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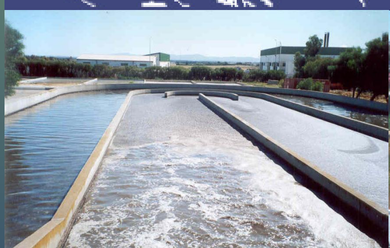
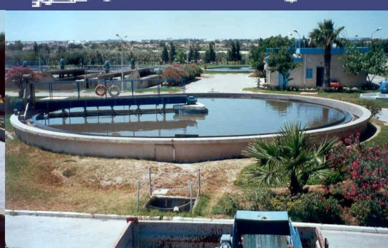
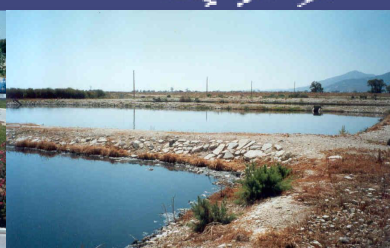

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Incentive Systems for Wastewater Treatment and Reuse in Irrigated Agriculture in the MENA Region:

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Incentive Systems for Wastewater Treatment and Reuse in Irrigated Agriculture in the MENA Region: *Evidence from Jordan and Tunisia*

DISSERTATION
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by

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To

my parents,
Abeer (my wife),
Sarah and Reham (my daughters)

Contents

Summary

Chapter 1 introduces the problem, objective, scope, and approach of the research. As a result of chronic water scarcity, the countries of the MENA region (Middle East and Northern Africa) recognize reclaimed wastewater as a non-conventional water resource. Nonetheless, in this region, substantial amounts of the wastewater that are collected are still discharged into the sea or water courses without treatment. Moreover, most of the treated wastewater is not re-used but discharged. The research objective is to analyze the technological, regulatory, institutional, financial, and socio-cultural opportunities (incentives) and constraints (disincentives) that influence the adoption of wastewater treatment and reuse for agricultural irrigation in the MENA region based on the experiences of Jordan and Tunisia. A fieldwork was conducted in Jordan (2000) and Tunisia (2001) to collect data on wastewater treatment, agricultural irrigation with the reclaimed wastewater, and crop marketing and consumption. The data collection in the two countries targeted 72 administrators, 31 wastewater treatment plants (WWTPs), 104 farmers and their irrigated farms, 326 households, and 3 crop markets.

Chapter 2 presents a conceptual framework for analysis and explains the typical wastewater treatment systems and the potential uses of reclaimed wastewater. Reclaimed wastewater is a commodity whose market comprises (i) a supply side which refers to wastewater production, collection, and treatment, (ii) a demand side which refers to the use of reclaimed wastewater, and (ii) market control and monitoring which refers to the pricing, regulatory and institutional frameworks. Thus, the reclaimed-wastewater market in the MENA countries is unbalanced. Balancing this market implies maximizing the rates of wastewater collection, treatment, and reuse. The collection rates are reasonably high in most countries, as these policies are driven by urbanization, and health and environmental objectives; thus this aspect lies beyond the scope of the study. Reducing the gap between supply and demand in the reclaimed-wastewater market entails increasing the rates of wastewater treatment and reuse. The currently-used indicators to quantify achievements in wastewater reuse account only for the reused amounts of wastewater from urban treatment plants and also omits that from rural communities. These indicators are reviewed and a new indicator called the Wastewater Reuse Index (*WRI*) is introduced. *WRI* quantifies the amounts actually reused as percentage of the total production of wastewater (urban and rural); it allows policy makers to quantify the gap between achievements in wastewater reuse at different junctures.

Chapter 3 presents a background on Jordan and Tunisia where this research was carried out. Both countries are pioneers in wastewater treatment and reuse. **Jordan** is located in the heart of the Middle East, and has a population of about 5 million distributed over 89,556 km^2. Agricultural irrigation takes about 71% of the total water use. The total production rates of municipal wastewater are about 241 million m^3 of which about 239 million m^3 are collected through sewerage (51%) and on-site systems (49%); *WRI* = 27.8. The amount of wastewater that receives treatment in 17 plants is about 80 million m^3 of which about 67 million m^3 is reused (in 2000). Direct reuse of the secondary-treated effluents is limited to a few farms near the existing treatment plants. Most of the (indirect) reuse takes place after blending the

secondary-treated effluent with freshwater available in wadis and dams (not for potable use), which is then used downstream in the Jordan Valley for unrestricted irrigation. The Ministry of Water and Irrigation (MWI) is the main institution responsible for policy, regulation and implementation concerning water supply, wastewater collection, treatment, and reuse. However, many other institutions are involved as well in wastewater management and reuse such as the Ministries of Health, Agriculture, and Industry in addition to the Standards and Metrology Establishment and others. **Tunisia** is located in the heart of North Africa, and has a population of about 9.5 million distributed over 164,418 km^2. Agricultural irrigation takes about 80% of the total water use. The total production rate of municipal wastewater is about 395 million m^3 of which about 316 million m^3 is collected through sewerage (40%) and on-site systems (60%); *WRI* = 12.7. The amount of wastewater that receives treatment in 61 plants is about 148 million m^3 of which about 50 million m^3 is reused (in 2001). Direct reuse of the secondary-treated treated effluents is practiced in many irrigation schemes that are designed for this purpose. Indirect reuse is partly practiced through blending with freshwater in the reservoirs and in deep aquifers (not for potable use). The *National Sewerage and Sanitation Office* or Office National de l'Assainissement (ONAS), which is a sub-organization of the Ministry of Environment and Land Use, is the main institution responsible for policy, regulation, and implementation for wastewater collection and treatment. Reuse is the responsibility of the Ministry of Agriculture. However, many other institutions are involved in wastewater managemnet and reuse sector such as the Ministries of Health, Industry, Interior and others.

