenario Two, there is less of a difference in CE ratios between secondary and tertiary treatment, but the secondary numbers were still lower.

Table 1: Cost results for wastewater treatment per cubic meter in Scenarios One and Two

WWTP	Treatment	Scenario One ($/m^3)	Scenario Two ($/m^3)
Tulkarem	Primary	0.0179	0.0385
Al Bireh	Secondary	0.2205	0.4795
West Nablus	Secondary	0.1897	0.5026
HodHasharon	Tertiary	0.3795	0.6205
Raanana	Tertiary	0.4718	nd

nd = no data

Table 2: Effectiveness results using percent removal for estrone, estriol, TSS, BOD, TN, and TP

Treatment Level	WWTP	Estrone (%)	Estriol (%)	TSS (%)	BOD (%)	TN (%)	TP (%)
Primary	Tulkarem	7	29	nd	nd	nd	nd
Secondary	Al Bireh	97	98	96	92	90	72
Secondary	West Nablus	97	100	98	98	81	63
Tertiary	HodHasharon	98	94	99	99	90	84
Tertiary	Raanana	100	100	98	100	60	nd

nd = no data

Treatment level comparison based on cost

Figure 1 provides a strong visual depiction of the comparison of CE ratios for estrone. The designated colors represent the added cost and added effectiveness when treatment is increased to each higher level. In both Scenarios (a) One and (b) Two, there is clearly a significantly greater effectiveness increase between primary and secondary levels in comparison to the cost of treatment per unit. By way of contrast, when moving from secondary to tertiary technologies, effectiveness hardly increases, while cost increases dramatically. To create this comparison figure, the tertiary cost and effectiveness values were each separately deemed 100% and the primary and secondary values were adjusted accordingly.

Sensitivity Analysis

In Scenario One, the extreme case scenario sensitivity analysis shows that best- and worst- case secondary treatment result in CE averages of 0.19 and 0.23, respectively. For tertiary treatment, the best-case scenario produces a 0.38 CE ratio, while the worst-case scenario has a 0.47 ratio. The sensitivity analysis shows that even in a worst-case scenario for secondary level removal, where the least favorable ratios from the sampling campaigns are used (0.23 CE ratios) and a best-case scenario inserted for tertiary level removal (0.38 CE ratios), the CE ratio for secondary treatment is still lower, and therefore remains more attractive. Scenario Two follows the same pattern: the worst-case scenario for secondary treatment produces a 0.52 ratio, while the best-case scenario in tertiary treatment yields a 0.62 ratio.

Discussion

Recommendation

The last step of a CEA is to recommend an action to take. The lower CE ratios point to an optimal treatment level, but cannot determine whether or not the actual investment is worthwhile. The CEA conducted for this study shows that secondary treatment is the most cost-effective option for removal of EDCs during wastewater treatment in the PA. Although tertiary treatment increases removal levels of EDCs by roughly 2 percent, the 200 percent increase in costs does not make it an efficient investment for the PA. In this case, an important factor to consider before choosing secondary treatment is the actual numerical level of the contaminant concentrations in the effluent of the WWTP.

Currently, both Israel and the PA have legal parameters in place for nutrient concentrations in wastewater effluent, as exhibited in Table 4. The Godinger T [33] data show that tertiary level treatment brought nutrient concentrations down to levels that meet the Israeli reuse standards.

Table 3: Cost Effectiveness ratio values for EDCs and nutrient parameters in Scenario One (SC1) and Scenario Two (SC2)

Treatment Level	WWTP	Estrone		Estriol		TSS		BOD		TN		TP	
		SC1	SC2	SC1	SC2	SC1	SC2	SC1	SC2	SC1	SC2	SC1	SC2
Primary	Tulkarem	0.24	0.54	0.06	0.13	nd	nd	nd	nd	nd	nd	nd	nd
Secondary	Al Bireh	0.23	0.50	0.22	0.49	0.23	0.50	0.24	0.52	0.25	0.54	0.31	0.67
Secondary	West Nablus	0.20	0.52	0.19	0.50	0.19	0.51	0.19	0.52	0.23	0.62	0.30	0.80
Tertiary	HodHasharon	0.39	0.63	0.41	0.66	0.38	0.62	0.38	0.62	0.42	0.69	0.45	0.73
Tertiary	Raanana	0.47	nd	0.47	nd	0.48	nd	0.47	nd	0.79	nd	nd	nd

nd = no data

Table 4: Concentrations of nutrients at outflow of each treatment plant in comparison to Israeli standards [36] and PA Standards [35].

	TSS (mg/L)	BOD (mg/L)	TN (mg/L)	TP (mg/L)
Al Bireh Secondary Treatment	79	39.6	8	2.1
West Nablus Secondary Treatment	12	14.0	32	1.8
Palestinian Standards	30	20	30	8
HodHasharon Tertiary Treatment	3	1.9	6	1.3
Israeli Standards *Irrigation/Streams	10/10	10/10	25/10	5/1

*Israel's standards for wastewater treatment are bifurcated: maximum concentration levels for effluents reused in irrigation vs. released into streams.

