Comparative Analysis of Wastewater Treatment Costs in Jordan and Tunisia

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Abstract

The finaincial aspects reflecting the annual capital and operational expenditures play a key role in the sustainablility of wastewater treatment facilities irrespective of the technology applied. This study presnts a comprehensive analysis of wastewater treatment costs for 26 wastewater treatment plants in Jordan and Tunisia. The most frequently used systems for wastewater treatment in these countries are activated sludge systems with its modifications, trickling filters, and lagoons. Performance of the treatment technologies varies considerably from one treatment plant to another, even among those plants that fall within one category and employ basically similar processes in the same country. Nevertheless, the activated sludge systems and trickling filters seem overall superior to lagoons in terms of effluent quality, land requirement, and popularity, but at the expense of more equipment, personell, maintenance, spare parts, and energy requirement. Comparison of the treatment costs (capital and operational) for the three systems shows that activated sludge systems are the most expensive followed by trickling filters. Lagoons are the cheapest, but if same effluent quality is required, upgrading and retrofing make the operation and maintenance costs almost similar to that for the activated sludge and trickling filter systems. Lagoon systems seem to be less commendable unless land is available at a reasonable price and the envisaged planning objectives are clearly made.

Keywords

Activated sludge; trickling filters; lagoons; financial analysis; economies of scale; wastewater treatment costs; Jordan; Tunisia

1. Introduction

The Middle East and North Africa (MENA) region is the world's poorest region in water availability, with <1%. Water scarcity is a major threat for food securicty and political stability in the region. Local, regional, and international efforts converge in search for additional water supplies. Thus, treatment and reuse of wastewater has been recognized as a valuable non-conventional water resource. However, Al-Sa`ed (2004) reported that the efficient use of this water resource is hampred due to prevailing social-cultural, environmental, political and financial factors. Worldwide, the common established watstewater treatment plants (WWTP) are the activated sludge, trickling filters, and lagoon systems. The financial performance of these treatment technologies is questionable under limited financial resources and variable national treatment objectives in most countries of the region. Jordan and Tunisia are pioneer countries in wastewater treatment and reuse in the MENA region (Angelakis *et al*., 1999). The two countries are selected for this study because (i) their experiences are broadly based and span two decades or longer, (ii) they represent the MENA region, (iii) they have already a relatively large number of WWTPs in operation, (iv) their wastewater treatment systems are common in the whole region, (v) they have similar levels of water stress, (vi) they produce the same agricultural crops, and (vii) they are similar in socio-cultural characteristics and in economic profile. Beside institutional management, financial and economical aspects of any wastewater treatment facility dictate its sustainability (Al-Sa`ed, 2005). Lack of data and experience in financial analysis of commonly applied treatment technologies are behind controversial judgement on their feasibility and applicability in developing countries as the MENA region. Hence, the objective of this study is to analyze and calculate the costs of wastewater treatment of different wastewater treatment technologies in the MENA region utilizing experience over the last 20 to 30 years gained in Jordan and Tunisia.

2. Research approach, and methodology

2.1. Field work and data collection

A fieldwork of five months was conducted in Jordan and Tunisia for collection of data on wastewater treatment, agricultural irrigation with the reclaimed wastewater, and crop marketing and consumption. In Jordan, a three months fieldwork was conducted in coordination with the Ministry of Water and Irrigation (MWI). This period was used as follows: (i) two weeks (8th-23rd January 2000) for exploratory and coordination purposes, (ii) two weeks (3rd-17th February 2000) for pilot testing of questionnaires, and (iii) two months (15th March-16th May 2000) for actual field surveys. In Tunisia, a two months fieldwork (24th May-25th July 2001) was conducted in coordination with the National Sewerage Agency (Office nationale de l'eau et assainissement, ONAS).

Collection of basic information through literature review, and extensive communication with these countries through e-mail and phone calls prior to the country visits helped in better time use during the fieldwork. The five months were effectively utilized through devoting five working days every week for visiting WWTPs and institutions responsible for treatment and reuse in each country. The weekends were devoted to surveying irrigated farms and households (Friday and Saturday in Jordan, and Saturday and Sunday in Tunisia).

Thirty-one WWTPs were selected and surveyed in the two countries based on the following criteria: (i) the sample has to represent the commonly used treatment systems (activated sludge, trickling filter, and lagoons) and should cover the spectrum of treatment capacity of WWTPs, (ii) capacity of the WWTPs is less than 15,000 m^3/day; however, three larger plants[1] were included in the surveys, but it was decided to not include them in the analysis, because their relatively large capacity would skew data analysis, (iii) interference from the host organization in the selection of WWTPs should be limited to avoid biased results, as the host could be expected to show the best performing plants; however, the role of the host was important in acquiring information about all existing WWTPs in terms of their location, capacity, population served, treatment type, and year of operation. Thereafter, a list of randomly selected plants for the survey was made based on the aforementioned considerations.

Table 1: Sample size and composition of the existing WWTPs in Jordan and Tunisia.

Type of WWTP	*Jordan*		*Tunisia*		*Both countries*	
	Total	*Surveyed*	*Total*	*Surveyed*	*Total*	*Surveyed*
Activated sludge (AS)	5	4 (80%)	44	11 (25%)	49	15 (31%)
Trickling filters (TF)	4	4 (100%)	2	1 (50%)	6	5 (83%)
Lagoons (L)	7	5 (71%)	14	6 (43%)	21	11 (52%)
Trickling filter + activated sludge	1	0 (0%)	1	0 (0%)	2	0 (0%)
Total	*17*	*13 (77%)*	*61*	*18 (30%)*	*78*	*31 (40%)*

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[1] Al-Samra lagoons in Jordan, and Cotiere-Nord lagoons and Sud-Meliane activated sludge plant in Tunisia.

Screening and filtering the raw data lead to exclusion of another two activated sludge plants (one in each country) from the analysis because of incomplete data. As a result, the sample size for the class of activated sludge systems was reduced from 31% (survey) to 25% (analysis), while for the class of lagoons systems it was reduced from 52% (survey) to 43% (analysis). Nonetheless, Table 1 shows that the sample is representative of the WWTPs in both countries. However, the limited sample size (n=26) did not allow analysis of design modifications in the three treatment systems under the study; AS, TF, and L.

Relevant data on the 26 finally selected WWTPs were primarily obtained from the records of the MWI in Jordan and ONAS in Tunisia. The records of the MWI could be fully accessed, while those of ONAS could only be partially accessed, based on the permission granted by the higher authorities in each country. For validation purposes, the same data were also collected in the field from records kept at the visited WWTPs. Tables 2 and 3 show the effluent quality from the surveyed WWTPs.

Table 2: Effluent characteristics of the surveyed WWTPs in Jordan (year-averages).