Chapter 4 analyzes the Jordanian and Tunisian experiences in wastewater treatment. The most frequently used systems for wastewater treatment are activated sludge systems with their common modifications, trickling filters, and lagoons or waste stabilization pond. The performance and the enabling environment in which these systems function are assessed for 26 WWTPs. The quality of effluents, the treatment costs (capital and operational), and land requirement are used as indicators of technology performance. The enabling environment for wastewater treatment is also assessed, which comprises the (i) regulatory and institutional capacity, (ii) financial capability, and (iii) technical capacity. Wastewater treatment in Jordan and Tunisia is not constrained by the treatment technology itself (i.e., the hardware), but by the enabling environment for proper functioning of the technology (i.e., the software). Performance of the treatment technologies varies considerably from one WWTP to another, even among plants in one country that fall within one type category and employ basically similar processes. 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, replacement parts, and energy requirement. Comparison of the treatment costs (capital and operational) for the three system types shows that activated sludge systems are the most expensive followed by trickling filters. Although lagoons are the cheapest, the mechanical modifications to some natural lagoon systems make the O&M requirements almost similar to that for the activated sludge and trickling filter systems. This does not mean that lagoons are necessarily "poor performers" for reuse; their relatively low BOD and COD removals are irrelevant for reuse purposes. However, lagoon systems seem to be less commendable unless land is available at reasonable price and the current perceptions about lagoons are changed.

Chapter 5 analyzes and assesses the factors (incentives and disincentives) that promote or discourage the use of reclaimed wastewater in irrigated agriculture. This analysis will help understand the underlying fundamental driving forces for wastewater reuse, as derived from existing field experiences. A number of selected irrigation schemes were surveyed and methodological interviews with stakeholders were conducted as part of the fieldwork. The stakeholders represented government administrators, operational staff, farmers, and the public (households). The regulatory and socio-cultural (dis)incentives were shown to be of great relevance in the shaping of the decisions of both the farmers– who have to buy the reclaimed water and apply certain agronomic approaches– and the public – that must decide whether to buy the crops watered with reclaimed wastewater. These (dis)incentives are arguably more influential than the technical considerations. The most prominent incentives, on one hand, are (i) national water scarcity and high demand for additional water supplies, (ii) wastewater being valued as a non-conventional resource of water, (iii) the existing WWTPs producing substantial amounts of secondary-treated effluents that is suitable for restricted irrigation, (iv) the perception of farmers and crop consumers seeming to be positive towards acceptance of reclaimed wastewater and of related crops, respectively, (v) the existing crop-marketing systems not allowing the public to distinguish between the crops irrigated with freshwater and those irrigated with reclaimed wastewater, and (vi) the attitudes of Islam being positive towards wastewater reuse. The disincentives on the other hand are (i) the national wastewater management policies aiming at discharge-- wastewater treatment plants are often designed for protection of public health and the environment, whereas reuse is often considered only after the implementation of these plants, (ii) many farmers having access to competitive freshwater at low tariff within the schemes that propose irrigation with reclaimed wastewater, (iii) the existing standards and guidelines being overly restrictive and permitting only the use of reclaimed wastewater for restricted irrigation (crops that are not eaten raw), (iv) inadequate institutional performance caused by the large number of involved organizations that lack for coordination and cooperation and that prioritize own interests, (v) insufficient storage of the treated effluents causing unreliable supply, (vi) insufficient level of awareness and education amongst farmers and public on the costs and benefits of wastewater reuse, (vii) over-reliance on donors' financing due to limited local funds and poor recovery of costs, and (viii) some farmers and crop consumers having a psychological aversion towards wastewater reuse and having concern for criticism by the society.

Chapter 6 assesses the existing water pricing policies and the viability of increasing the freshwater tariffs as a tool to stimulate reclaimed wastewater through increasing the gap between the tariffs of both water qualities. It also analyzes the impact of increased water tariff on agricultural profitability to farmers. If the existing tariffs of freshwater remain unchanged, reclaimed wastewater can be attractive only if given to farmers at a very low tariff or free of charge. The benefits of a rational increase of freshwater tariffs are threefold. First, it would make reclaimed wastewater more attractive. Second, it may help in saving water and release pressure on scarce groundwater resources. Third, it could be used to recover part of the costs of conveyance and distribution of reclaimed wastewater. The existing water (groundwater, surface water, blended water, secondary treated wastewater) tariffs have minor influence on agricultural profitability, mainly because these tariffs are very low. Increasing these tariffs by US\$0.05/m^3 reduces farmers' profit by US\$250-700/ha/year. Increasing the tariffs by US\$0.10/m^3 would double the aforementioned reduction in farmers' profit. Such a reduction in agricultural profitability is crucial for some farmers and trivial for others. However, increasing the freshwater tariffs beyond US$0.10/m^3 would make agricultural irrigation unfeasible and might force farmers to shift to using reclaimed wastewater if its tariffs are maintained low and if its supply and quality are reliable. This incentive might be constrained by the fact that many farmers control their own facilities for meeting their water needs from surface as well as ground resources; thus, energy tariffs should also be considered. In those cases, increasing the diesel/electricity prices and reducing subsidies might prove a less effective tool to stimulate reclaimed-wastewater consumption.