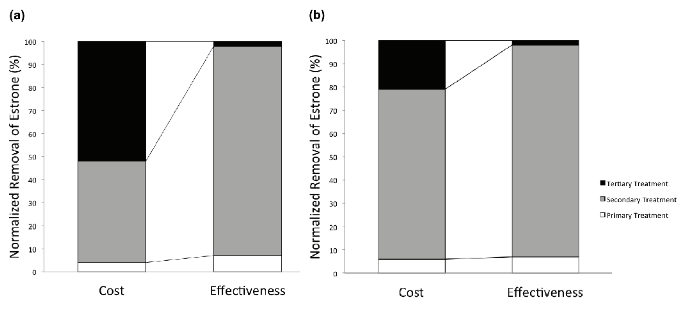

Figure 1: Cumulative increase in cost and effectiveness as treatment level advances for estrone in (a) Scenario One and (b) Scenario Two

For the Palestinian WWTPs, the West Nablus plant produces effluent water that is very close to meeting all of the PA standards for nutrient concentrations. The only standard not met is TN at 32 mg/L for West Nablus, while the standard is set at 30mg/L. The TSS, BOD, and TN standards listed in Table 4 offer the average values of the second and third tiers from a recent report, and the TP is reported in a recent USAID approved project called Compete [34,35]. Relying on secondary treatment alone, the West Nablus WWTP produces effluent water that is extremely close to meeting all of the PA standards for nutrient concentrations.

The same comparison of effluent concentrations to standards should also be conducted for EDCs. Currently, no country in the world has legal standards for EDCs in treated outflow. The state of California, however, has put much effort into studying the risks associated with exposure to EDCs and has proposed a set of general guidelines ranging from 1-10 ng/L, depending on the EDC and for particular types of reuse [37]. Similarly, the European Union published recommended limits, also in the 1ng/L range, based on studies conducted in Europe [38]. Using these recommended standards, tertiary treatment would be the preferred treatment option. The results of the sampling campaign [33] show final effluent value concentrations of EDCs in tertiary treatment to be closer to 1 ng/L than those in secondary treatment. From a strict, precautionary and public health perspective, tertiary treatment would be the best solution. Nonetheless, the PA and other nations with extremely limited financial resources may need to take economics and feasibility into consideration.

The economic situation in the West Bank is significantly different than in Israel. In 2014, per capital yearly income in the West Bank was $3,000, compared to $37,000 in Israel. Typically, local citizens pay a tax to the municipality to cover the costs of building and operating wastewater treatment plants. With a per capita income, roughly ten times lower than that of Israel's, a Palestinian choice to remain at secondary treatment levels might be the more judicious one.

Economic feasibility

An economic feasibility study can assess a site-specific context of whether the level of treatment is economically viable. The Israeli experience is germane: in 2007 roughly 70% of the wastewater produced in Israel was reclaimed for agricultural use [36]. In 2009, the amount went up to 75% [22] and today the Water Authority estimates it to be as high as 85%. The number has only continued to grow due to the economic incentives for the different stakeholders: farmers pay less for irrigation water and wastewater treatment plants increase their revenues. The same dynamics should exist in the neighboring West Bank.

A basic review of the economic figures is instructive: The cost to the West Nablus WWTP for treating wastewater is $\$0.19/m^3$. If the Nablus municipality charged a small wastewater treatment fee of $\$0.15/m^3$ to the served population, the WWTP's incurred costs would decrease to $\$0.04/m^3$. To cover this expense, the plant could sell the treated wastewater to farmers, as is commonly done in Israel [22,36] and elsewhere in the world [6,39]. In Israel, the current market value of reused wastewater varies from $\$0.25$- $0.32/m^3$ [40]. Even using the lowest resell rate, the WWTP would still make a meaningful profit:

$\$0.25/m^3$- $\$0.04\ /m^3$=21 cents profit on every cubic meter sold.

West Nablus has a daily inflow of roughly 9,000 cubic meters, reaching an annual level of 3.3 MCM of sewage treated per year. Selling the effluent would result in a profit of $689,850/yr, which exceeds the yearly operational costs of the facility ($615,000/yr). Moreover, inflow at the West Nablus WWTP is expected to increase to its full capacity of 15,000 cubic meters per day, which would produce roughly 5.5 MCM of treated wastewater per year and profit 1.15 million dollars annually. The 5 MCM of effluent produced annually could be used by local agriculture. In the West Bank alone, there is an annual consumption of 55 to 60 MCM of water for agricultural use, which does not even meet the full needs of local farmers [41].

Conclusions

These CEA findings are consistent with international findings in the field. Studies in Spain, for example, show comparable operational costs for WWTPs to those found in this study [42]. Many CBA studies evaluating the reuse of treated wastewater report positive Net Present Values (NPVs), confirming sewage reclamation strategies [39,43, 42]. These studies also suggest that the PA can expect economic benefits by creating a market for treated wastewater. Thus far, CEA studies particularly on EDC removal have not been conducted elsewhere. This study is unique in that it brings CEA and EDCs together. As both factors are critical in making management decisions about optimal infrastructure investment strategy, the results offer a clear direction to a government with a commitment to environmental and public health, but with the narrow tax base of a developing economy.

Ultimately, the move from secondary treatment to tertiary treatment must be a holistic, societal decision, in which myriad factors are taken into consideration. The option to move up to tertiary treatment levels need to remain open for the future, and should eventually be implemented. But in the interim, achieving a secondary level of treatment across the entire West Bank would constitute meaningful progress for Palestinian public health and sanitation. The same can be said for other nations in semi-arid areas with similar financial capacity. Secondary level treatment represents an optimal solution because it attains reasonable environmental results while maintaining economic efficiency in a society with extremely limited financial resources.

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