WWTP	*Type*	*Year*	*Actual Capacity (m^3/d)*	*Design Capacity (m^3/d)*	*BOD (mg/l)*	*COD (mg/l)*	*TSS (mg/l)*	*TDS (mg/l)*	*NH_4-N (mg/l)*	*NO_3-N (mg/l)*	*PO_4-P (mg/l)*	*Faecal coliform (MPN/100 ml)*
Jerash	AS	1983	1,603	3,500	33	123	68	1,168	185	2	38	1,000
Abu Nuseir	AS	1986	1,411	4,000	17	79	29	823	37	11	23	222
Fuheis	AS	1997	1,019	2,400	11	72	21	669	1	94	14	850
Ramtha	L	1987	2,174	1,920	239	540	361	1,546	159	4	43	2,000
Aqaba	L	1987	8,774	9,000	111	407	384	879	63	250	20	24,330
Mafraq	L	1988	1,933	1,800	198	525	249	1,432	135	3	68	28,840
Madaba	L	1989	3,609	2,000	282	784	239	1,439	109	3	37	25,201
Karak	TF	1988	1,146	786	46	225	82	896	72	10	56	1,500
Kufranja	TF	1989	1,734	1,900	65	209	34	935	80	23	35	3,198
Tafila	TF	1987	851	800	35	138	47	798	14	35	33	1,272
Baq'a	TF	1988	10,284	6,000	80	348	115	1,093	88	3	43	38,330

AS: activated sludge; TF: trickling filter; L: lagoon.

Table 3: Effluent characteristics of the surveyed WWTPs in Tunisia (year-averages).

WWTP	*Type*	*Year*	*Actual Capacity (m^3/d)*	*Design Capacity (m^3/d)*	*BOD (mg/l)*	*COD (mg/l)*	*TSS (mg/l)*	*Faecal coliform (MPN/100 ml)*
SE1 Hammamet	AS	1980	3,646	4,208	17	70	15	41,000
SE3 Nabeul	AS	1981	2,326	3,500	19	92	23	290,000
Wardanin	AS	1993	1,060	1,500	15	77	20	na
Grombalia	AS	1993	2,165	2,445	14	76	13	920,000
Sahline	AS	1993	3,001	2,560	9	52	8	410,000
Mejdez El Bab	AS	1994	933	4,500	27	75	21	28,000
Beja	AS	1994	7,302	14,000	43	267	42	43,000
Hammamet Sud	AS	1995	5,433	11,386	24	90	24	23,000
Menzel Borguiba	AS	1997	4,024	11,065	11	61	11	15,000
Rades	L	1976	1,282	700	96	381	184	3,000
Lella Meriam	L	1982	797	1,726	97	197	56	170,000
Houmt Essouk	L	1991	1,733	3,500	68	193	51	3,000
Kalaat El Andalos	L	1994	379	1,500	87	330	130	3,500
Sidi Bou Ali	L	1996	385	644	49	302	58	na
Monastir El Ghadir	TF	1962	2,633	2,600	16	77	17	na

2.2. Methods of analysis

The financial performance of the surveyed 26 WWTPs is assessed based on the (i) annuatized capital expenditures (CAPEX), (ii) annuatized operational expenditures (OPEX), (iii) total annual expenditures (TOTEX), (iv) per *actual* population-equivalent costs, and (v) per cubic meter costs. CAPEX is calculated by dividing the total capital cost of equipment and construction (including land purchase cost) over the estimated economic life period of the WWTP. Due to lack of cost details on the various components of WWTPs, an economic life period of 20, 20, and 30 years is assumed for the AS, TF, and L plants, respectively. The principal elements of OPEX include (i) energy, (ii) spare parts, and supply materials, and (iii) salaries (Metcalf and Eddy, 1991). For assessing the economies of scale, the various costs are studied against the actual capacity (average inflow) of the WWTPs.

The cost data, especially of CAPEX, has to be calculated carefully in a standardized fashion to reduce inaccuracy prior to analysis. The major causes of inaccuracy and the mitigation measures employed in this study are as follows:
i) Change of prices over time. The capital costs available for comparison belong to different years. Prices change considerably with time due to changes in economic conditions. Therefore, costs from different years need to be adjusted to a common basis (year 2000) by use of appropriate cost indexes. The present-equivalent costs at a particular year are determined by using Equation 1 (Metcalf and Eddy, 1991; Peters and Timmerhaus, 1991):

$$\textit{Equivalent cost at year}\,\boldsymbol{A} = \textit{Cost at year}\,\boldsymbol{B} \times \frac{\textit{Cost index at year}\,\boldsymbol{A}}{\textit{Cost index at year}\,\boldsymbol{B}} \qquad (1)$$

Where possible, cost index values for the different components should be adjusted to reflect local costs. For instance, the U.S. Environmental Protection Agency (EPA) includes costs for various geographical locations and publishes indexes for 25 cities (Metcalf and Eddy, 1991). Unfortunately, this is not available in the MENA region. However, the average annual cost indexes for equipment and construction costs are available and are used in this study as a reasonable approximation. In the case of some of the old WWTPs where limited cost data could be retrieved, estimation of the costs was also enhanced by using indexes. The present-equivalent costs for the year 2000 of the visited WWTPs are calculated in local currencies (Jordanian and Tunisian Dinars). These costs are then converted into US Dollars using the exchange rates of the year 2001.

ii) Price differences between countries. Comparing costs between different countries is cumbersome because unit prices vary from one country to another depending on the economic conditions of each country, and so do the currency exchange rates, the availability of materials and skills, the import regulations and the taxation system, and the interest and inflation rates. The studied countries of Jordan and Tunisia, however, exert remarkable similarity in these respects, and they have comparatively large numbers of WWTPs.

iii) Design variations. Even though the overall process applies the same basic technology such as activated sludge or lagoon, treatment plants still may comprise different processes and/or apply different designs. The sample size does not allow distinguishing between these different sub-types of processes. For example, the activated sludge class of processes can include notably conventional activated sludge plants, oxidation ditches, and extended aeration plants. The lagoon class can include different types of pond systems (anaerobic, aerated, facultative, and maturation), and these natural systems sometimes also have mechanized modifications. Moreover, there are differences in sludge processing. This will inevitably cause some divergence in cost comparisons, but this divergence is considered of minor importance and inevitable “noise”, compared to the weight of the bulk expenditure on the main components.

iv) Lack of cost details. Capital costs are usually not well-documented or specified, especially for first-generation WWTPs. Often, the available figures are not broken down for the various components of each plant. Fortunately, at least the gross equipment cost and the construction cost including land purchase cost were provided, and when necessary, persons familiar with the project construction could be consulted in order to improve on the estimates. These costs were based on a post-construction calculation of the real costs provided by the operating agency.