Chapter 7 assesses the willingness of farmers to pay for reclaimed wastewater. A regression model was developed to correlate farmers' decisions with financial stimuli that induce them. The model shows that water tariffs and agricultural profitability have a significant influence on willingness of farmers to pay for reclaimed wastewater. About 97% of the farmers showed interest to take reclaimed wastewater if given to them free of charge and if its supplies are reliable and allowed for unrestricted irrigation. This willingness declined to 84% and 47% when the proposed tariffs were US$0.05/m^3 and US$0.10/m^3, respectively. Such tariffs, however, can barely recover the minimum operational costs of supplying a secondary treated wastewater. Making this water comply with farmers' requirements for unrestricted irrigation implies additional treatment costs. Therefore, ambitious attempts to recover costs through increasing the tariffs of reclaimed wastewater are unlikely to succeed since farmers still have easy and cheap access to the competitive freshwater.

Chapter 8 presents the conclusions drawn from the research. The main conclusions are: (i) the imbalance in the reclaimed-wastewater market– high supply and low demand – is due to high rates of wastewater production and collection, medium rates of treatment, and low rates of effluent use, and (ii) balancing the reclaimed-wastewater market implies maximizing the treatment rates close to collection rates and increasing the reuse rates close to the treatment rates, (iii) improved quality and quantity of treated wastewater is determined by the enabling environment in which the existing technologies perform, and (iv) increased rates of reclaimed-wastewater use in irrigated agriculture seem to be determined more by regulatory, institutional, and socio-cultural (dis)incentives than by technical considerations.

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"Who does not thank for little will not thank for much"
[Estonian Proverb]

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Chapter 1: Introduction

1.1 Background

The crisis of water scarcity looming on the horizon threatens the stability and security of the Middle East and North Africa region (MENA[1]) that is home to five percent of the world's people yet has less than one percent of the world's renewable freshwater (Mubarak, 1998; Brooks, 1999). As MENA's population and economy grow against finite freshwater resources, the annual per capita availability, which was about 3,300 m^3 in 1960, has fallen by 60% to about 1,250 m^3 in 1995; it is predicted to fall by another 50% to about 650 m^3 by 2025 (World Bank, 1996). However, in many countries like Jordan, Libya, Palestine, Saudi Arabia, United Arab Emirates, and Yemen the per capita availability was less than 180 m^3 in 1995, far below the benchmark level of 1,000 m^3 used as an indicator of severe water stress (Annexes B.4 and B.5). The map and development indicators of the region are available in Annexes A.1 and B.1.

Much of the water crisis is caused by the way water is used. More than 87% of MENA's withdrawn water is allocated to agriculture and only 13% to municipal and industrial uses, compared with worldwide 69% and 31%, respectively. This implies reallocation of freshwater from agricultural to domestic and industrial uses. According to the World Bank (1996), a reduction in agricultural water use by 15% would double the water available to households and industry in the region. This would reduce irrigated agriculture at the time many countries aim to expand it due to food security reasons. For example, Tunisia and Egypt wish to increase their area of irrigated agriculture by at least 30,000 and 880,000 hectares, respectively (Faruqui, 2000; World Bank, 2000). Besides, the MENA countries avoid inter-sector water transfer, mainly due to internal political considerations (Saghir *et al*., 2000). On the contrary, these countries adopt low water tariffs for agricultural irrigation (at least 10 times lower than that for urban use), which encourages agricultural water consumption (Gibbons, 1986). Thus, the region will increasingly suffer from water scarcity and consequent food insecurity. This fact has converged national, regional, and international efforts in search for additional and alternative sources of water.

Most attention was turned to desalination of brackish and sea water, inter-basin transfers by pipeline, and import of water by shipment. All of these options are technically feasible, but none is affordable or easy since they are capital and energy intensive (Table 1.1), many have severe ecological impacts, and all are politically complex (Brooks, 1999). Moreover, these options can solve the quantity dimension of the problem temporarily, but cannot prevent environmental pollution and risks to public health. Therefore, the reuse of treated wastewater is well recognized for having a potentially significant role in alleviating the quantitative and

[1] The MENA region refers to the countries and territories of Algeria, Bahrain, Egypt, Iraq, Israel, Jordan, Kuwait, Lebanon, Libya, Morocco, Oman, Palestine, Qatar, Saudi Arabia, Syria, Tunisia, United Arab Emirates, and Yemen.

qualitative stress on water resources the region (Khouri, 1992; Haruvy, 1997, 1998; Mubarak, 1998; Angelakis *et al*., 1999; Bahri, 1999; Al-Hamdi, 2000). The increasing concern for wastewater reuse as an integral part of total water balance (Figure 1.1) stems from the following considerations:

i) Growing water scarcity in many arid and semi-arid regions of the world increases demands for additional water supplies.
ii) High population growth leads to greater quantities of wastewater production.
iii) Environmental concerns increase, reflected by stricter pollution control measures, leading to larger quantities of wastewater to be treated at high expenses.
iv) A wide range of technologies now exists to purify wastewater to acceptable levels, increasing the opportunities to reclassify wastewater as a renewable water resource rather than waste.
v) The nutrients in reclaimed wastewater add attraction for use in agriculture, and consequently reduce use of chemical fertilizers.
vi) Rain-fed farming can be converted into more productive wastewater irrigated agriculture.
vii) Depending on the degree of treatment, reclaimed wastewater is a reliably available resource that may be fit for irrigation, industrial, and municipal uses at relatively low costs.

Table 1.1: Cost comparison of options for enhancing water resources in the MENA (World Bank, 1996; Abdulrazzak and Kobeissi, 2002).