3. Results and discussion

3.1. Capital expenditures for treatment (CAPEX)

The high overall cost of the conventional treatment systems has forced engineers in industrialized and developing countries alike to search for cost-effective and environmentally sound solutions. The prohibitive costs of “complete” treatment prevents full coverage of the population with sewerage and treatment systems even in the industrialized world; thus, wastewater management policies can be implemented only if they are reasonable and find a compromise between technical and financial performance (Tsagarakis *et al.*, 2003). Most countries of the MENA region tend to be more careful with considerations regarding OPEX than CAPEX. This behavior is mainly driven by the external character of the funding of CAPEX, which is common in the region, while OPEX has to be funded locally through sanitation revenues and national government subsidies. In all cases, however, funds have to be carefully managed to ensure reducing the massive investment of either local or foreign capital (CEHA, 1995).

Table 4: Equipment costs (US$/PE/y) according to country and treatment system.

Country	*AS*				*TF*				*L*			
	Min.	*Max.*	*Avg.*	*STD.*	*Min.*	*Max.*	*Avg.*	*STD.*	*Min.*	*Max.*	*Avg.*	*STD.*
Jordan (n=3, 4, 4)	3.50	8.30	*5.48*	2.50	0.70	3.52	*1.58*	1.33	0.06	0.47	*0.26*	0.17
Tunisia (n= 9, 1, 5)	0.44	9.13	*2.99*	2.96	0.28	0.28	*0.28*	-	0.05	2.31	*0.75*	0.95
Both countries (n=12, 5, 9)	*0.44*	*9.13*	*3.61*	*2.97*	*0.28*	*3.52*	*1.32*	*1.29*	*0.05*	*2.31*	*0.53*	*0.73*

AS: activated sludge; TF: trickling filter; L: lagoon.

Table 5: Construction costs (US$/PE/y) according to country and treatment system.

Country	*AS*				*TF*				*L*			
	Min.	*Max.*	*Avg.*	*STD.*	*Min.*	*Max.*	*Avg.*	*STD.*	*Min.*	*Max.*	*Avg.*	*STD.*
Jordan (n=3, 4, 4)	6.97	8.45	*7.66*	0.75	0.51	8.40	*3.72*	3.47	0.52	2.74	*1.59*	0.93
Tunisia (n= 9, 1, 5)	0.43	5.81	*2.88*	1.95	0.52	0.52	*0.52*	-	0.32	9.17	*2.86*	3.61
Both countries (n=12, 5, 9)	*0.43*	*8.45*	*4.07*	*2.75*	*0.51*	*8.40*	*3.08*	*3.33*	*0.32*	*9.17*	*2.29*	*2.70*

Table 6: Equipment costs as percentage of CAPEX according to country and treatment system.

Country	*AS*				*TF*				*L*			
	Min.	*Max.*	*Avg.*	*STD.*	*Min.*	*Max.*	*Avg.*	*STD.*	*Min.*	*Max.*	*Avg.*	*STD.*
Jordan (n=3, 4, 4)	33.4	49.5	*40.3*	8.3	24.6	57.9	*35.3*	15.2	9.6	14.7	*13.2*	2.4
Tunisia (n= 9, 1, 5)	25.5	64.6	*45.9*	12.3	35.0	35.0	*35.0*	-	9.4	39.6	*19.6*	11.8
Both countries (n=12, 5, 9)	*25.5*	*64.6*	*44.5*	*11.4*	*24.6*	*57.9*	*35.2*	*13.2*	*9.4*	*39.6*	*16.7*	*9.1*

Table 7: Construction costs as percentage of CAPEX according to country and treatment system.

Country	*AS*				*TF*				*L*			
	Min.	*Max.*	*Avg.*	*STD.*	*Min.*	*Max.*	*Avg.*	*STD.*	*Min.*	*Max.*	*Avg.*	*STD.*
Jordan (n=3, 4, 4)	50.5	66.6	*59.7*	8.3	42.1	75.4	*64.7*	15.2	85.3	90.4	*86.8*	2.4
Tunisia (n= 9, 1, 5)	35.4	74.5	*54.1*	12.3	65.0	65.0	*65.0*	-	60.4	90.6	*80.4*	11.8
Both countries (n=12, 5, 9)	*35.4*	*74.5*	*55.5*	*11.4*	*42.1*	*75.4*	*64.8*	*13.2*	*60.4*	*90.6*	*83.3*	*9.1*

Table 8: CAPEX (US$/PE/y) according to country and treatment system.

Country	*AS*				*TF*				*L*			
	Min.	*Max.*	*Avg.*	*STD.*	*Min.*	*Max.*	*Avg.*	*STD.*	*Min.*	*Max.*	*Avg.*	*STD.*
Jordan (n=3, 4, 4)	10.47	29.24	*17.31*	10.37	1.21	11.92	*5.29*	4.77	0.57	3.21	*1.85*	1.11
Tunisia (n= 9, 1, 5)	0.88	14.14	*5.60*	4.78	0.80	0.80	*0.80*	-	0.37	11.49	*3.61*	4.50
Both countries (n=12, 5, 9)	*0.88*	*29.24*	*8.52*	*8.01*	*0.80*	*11.92*	*4.40*	*4.60*	*0.37*	*11.49*	*2.83*	*3.39*

Table 9: CAPEX (US$/m^3) according to country and treatment system.

Country	*AS*				*TF*				*L*			
	Min.	*Max.*	*Avg.*	*STD.*	*Min.*	*Max.*	*Avg.*	*STD.*	*Min.*	*Max.*	*Avg.*	*STD.*
Jordan (n=3, 4, 4)	0.34	0.63	*0.51*	0.15	0.06	0.27	*0.16*	0.09	0.03	0.08	*0.05*	0.02
Tunisia (n= 9, 1, 5)	0.02	0.80	*0.18*	0.25	0.04	0.04	*0.04*	-	0.01	0.25	*0.11*	0.11
Both countries (n=12, 5, 9)	*0.02*	*0.80*	*0.27*	*0.27*	*0.04*	*0.27*	*0.14*	*0.09*	*0.01*	*0.25*	*0.09*	*0.08*