Options	*Estimated costs (US\$/m^3)*
Reducing end-user demand (re-circulation, low water-use technologies) and leakage prevention	0.05 – 0.50
Wastewater treatment for irrigation	0.30 – 0.60
Desalination of brackish water	0.45 – 0.70
Desalination of seawater	0.48 – 2.20

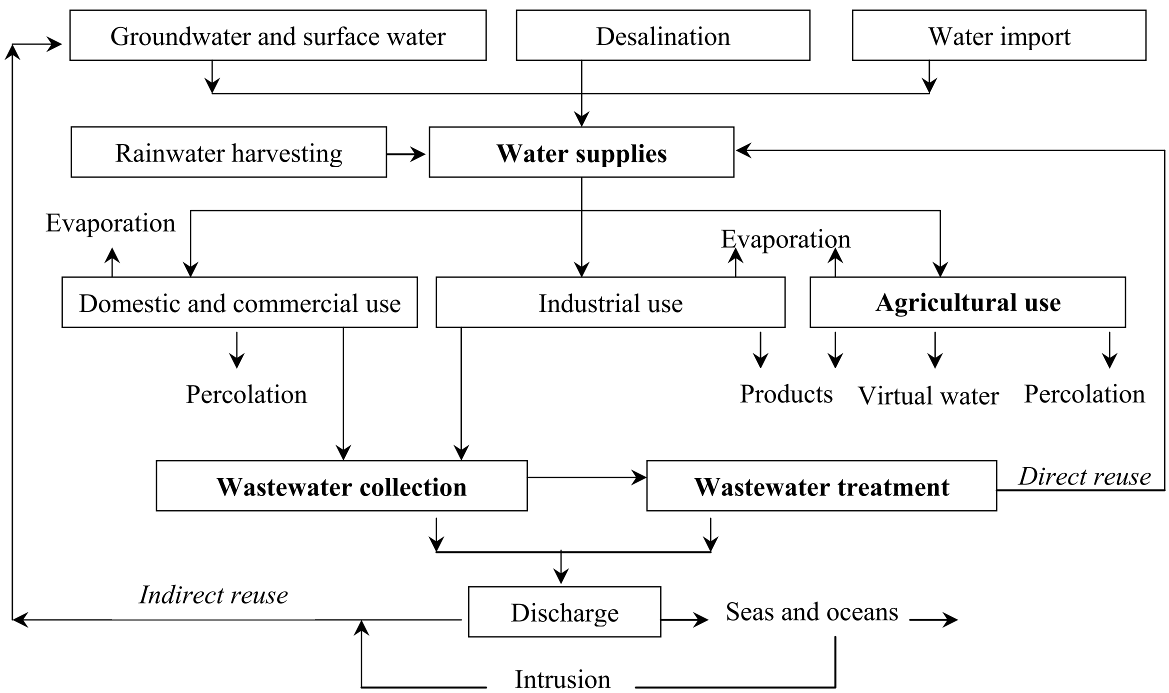


Figure 1.1: Wastewater reuse in integrated water resources management.

1.2 Problem description

The rates of wastewater reuse in most MENA countries are still very low despite (i) water scarcity and the fast growing need for additional water supplies, (ii) increasing recognition of treated wastewater as a valuable non-conventional resource, and (iii) technological advances in wastewater collection and treatment. In other words, reclaimed wastewater is a commodity whose market in the MENA countries is unbalanced. On the supply side of the market there is growth, demonstrated by the increasing amounts of collected and treated wastewater. On the demand side of the market there is stagnancy, revealed by the substantial proportions of treated effluents discharged into the receiving water bodies. Figure 1.2 shows that wastewater reuse in the region is still very low compared to generation, even in pioneer countries like Israel, Jordan, and Tunisia. Balancing the market for reclaimed wastewater implies reducing the gap between supply and demand through maximizing wastewater utilization; collection, treatment, and reuse (Chapter 2).

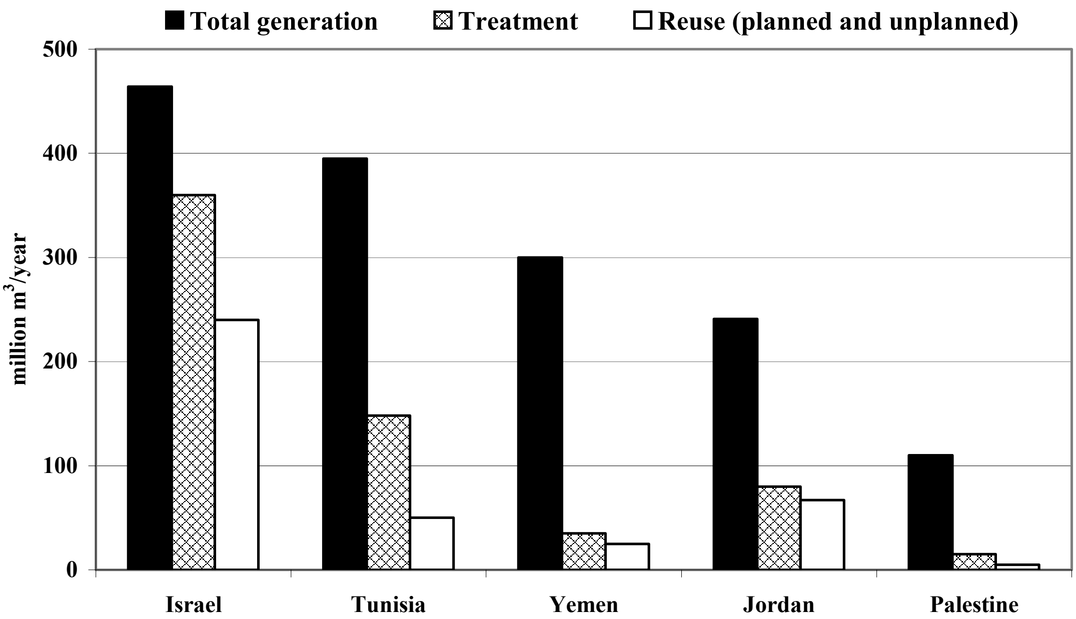


Figure 1.2: Wastewater reuse in selected MENA countries (MWI, 2000; ONAS, 2000; World Bank, 2001).

1.3 Objective

The objective is to analyze the technological, regulatory, institutional, financial, and socio-cultural opportunities (incentives) and constraints (disincentives) that influence wastewater treatment and reuse for agricultural irrigation in the MENA region (i.e., for middle-income economies, in water-stressed environments) based on the experiences of Jordan and Tunisia.

1.4 Scope of the study

The boundaries to the study scope are the following:

The study area. Israel was a pioneer in wastewater reuse, and soon was followed by Tunisia and Jordan (Angelakis *et al*., 1999). Jordan and Tunisia 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. Israel and Palestine were scheduled for the fieldwork in the early stages of this study, but they had to be excluded due to political complications. As a result, the sample organization and size in Jordan and Tunisia were almost doubled in order to arrive at meaningful conclusions.

Urban municipal wastewater treatment and reuse for agricultural irrigation. This research focuses on urban domestic wastewater because of the large per capita water consumption and wastewater production. The exclusion of industrial wastewater is mainly because (i) characteristics of industrial effluent vary as much as the types of industries producing them and treatment has to be very specific to the kind of industry involved, (ii) regulations concerning industrial pollutants differ greatly between countries in general and developing countries in particular (Loetscher, 1999), and (iii) industries show more often willingness to pay and comply with regulations. This research does not include the wastewater collection phase but focuses on wastewater treatment and reuse. This is mainly because all countries of the region achieved relatively high collection rates of wastewater through sewerage systems. Finally, the focus of this research on reuse of reclaimed wastewater for agricultural irrigation does not suggest that other uses of reclaimed wastewater such as artificial recharge, industrial reuse, and reuse for non-domestic purposes, are less important.

1.5 Approach of the Study

1.5.1 Fieldwork in Jordan and Tunisia

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).

Despite the prior coordination with key persons in each country, major logistical obstacles were encountered in the beginning. Cooperation was smooth and stimulating at high levels, but at lower levels in the organizations cooperation proved often cumbersome if not elusive.

Some staff suspected the study had the intention of spying, many asked for written permission from higher authorities, and very few showed any interest in sharing information. However, support from senior management in the hosting institutions (MWI and ONAS) proved effective in the long run and, many times, the company of a local professional colleague proved a necessary condition for progress.

1.5.2 Preparation and pilot testing of questionnaires

Different techniques were employed to collect the data necessary to achieve the objectives of this study. In addition to literature review, focus discussions, and observations, four types of questionnaires were designed with the help of two specialists from the Palestinian Central Bureau of Statistics (Table 1.2).

The first version of questionnaires was prepared in English and pilot-tested in Jordan. The use of English rather than Arabic was a major reason for skepsis from farmers and households' representatives. Therefore, pilot testing was halted until all questionnaires were translated into Arabic. They were subsequently tested on 3 WWTPs, 15 irrigated farms, 5 administrators, and 20 households. Pilot testing helped restructuring of the questionnaires which saved time during the actual survey, and most importantly, helped coming to better identification of the list of potential factors that influence wastewater treatment and reuse for agricultural irrigation in each country (Chapters 4 and 5). The pilot-tested questionnaires were employed for conducting the field surveys.

Table 1.2: Research questionnaires, target groups, and sample size.

Targeted group	*Data collection technique*	*Sample size*		
		Jordan	*Tunisia*	*Total*
Administrators representing government, NGOs, research centers, plant managers, and farmers' unions	Questionnaire (**A**) + focus discussions	38	34	*72*
Wastewater treatment plants	Questionnaire (**B**) + literature	13	18	*31*
Farms irrigated with groundwater	Questionnaire (**A**) + (**C**)	12	6	*18*
Farms irrigated with surface water	Questionnaire (**A**) + (**C**)	15	5	*20*
Farms irrigated reclaimed wastewater	Questionnaire (**A**) + (**C**)	11	40	*51*
Farms irrigated with blended wastewater with freshwater	Questionnaire (**A**) + (**C**)	10	5	*15*
Households (crop consumers)	Questionnaire (**D**)	175	151	*326*
Crop markets	Observations and discussion	2	1	*3*

Notes:

A) A short questionnaire that targeted 58 administrators, 14 plant managers, and 104 farmers with the objective to identify potential incentives and disincentives for wastewater treatment and reuse (Annex D.1).

B) In-depth questionnaire and checklist that targeted 31 WWTPs with the objective to collect necessary data for assessment of wastewater treatment performance (Annex D.2).

C) In-depth questionnaire that targeted the aforementioned farmers (104) with the objective to collect necessary data for analysis of agronomics of reuse as well as to elicit the perceptions and attitudes of farmers (Annex D.3).

D) A questionnaire that targeted 326 households with the objective to elicit the perceptions and attitudes of the public with regard to use of crops irrigated with reclaimed wastewater (Annex D.4).