The capital costs are categorized into two main clusters: (1) equipment (mechanical/electrical) including sludge processing, and (2) construction. The costs of construction include those for land purchase, civil works, equipment installation, ancillary buildings, and engineering design and supervision. Results show that the average per capita cost of construction (US$/PE/y) for the L plants is within the same range of that for the TF, and AS plants, which is 0.32-9.17(2.29), 0.51-8.4(3.08), and 0.43-8.45(4.07), respectively (Table 5). The per capita cost of equipment (US$/PE/y) for the L plants is less than for the TF and AS plants; these are 0.05-2.31(0.53), 0.28-3.52(1.32), and 0.44-9.13(3.61), respectively (Table 4). Apparently, the high equipment costs for the AS and TF plants are balanced by a combination of low equipment cost but high construction (land purchase) cost for the L plants. The equipment cost as percentage of CAPEX for the AS, TF, and L plants averages 44.5%, 35.2%, and 16.7%, respectively (Table 6), and the construction cost as percentage of CAPEX averages 55.5%, 64.8%, and 83.3%, respectively (Table 7). The per capita CAPEX (US$/PE/y) for the three systems is 0.88-29.24(8.52), 0.8-11.92(4.4), and 0.37-11.49(2.83), respectively, while the cost per unit of treated wastewater (US$/m^3) is 0.02-0.8(0.27), 0.04-0.27(0.14), and 0.01-0.025(0.09) for the three systems, respectively (Tables 8 and 9). CAPEX varies considerably between WWTPs and depends upon a number of factors such as (i) inaccuracies in standardizing the costs, (ii) country and geographical characteristics, (iii) differences in process design, (iv) differences in the levels of automation, and (v) different sources of funding, and costs of capital. The costs are also sensitive to other factors such as special site preparations, quality of materials used, tender procedure, housing of unit processes other than preliminary works, and others. Moreover, the inclusion of the land cost widens the range of construction costs. Very often, the WWTPs are built on government-owned land; when land is not available it is purchased at low cost. Nonetheless, it can be concluded that the AS plants are more expensive than the TF plants which in turn are more expensive than the L plants.

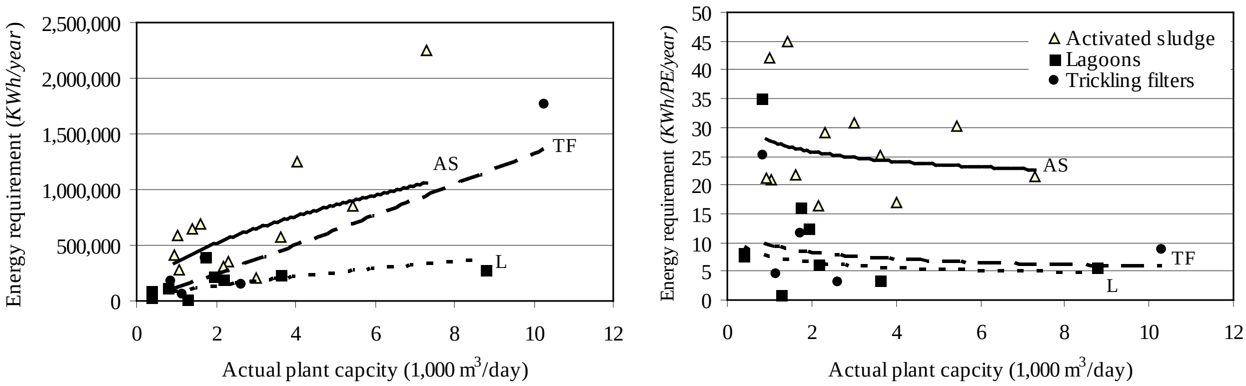
3.2. Operation and maintenance costs of treatment (OPEX)

The operational expenditures (OPEX) can be divided into three major categories: energy, personnel, and spare parts and supplies (chemicals and maintenance). The operational costs of sludge treatment and disposal are included within these. Each of these categories is discussed below.

3.2.1. Energy

Energy here refers to the power within the treatment process, including sludge processing. Power used for pumping of raw sewage or treated effluent is excluded. In general, energy is required for screening, grit removal, sedimentation, aeration, and recirculation, and for sludge digestion, thickening, and dewatering. In practice energy requirements vary from one treatment plant to another even among those employing identical treatment systems. It depends on the efficiency of equipment, variability of the operation mode, and personnel skills. Also, process design may be different. For instance, screens and grit chambers can be designed as either manual or automatic. Also here, the specific activated sludge process that is applied, such as conventional activated sludge, extended aeration, or oxidation ditch, consumes varying levels of energy. The systems for sludge processing may consist of mechanical dewatering, which are energy-intensive, or natural drying beds. Moreover, some of the newer treatment plants are fully automated. These factors explain the scattered nature of data in Figure 1.

In Jordan the annual per capita energy requirement (KWh/PE/y) for the AS plants is high (21.8-45.0(36.3)) compared to that for the TF plants (4.6-25(12.5)) and L plants (3.4-12.5(6.9)) (Table 10). In Tunisia, the energy requirement (KWh/PE/y) is 16.5-30.7(23.6), 3.1, and 0.8-35.0(13.2) for the AS, TF, and L plants, respectively. The less energy consumption in the Tunisian WWTPs is due to warmer climate and better operational skills. In other countries such as Greece the energy requirement (KWh/PE/y) for the AS plants is 17-26 (Tsagarakis *et al.*, 2003), which is lower than the range (30-50 kWh/PE.y) reported by Böker (1999) for AS systems in Germany. The per capita cost of energy (US$/PE/y) in the Jordanian WWTPs is 1.1-2.7(1.9), 0.2-1.9(0.8), and 0.2-0.6(0.3) for the AS, TF, and L plants, respectively, compared with 0.9-2.4(1.4), 0.2, and 0.1-1.9(0.8) for the three systems, respectively, in Tunisia (Table 11). The energy cost in the Jordanian WWTPs represents 27%, 17%, and 15% of OPEX for the AS, TF, and L systems, respectively, while in Tunisia it is 42%, 9.4%, and 24.1% for the three systems, respectively (Table 12). The annual energy requirement in the AS and TF plants drastically increases (almost 1:1) with increased treatment capacity, while the annual per capita energy requirement slightly decreases. The L systems in Jordan and Tunisia have a high energy requirement due to the addition of aeration units in some of the lagoons in order to improve their performance.



(a) **(b)**

Figure 1: Energy requirement: (**a**) KWh/year, (**b**) KWh/PE/year).

Table 10: Energy requirement (KWh/PE/y) according to country and treatment system.

Country	*AS*				*TF*				*L*			
	Min.	*Max.*	*Avg.*	*STD.*	*Min.*	*Max.*	*Avg.*	*STD.*	*Min.*	*Max.*	*Avg.*	*STD.*
Jordan (n=3, 4, 4)	21.8	45.0	*36.3*	12.6	4.6	25.0	*12.5*	8.8	3.4	12.5	*6.9*	3.9
Tunisia (n= 9, 1, 5)	16.5	30.7	*23.6*	5.5	3.1	3.1	*3.1*	-	0.8	35.0	*13.5*	13.2
Both countries (n=12, 5, 9)	*16.5*	*45.0*	*26.8*	*9.2*	*3.1*	*25.0*	*10.6*	*8.7*	*0.8*	*35.0*	*10.6*	*10.2*

Table 11: Energy cost (US$/PE/y) according to country and treatment system.