1.5.3 Selection and size of sample

Administrators. Selection of the surveyed administrators was limited to 72 knowledgeable staff of the visited institutions including 14 managers of WWTPs.

WWTPs. Selection of the surveyed WWTPs was limited to 13 WWTPs in Jordan and 18 WWTPs in Tunisia. The sample represents the commonly used treatment systems (activated sludge, trickling filter, and lagoons) and is intended to cover the spectrum of treatment capacities of WWTPs (see also Chapter 4).

Irrigated farms. The survey covered 104 farms although the original aim was to survey 200 farms. Roughly half of this sample (n=51) used reclaimed wastewater, while the other half used either groundwater (n=18), surface water (n=20), or such water blended with wastewater (n=15). The reasons for the sample restriction were: (i) absence of the right persons who could provide reliable information; in many cases either only workers or farmers' kin were available, (ii) some farmers were suspicious and hesitant to cooperate, and (iii) logistical and budget limitations. Still, this sample provided sufficiently consistent information to achieve the objective of the study. Farmers irrigating with raw wastewater were excluded although they were originally considered in the target groups of the survey. This is mainly because (i) it was extremely difficult to identify those farmers in the field; they disguisedly use raw wastewater to grow rain-fed and freshwater crops, and (ii) the few farmers that could be surveyed did not give relevant contribution to this research since most, if not all, denied using untreated wastewater and suspected the survey intentions.

Households. The surveyed households (n=326) were randomly selected by selecting every 10th household in urban, peri-urban, and rural communities. The sample was distributed to represent those households served with sewerage and those that use cesspits. Interviewing of people outside their households was avoided, as the pilot testing of the questionnaires proved that interviewing respondents in their homes gives more reliable information than when interviewed on the street.

Crop markets. In order to understand the crop marketing system, and the economic/financial value of the different types of irrigation water, three crop markets were visited and pricing and marketing strategies analyzed. The plan to conduct an experiment at central crop markets in each country to study the response of crop consumers to different freshwater irrigated crops and reclaimed-wastewater irrigated crops was discouraged by authorities since it would have created rumors that would influence the crop market prices, and thus yield unreliable results.

1.5.4 Reliability of collected data

In order to ensure collection of reliable information, the following measures were applied (Casley and Kumar, 1995):

- *Surveyor's knowledge about the targeted group*. Literature review and early discussions with local experts prior to conducting the field survey improved dialogue quality and management of the interviews.

- *Knowledgeable respondents*. Interviewing only knowledgeable persons who could provide detailed information increased the chances of getting reliable information.
- *Mitigation of respondent's suspicions*. At the outset of the interview, a few pleasant observations would be made that would help put the respondent at ease. This considerably helped in gaining trust and ultimately getting more reliable information. This could mean, in some instances admiring a kid that sticks to his father, in other cases flattering a respondent for having a nice farm or house, or a well-maintained WWTP. However, excess flattering and sympathy (in the case of farmers) were avoided to prevent overly positive responses.
- *Data crosscheck*. The water quality and financial data on WWTPs were primarily collected from the records of MWI and ONAS. For validation purposes, the same data were also collected in the field from records kept at the visited WWTPs. Both countries have good quality record keeping systems; data are filed in daily, monthly, and annual reports. The monthly and annual reports are regularly submitted to the MWI and ONAS. These records could only be partially accessed based on the permission granted by higher authorities in each country. Both institutions were cooperative and helpful, especially in facilitating field visits to the selected WWTPs. In Tunisia, the collected data were presented and reviewed in two workshops with a dozen of experts in each. In Jordan, the collected data were discussed individually with experts from MWI, the University of Jordan, the Royal Scientific Society, and the National Center for Agricultural Research and Technology Transfer, as well as WHO-CEHA. The purpose of these workshops and discussions was to corroborate the collected data and to achieve a better understanding of the systems in each country.

  With respect to farm surveys, three different levels of crosscheck were applied. The first is based on the structure of the questionnaire by having questions that have direct and indirect answers. The second was having side talks with the field workers either before or after interviewing the eligible person. The third was confirming parts of the quantitative data from staff of the agricultural departments within the area and representatives of the farmers' unions, if available. As a result, 8 out of the 104 cases were rejected because farmer's responses appeared contradictory and/or misleading.

1.6 Structure of the thesis

Chapter 2 provides a conceptual framework for wastewater treatment and reuse by explaining the commonly used treatment technologies and the common uses of the reclaimed wastewater. It also analyzes the yardsticks and indicators often used for quantification achievements in wastewater reuse, and introduces a new indicator called the *Wastewater Reuse Index* (*WRI*). The Chapter also provides a general preview of the incentives and disincentives that may influence decision-making on wastewater treatment and reuse. Chapter 3 provides a description of Jordan and Tunisia on which this study is based. Based on a sample of 26 WWTPs in Jordan and Tunisia, Chapter 4 analyzes the performance of the frequently used technologies for wastewater treatment as well as the enabling environment under which these technologies are functioning. Chapter 5 analyzes the technical, financial, regulatory, institutional, and socio-cultural aspects for using the reclaimed wastewater in irrigated agriculture. Chapter 6 analyzes the existing systems of water pricing and assesses agricultural profitability and viability of increasing the tariffs of freshwater and reclaimed wastewater. Chapter 7 assesses the willingness of farmers to pay for reclaimed wastewater and demonstrates which part of the incurred costs may be recovered. Finally, the conclusions are summarized in Chapter 8.

1.7 References

Abdulrazzak, M. and Kobeissi, L. (2002). UNDP-ESCWA initiative on national framework for water resources management in Lebanon. Beirut, Lebanon.