Country	*AS*				*TF*				*L*			
	Min.	*Max.*	*Avg.*	*STD.*	*Min.*	*Max.*	*Avg.*	*STD.*	*Min.*	*Max.*	*Avg.*	*STD.*
Jordan (n=3, 4, 4)	1.1	2.7	*1.9*	0.8	0.2	1.9	*0.8*	0.7	0.2	0.6	*0.3*	0.2
Tunisia (n= 9, 1, 5)	0.9	2.4	*1.4*	0.5	0.2	0.2	*0.2*	-	0.1	1.9	*0.8*	0.7
Both countries (n=12, 5, 9)	*0.9*	*2.7*	*1.5*	*0.6*	*0.2*	*1.9*	*0.6*	*0.7*	*0.1*	*1.9*	*0.6*	*0.6*

Table 12: Energy cost as percentage of OPEX according to country and treatment system.

Country	*AS*				*TF*				*L*			
	Min.	*Max.*	*Avg.*	*STD.*	*Min.*	*Max.*	*Avg.*	*STD.*	*Min.*	*Max.*	*Avg.*	*STD.*
Jordan (n=3, 4, 4)	24.4	31.1	*27.3*	3.5	3.9	35.9	*17.0*	13.6	11.0	18.7	*14.5*	3.2
Tunisia (n= 9, 1, 5)	19.6	62.3	*41.9*	13.9	9.4	9.4	*9.4*	-	4.4	38.0	*24.1*	17.4
Both countries (n=12, 5, 9)	*19.6*	*62.3*	*38.3*	*13.6*	*3.9*	*35.9*	*15.5*	*12.2*	*4.4*	*38.0*	*19.8*	*13.4*

3.2.2. Personnel

The number of personnel working in each treatment plant includes plant manager, O&M staff, non-technical staff, lab technicians, and guards. Comparing data from both countries shows that in Jordan, the average number of personnel per WWTPs is about 26, 25, and 18 in the AS, TF, and L plants, respectively, while in Tunisia it is 9, 13, and 11, respectively (Table 13). The average number of personnel in each treatment plant per 1,000 of PE served in Jordan is 1.5, 1.4, and 0.5 in the AS, TF, and L plants, respectively, while in Tunisia it is 0.5, 0.3, and 0.8, respectively (Table 14). The low number of personnel in the Tunisian plants is largely explained by a higher degree of out-contracting: ONAS keeps only the basic necessary staff and when there is an occasional need for extra staff, part time staff or companies are contracted, for example for mechanical installations and repairs and for desludging. In Jordan, the tendency of the MWI towards self-sufficiency within the WWTPs causes over-staffing. This partly explains the scatter of the data points in Figure 2a. In terms of number of personnel per 1,000 PE served, when the treatment capacity exceeds 3,000 m^3/day, the number of personnel required drastically decreases (<0.5/1,000 PE) for the three compared systems (Figure 2b). In Austria and Sweden, the total number of personnel per 1,000 PE was reported to be 0.15-0.37 at WWTPs between 5,000-40,000 PE which decreases to 0.08-0.15 (almost constant) at WWTPs between 40,000-130,000 PE (Nowak, 2000). Apparently, the number of personnel in each WWTP does not depend so much on the treatment system but on the plant capacity and population served. Therefore, large capacity WWTPs are decidedly more economical in terms of manpower.

In general, there are two to three senior persons in each WWTP, namely the plant manager and one to two O&M staff, who play a major role in the operation of the treatment plant. The other staff directly receives instructions and orders from the senior staff. The annual expenditure on personnel is about 46-75% and 17-76% of OPEX in the Jordanian and Tunisian WWTPs, respectively (Table 15). These results confirm the findings of Kemper *et al*. (1994) which show that in developing countries the cost of personnel in the wastewater treatment sector is proportionately higher than that for developed countries. For example, the costs of personnel in Spain, France, and Great Britain are, respectively, 28%, 24%, and 38% of the OPEX of a WWTP. On the other hand, in Thailand, Colombia, Brazil, Mexico, and Costa Rica, it is 52-68% (Figure 3). This means that WWTPs in developing countries are overstaffed, and thus reducing the number of personnel in each WWTP significantly decreases the treatment costs. The low number of personnel in Tunisian WWTPs positively reflects on the costs. Therefore, having a basic number of permanent staff and contracting part time personnel only when necessary is more economical than full reliance of permanent staff.

Table 13: Number of personnel per WWTP according to country and treatment system.

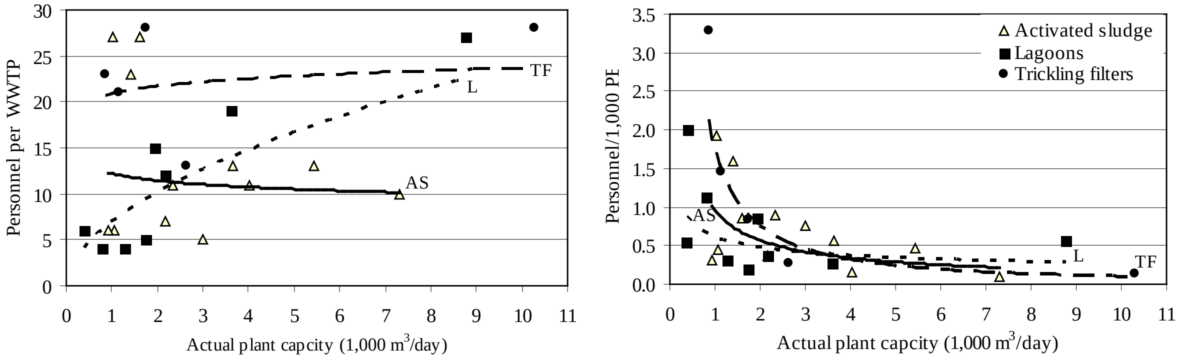
Country	*AS*				*TF*				*L*			
	Min.	*Max.*	*Avg.*	*STD.*	*Min.*	*Max.*	*Avg.*	*STD.*	*Min.*	*Max.*	*Avg.*	*STD.*
Jordan (n=3, 4, 4)	23.0	27.0	*25.7*	2.3	21.0	28.0	*25.0*	3.6	12.0	27.0	*18.3*	6.5
Tunisia (n= 9, 1, 5)	5.0	13.0	*9.1*	3.1	13.0	13.0	*13.0*	-	4.0	6.0	*5.0*	1.0

Table 14: Number of personnel per 1,000 PE according to country and treatment system.

Country	*AS*				*TF*				*L*			
	Min.	*Max.*	*Avg.*	*STD.*	*Min.*	*Max.*	*Avg.*	*STD.*	*Min.*	*Max.*	*Avg.*	*STD.*
Jordan (n=3, 4, 4)	0.8	1.9	*1.5*	0.6	0.1	3.3	*1.4*	1.4	0.3	0.8	*0.5*	0.3
Tunisia (n= 9, 1, 5)	0.1	0.9	*0.5*	0.3	0.3	0.3	*0.3*	-	0.2	2.0	*0.8*	0.7

Table 15: Personnel cost as percentage of OPEX according to country and treatment system.

Country	*AS*				*TF*				*L*			
	Min.	*Max.*	*Avg.*	*STD.*	*Min.*	*Max.*	*Avg.*	*STD.*	*Min.*	*Max.*	*Avg.*	*STD.*
Jordan (n=3, 4, 4)	55.2	65.8	*59.3*	5.6	46.1	78.6	*63.0*	13.4	57.6	75.0	*64.3*	7.8
Tunisia (n= 9, 1, 5)	16.6	55.5	*38.8*	15.0	65.6	65.6	*65.6*	-	58.9	76.1	*64.3*	7.0



(a) **(b)**

Figure 2: Effect of plant scale on total number of personnel: (**a**) per WWTP, (**b**) per 1,000 PE.

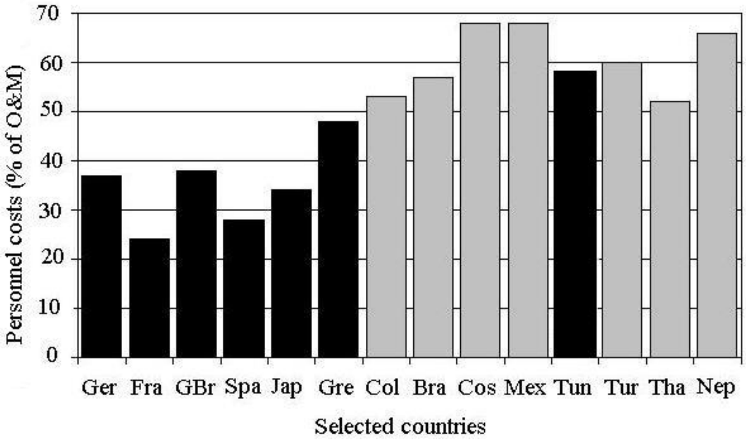


Figure 3: Personnel cost as percentage of OPEX in selected countries (Kemper *et al*., 1994).

3.2.3. Equipment replacement and parts

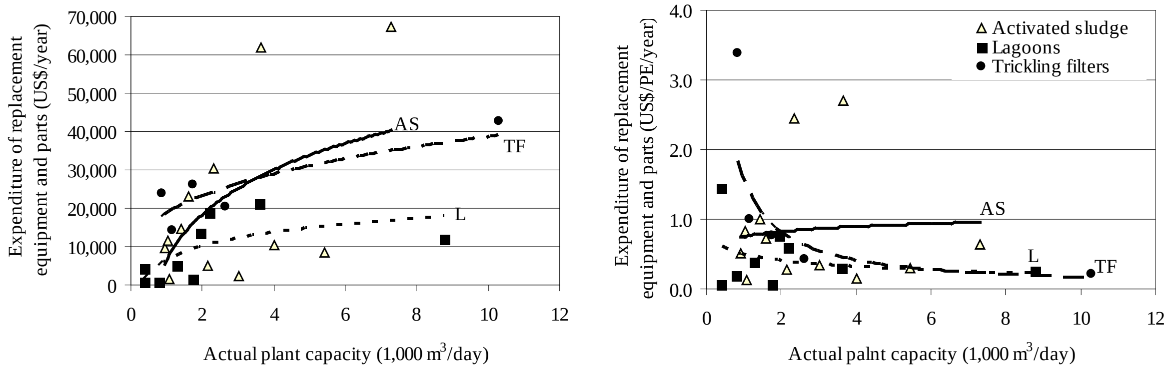
The data show that the annual expenditure on equipment replacement and parts (spare parts and supplies) in Jordan represents approximately 13.3%, 20.0%, and 21.2% of OPEX of the AS, TF, and L plants, respectively, compared with 19.3%, 25.0%, and 11.6%, respectively, in Tunisia (Table 16). The annual per capita expenditure on equipment replacement and parts (US$/PE/y) in Jordan is 0.7-1.0(0.9), 0.2-3.4(1.3), and 0.2-0.8(0.5) for the AS, TF, and L plants, respectively, compared with 0.1-2.7(0.8), 0.4, and 0.1-1.5(0.4), respectively, in Tunisia (Table 17). Figure 4 shows that, with respect to equipment replacement and parts, treatment through TF and L systems tends to become more economical (<US$0.5/PE/y) when the plant capacity exceeds 3,000 m^3/day. Results for the AS systems are inconclusive which can be attributed to the variability within the data set due to the various process modifications. However, it can be concluded that equipment replacement and parts are not necessarily decisive in differentiating treatment technologies on their overall financial performance.

Table 16: Cost of equipment replacement and parts (US$/PE/y) according to country and treatment system.

Country	*AS*				*TF*				*L*			
	Min.	*Max.*	*Avg.*	*STD.*	*Min.*	*Max.*	*Avg.*	*STD.*	*Min.*	*Max.*	*Avg.*	*STD.*
Jordan (n=3, 4, 4)	0.7	1.0	*0.9*	0.1	0.2	3.4	*1.3*	1.4	0.2	0.8	*0.5*	0.2
Tunisia (n= 9, 1, 5)	0.1	2.7	*0.8*	1.0	0.4	0.4	*0.4*	-	0.1	1.5	*0.4*	0.6

Table 17: Cost of equipment replacement and parts as percentage of OPEX.

Country	*AS*				*TF*				*L*			
	Min.	*Max.*	*Avg.*	*STD.*	*Min.*	*Max.*	*Avg.*	*STD.*	*Min.*	*Max.*	*Avg.*	*STD.*
Jordan (n=3, 4, 4)	9.9	18.3	*13.3*	4.4	17.5	22.3	*20.0*	2.6	14.0	28.2	*21.2*	7.0
Tunisia (n= 9, 1, 5)	4.6	52.8	*19.3*	16.0	25.0	25.0	*25.0*	-	2.7	30.6	*11.6*	12.4



(a) **(b)**

Figure 4: Effect of plant scale on expenditure on equipment replacement and parts: (**a**) US$/year, (**b**) US$/PE/year.