Al-Hamdi, M. (2000) Competition for scarce groundwater in Sana'a plain, Yemen: a study on the incentives system for urban and agricultural water use. PhD thesis, IHE-Delft, The Netherlands.

Angelakis, A., Marecos, M., Bontoux, L., and Asano, T. (1999). The status of wastewater reuse practice in the Mediterranean basin: Need for guidelines. *Wat. Res*., **33**(10): 2201-2217.

Asano, T. and Levine, A. (1995). Wastewater reuse: a valuable link in water resources management. Water Reuse, WQI, No. 4.

Asano, T. and Levine, A. (1996). Wastewater reclamation, recycling and reuse: past, present and future. *Wat. Sci. Tech*., **33**(10-11): 1-14.

Bahri, A. (1999). Agricultural reuse of wastewater and global water management. *Wat. Sci. Tech*., **40**(4-5): 339-346.

Bakir, H. (2000). Guiding principles and options for accelerated extension of wastewater management services to small communities in EMR countries. World Health Organization. Regional Office for the Eastern Mediterranean. Regional Center for Environmental Health Activities (CEHA). (Draft). December 2000, Amman, Jordan

Brooks, B. (1999). Presentation to donors' meeting. Water demand management research network. International Development Research Center (IDRC). Cairo, Egypt. www.idrc.ca/waterdemand/SpecialPapers_e.html

Casley, D. and Kumar, K. (1995). The collection, analysis, and use of monitoring and evaluation data. World Bank publication.

Eden, R. (1996). Wastewater reuse - limitations and possibilities. *Desalination*, **106**: 335-338.

Faruqui, N. (2000). Wastewater treatment and reuse for food and water security. IDRC. Ottawa, Canada. www.idrc.ca/waterdemand/SpecialPapers_e.html

Gibbons, D. 1986. The Economic Value of Water. Resources for the future, Washington, DC.

Haruvy, N. (1997). Agricultural reuse of wastewater: nation-wide cost benefit analysis. *Agricultural, Ecosystem and Environment*, **66**: 113-119.

Haruvy, N. (1998). Wastewater reuse - regional and economic considerations. *Resources, Conservation and Recycling*, **23**: 57–66.

Kalbermatten Associates, Inc. (1999). Study to identify gaps, issues and constraints in urban environmental sanitation. Report No. 1: Preliminary identification of gaps. A study funded by the Department for International Development, United Kingdom, and executed by the UNDP/World Bank Water and Sanitation Program Washington, D.C., U.S.A.

Khouri, N. (1992). Wastewater reuse implementation in selected countries of the Middle East and North Africa. Canadian Journal of Development Studies, special issue.

Loetscher, T. (1999). Appropriate sanitation in developing countries: the development of a computerized decision aid. PhD thesis. The University of Queensland. Australia.

Mubarak, J. (1998). Middle East and North Africa: Development policy in view of a narrow agricultural natural resource base. *World Development*, **26**(5): 877-895.

MWI, Jordanian Ministry of Water and Irrigation. (2000). Annual report. Amman, Jordan.

ONAS, Tunisian National Sewerage and Sanitation Office. (2000). Annual Report. Tunisia.

Otterphol, R., Albold, A. and Oldenburg, M. (1999). Source control in urban sanitation and waste management: Ten systems with reuse of resources. *Wat. Sci. Tech*., **39**(5): 153-160.

Saghir, J., Schiffler, M., and Woldu, M. (2000). Urban water and sanitation in the Middle East and North Africa Region: The way forward. The World Bank, Middle East and North Africa Region, Infrastructure Development Group.

Shelef, G. and Azov, A. (1996). The coming era of intensive wastewater reuse in the Mediterranean region. *Wat. Sci. Tech*., **33**(10-11): 115-125.

World Bank. (1996). From Scarcity to security: averting a water crisis in the Middle East and North Africa. Report. Washington, DC.

World Bank. (2000). Wastewater treatment and reuse in the Middle East and North Africa Region (MENA). World Bank, Washington, DC.

World Bank. (2001). Summary report of the Regional Workshop: Water Reuse in the Middle East and North Africa, July 2-5, 2001, Cairo.

Chapter 2: A Conceptual Framework for Analysis of Wastewater Utilization

2.1 Introduction

The research problem that has been described in the previous Chapter can be summarized as follows: wastewater utilization in the MENA is low despite water scarcity and strong demand for water supply augmentation. This Chapter intends to analyze this problem through:

i) Identification of the components that make up a successful wastewater utilization program.
ii) Description of the frequently-used treatment processes and end uses of reclaimed wastewater.
iii) Analysis of indicators for quantifying achievements in wastewater reuse, and introduction of a new inclusive yardstick called Wastewater Reuse Index (*WRI*).
iv) Conceptual understanding of the incentives and disincentives that influence wastewater treatment and use of reclaimed wastewater in irrigated agriculture.

2.2 Wastewater utilization

2.2.1 General

Oron *et al*. (1999) identified two basic requirements for utilization of wastewater as a solution for water shortage problems whilst minimizing the health and environmental risks: (i) the need for comprehensive wastewater collection systems, and (ii) the need for well-operated wastewater treatment facilities. Mills and Asano (1996) rightly emphasized a third requirement, namely securing users for the treated effluents. Thus, to maximize the contribution of wastewater reuse to the total water availability, the produced wastewater needs to be collected, treated, and used: three "pillars" of wastewater utilization. In order to better understand the research problem, reclaimed wastewater is recognized as a commodity whose market comprises (Figure 2.1): (i) a supply side, which refers to the production, collection, and treatment of wastewater, (ii) a demand side, which refers to the use of the reclaimed wastewater, and (iii) market control and monitoring, which refers to the regulatory and institutional framework.