3.2.4. Total operation and maintenance costs

In both countries the per capita OPEX (US$/PE/y) for the L plants is low (1.15-8.06(3.23)) compared to that for the AS plants (1.5-8.5(4.6)) and the TF plants (1.2-15.18(5.45)) (Table 18). These costs represent 13.7-85.3(41.6)%, 49.8-68.4(56.6)%, and 41.2-82.9(57.9)% of TOTEX for the AS, TF, and L systems, respectively (Table 19). The wide range of variation in OPEX is attributed to differences in (i) number of personnel, (ii) power input, (iii) sludge processing techniques, and (iv) availability of spare parts and supplies. The sample size does not allow analyzing the cost structure of each of the treatment processes independently. In Greece, the per capita OPEX for conventional treatment plants, mainly AS, is about US$3.3-6.5/PE/y compared with US$2.3/PE/y for lagoons (Tsagarakis *et al*., 2003). In Sweden, Austria, the Netherlands, and Germany, the total operational costs of municipal WWTPs are about Euro13, 16, 20, and 23/PE/y, respectively (Nowak, 2000; Bode and Grüebaum, 2000).

In both countries, the average recurring cost per unit of treated wastewater (US$/m^3) is low for the L plants (0.02-0.17(0.09)) and low to moderate for the TF plants (0.06-0.34(0.17)) and the AS plants (0.04-0.32(0.13)) (Table 20). These costs are typical for many countries in the MENA region. For example, the recurring cost of treatment is US$0.12/m^3 in Tunisia, US$0.19/m^3 in Syria, US$0.24/m^3 in Qatar, US$0.37/m^3 in Jordan, and US$0.4/m^3 in Kuwait (Khouri, 1992).

Table 18: OPEX (US$/PE/y) according to country and treatment system.

Country	*AS*				*TF*				*L*			
	Min.	*Max.*	*Avg.*	*STD.*	*Min.*	*Max.*	*Avg.*	*STD.*	*Min.*	*Max.*	*Avg.*	*STD.*
Jordan (n=3, 4, 4)	3.99	8.54	*6.97*	2.58	1.20	15.18	*6.39*	6.14	1.15	5.54	*2.57*	2.02
Tunisia (n= 9, 1, 5)	1.54	8.08	*3.81*	2.22	1.70	1.70	*1.70*	-	1.25	8.06	*3.76*	2.85
Both countries (n=12, 5, 9)	*1.54*	*8.54*	*4.60*	*2.61*	*1.20*	*15.18*	*5.45*	*5.71*	*1.15*	*8.06*	*3.23*	*2.45*

Table 19: OPEX (US$/m^3) according to country and treatment system.

Country	*AS*				*TF*				*L*			
	Min.	*Max.*	*Avg.*	*STD.*	*Min.*	*Max.*	*Avg.*	*STD.*	*Min.*	*Max.*	*Avg.*	*STD.*
Jordan (n=3, 4, 4)	0.22	0.32	*0.26*	0.05	0.06	0.34	*0.20*	0.11	0.02	0.14	*0.08*	0.05
Tunisia (n= 9, 1, 5)	0.04	0.13	*0.08*	0.03	0.08	0.08	*0.08*	-	0.03	0.17	*0.10*	0.06
Both countries (n=12, 5, 9)	*0.04*	*0.32*	*0.13*	*0.09*	*0.06*	*0.34*	*0.17*	*0.11*	*0.02*	*0.17*	*0.09*	*0.05*

Table 20: OPEX as percentage of TOTEX according to country and treatment system.

Country	AS				TF				L			
	Min.	Max.	Avg.	STD.	Min.	Max.	Avg.	STD.	Min.	Max.	Avg.	STD.
Jordan (n=3, 4, 4)	22.3	41.2	30.3	9.7	49.8	58.2	53.7	4.1	41.6	66.6	57.4	11.1
Tunisia (n= 9, 1, 5)	13.7	85.3	45.4	23.9	68.4	68.4	68.4	-	41.2	82.9	58.3	20.1
Both countries (n=12, 5, 9)	13.7	85.3	41.6	21.9	49.8	68.4	56.6	7.5	41.2	82.9	57.9	15.8

3.3. Total costs of treatment (TOTEX) and economies of scale

WWTPs with large capacity enjoy economies of scale (Figures 5-7). When plant capacity exceeds 3,000 m^3/day, each of CAPEX and OPEX decreases to less than US$4.0/PE/y for the AS plants, and to less than US$2.0/PE/y for the TF and L plants. The L plants, however, are the cheapest since their per capita TOTEX (US$/PE/y) is about 1.6-19.6(average 6.1) compared with that for the TF plants (2.4-27.1(9.85)) and AS plants (4.7-37.6(13.1)) (Table 21). In Greece, these costs are about 5-20/PE/y for AS and other conventional systems that serve 3,000-200,000 PE (Tsagarakis *et al*., 2003). The total per unit cost of treatment (US$/$m^3$) is low for the L plants (0.04-0.42(0.18)), moderate for the TF plants (0.12-0.61(0.31)), and low to high for the AS plants (0.09-0.95(0.39)) (Table 22). These results show that the treatment costs of wastewater in the region are moderate to high compared with that around the world. For example, TOTEX of secondary treated effluent in the USA is about US$0.16/$m^3$ (Haruvy, 1997; Al-Hamdi, 2000). In the Netherlands and Germany, the TOTEX of municipal WWTPs are about Euro36, and 46/PE/y, respectively (Bode and Grüebaum, 2000).

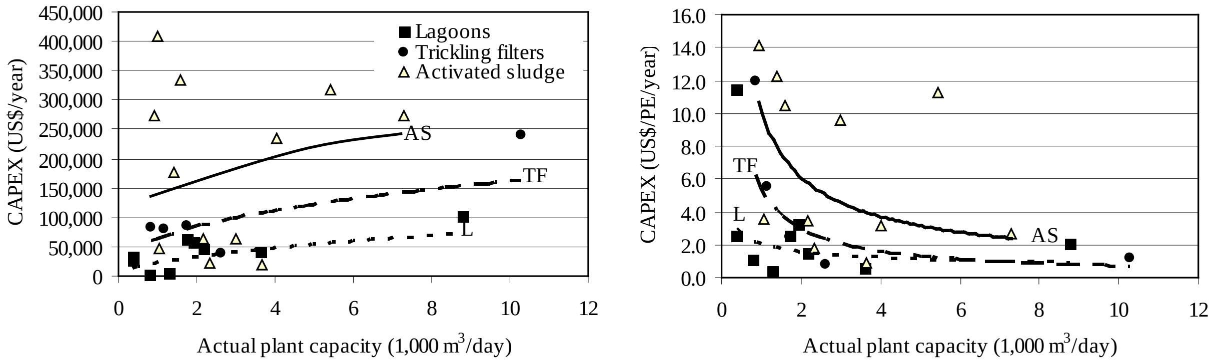
In conclusion, the financial performance of the treatment technologies varies considerably from one WWTP to another, even among those plants that fall within one process category and employ basically similar processes, within the same country. On the other hand, the sample size was large and diverse enough to allow meaningful comparison. The performance is determined mainly by (i) level of design skills, (ii) local availability of materials and equipment for construction and maintenance, and (iii) level of skills for process design and O&M. Therefore, there is no ideal system applicable for all conditions and the adoption of standard solutions and designs is difficult. This makes technology selection country and site specific, and consequently makes wastewater treatment such a fascinating subject (Sperling, 1996).

Table 21: TOTEX (US$/PE/y) according to country and treatment system.

Country	AS				TF				L			
	Min.	Max.	Avg.	STD.	Min.	Max.	Avg.	STD.	Min.	Max.	Avg.	STD.
Jordan (n=3, 4, 4)	14.46	37.63	24.28	11.98	2.41	27.10	11.69	10.89	1.72	8.75	4.42	3.02
Tunisia (n= 9, 1, 5)	4.70	16.39	9.40	5.01	2.50	2.50	2.50	-	1.62	19.55	7.37	7.02
Both countries (n=12, 5, 9)	4.70	37.63	13.12	9.47	2.41	27.10	9.85	10.29	1.62	19.55	6.06	5.52

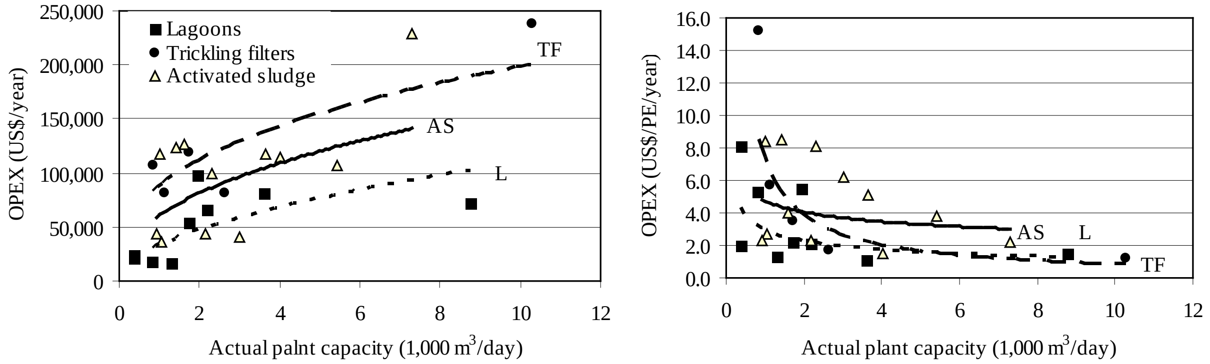
Table 22: TOTEX (US$/$m^3$) according to country and treatment system.

Country	AS				TF				L			
	Min.	Max.	Avg.	STD.	Min.	Max.	Avg.	STD.	Min.	Max.	Avg.	STD.
Jordan (n=3, 4, 4)	0.58	0.95	0.77	0.18	0.13	0.61	0.36	0.20	0.05	0.22	0.13	0.07
Tunisia (n= 9, 1, 5)	0.09	0.93	0.26	0.26	0.12	0.12	0.12	-	0.04	0.42	0.22	0.17
Both countries (n=12, 5, 9)	0.09	0.95	0.39	0.33	0.12	0.61	0.31	0.20	0.04	0.42	0.18	0.13



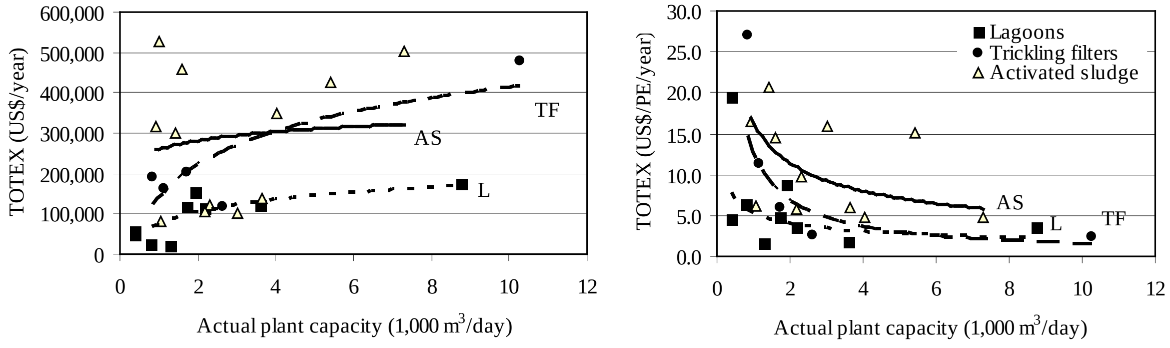
(a) **(b)**

Figure 5: Effect of plant scale on CAPEX: (**a**) US$/year, (**b**) US$/PE/y.



(a) **(b)**

Figure 6: Effect of plant scale on OPEX: (**a**) US$/year, (**b**) US$/PE/y.



(a) **(b)**

Figure 7: Effect of plant scale on TOTEX: (**a**) US$/year, (**b**) US$/PE/y.

4. Conclusions and recommendations

The main finding in this study is that wastewater treatment in Jordan and Tunisia is not constrained by the treatment technology itself– i.e., the "hardware", but by the institutional environment that should enable proper functioning of the technology– i.e., the "software". Performance of the treatment technologies varies considerably from one WWTP to another, even among those plants in the same country that are of the same type and apply basically similar processes.

Comparison of the treatment costs (capital and operational) for the three systems shows that activated sludge systems are the most expensive followed by trickling filters. Although lagoons are the cheapest, their mechanical modifications make their O&M requirements almost similar to that for the activated sludge and trickling filter systems. Lagoons are not necessarily “poor performers” for reuse; they are more expensive in land purchase cost, but their O&M is much lower especially because of the absence of imported complex equipment, and, importantly, for the reuse purpose their somewhat lower BOD and COD performance is irrelevant. Nevertheless, lagoon systems seem to be less commendable unless land is available at reasonable price and the current perceptions about lagoons are changed.

In each of the two countries, the treatment costs vary from very low to very high, even among those plants that have similar capacity and employ similar processes. This means that the existing treatment systems are in principle capable of producing treated effluents of acceptable quality at the lower cost levels, depending upon the enabling environment for these technologies to function properly and cost effectively.

The limited financial resources in the two countries have resulted in over-reliance on foreign grants and loans for financing the construction of new WWTPs, even though these are also limited. Consequently, substantial portions of the wastewater that is properly collected, are discharged without treatment or dedicated reuse (although such discharges partly get reused as the river water is being pumped up downstream from the discharge point). Moreover, these countries barely recover the O&M costs of wastewater treatment since they persist in adopting technologies such as activated sludge, that are a preferred option in industrialized countries for the purposes of these countries, but that may possibly be less attuned to the MENA treatment objectives, and that sometimes tend to work out as more expensive. However, other financing options such as recovery of the costs and involvement of the private sector are expected to inject additional funds and may help to partly overcome the financing gap.

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