In the MENA countries, the reclaimed-wastewater market is unbalanced; i.e., growing supply – which is demonstrated by the increasing sewerage coverage and number of wastewater treatment plants (WWTPs) – and stagnant demand – which is demonstrated by the substantial proportions of treated effluents that are not used but discharged into the receiving water bodies. Balancing the reclaimed-wastewater market (i.e., reducing the gap between supply and demand) implies increasing the rates of collection, treatment, and reuse close to the rate of wastewater production.

Part of this Chapter has been submitted as:
Abu-Madi, M., Braadbaart, O., Al-Sa'ed, R., and Alaerts, G. Conceptual quantification of achievements in wastewater reuse in the Middle East and North Africa region. *Water Policy*.

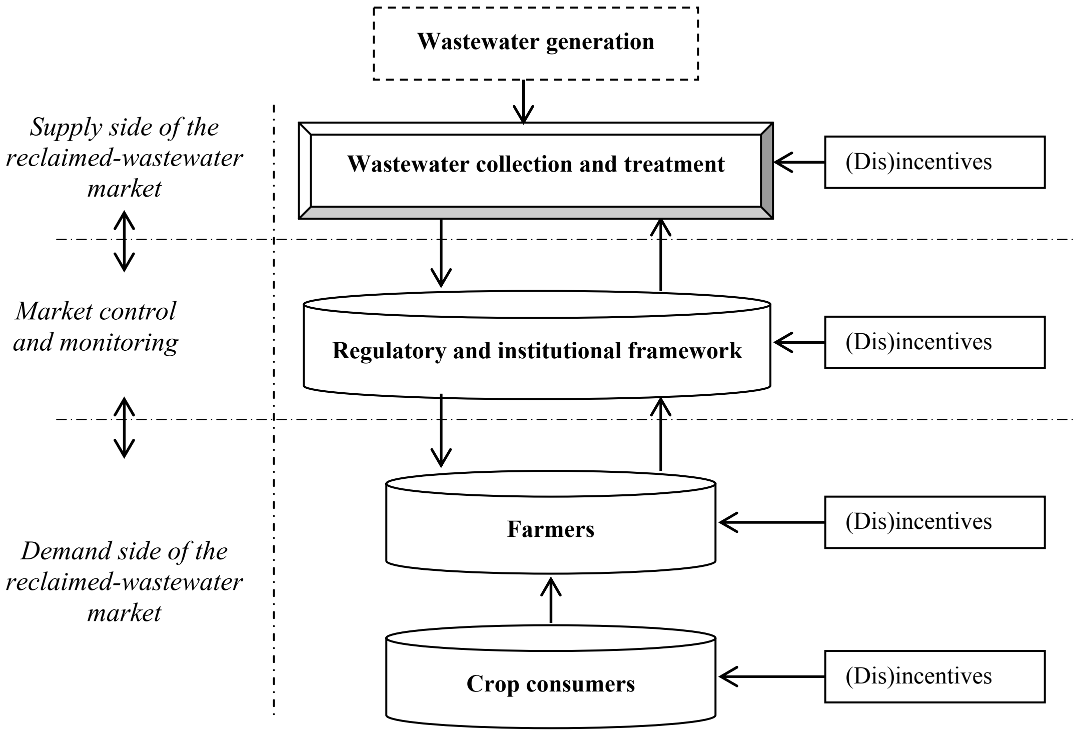


Figure 2.1: Composition of the reclaimed-wastewater market.

2.2.2 Wastewater production

The total amount of wastewater production is the hydraulic capacity of the wastewater resource, which can be quantified in three different ways:

- *Measuring water supply*. The generated amounts of wastewater can be derived from the total water supply for domestic, industrial, and commercial uses. This method is not favored since it is difficult to make countrywide estimates for the amounts of water supplied from alternative non-public sources such as private water vendors, rainwater harvesting, and springs. Moreover, the unaccounted-for water in the supply systems adds uncertainty.
- *Measuring wastewater flows*. This method measures only the metered wastewater flows from sewered communities. The amounts of wastewater generated from communities using cesspits and septic tanks must to be estimated.
- *Measuring water consumption*. This method quantifies the amount of wastewater generated from domestic, commercial, and industrial water uses based on the average per capita water consumption, taking into consideration that not all the consumed water enters the sanitation system. This technique is most recommended since it allows easy calculation and takes into consideration the water saving efforts. Water saving means less per capita water consumption, less wastewater generation, and therefore lower costs. Table 2.1 shows estimates for the amounts of domestic wastewater being produced in some MENA countries.

2.2.3 Wastewater collection

Collection here refers to the wastewater produced across the country that enters the sewerage system or the on-site disposal systems; to a large extent, it is approximated by figures of sanitation coverage. In most MENA countries, there is a continuing increase in the collection rate of wastewater, especially through sewerage networks that are gradually expanding. This is driven mainly because wastewater collection is considered an urban necessity that serves health and environmental purposes (Bakir, 2000; WHO, 2000). The estimates for total collection rates of wastewater are very high in many MENA countries (Table 2.1); this includes conventional sewerage and on-site disposal such as cesspits and septic tanks. Thus, it can be assumed that sanitation coverage and wastewater collection are not the limiting factors for reuse in most of the region. Therefore, wastewater collection will be considered beyond the scope of this research.

Table 2.1: Domestic wastewater production and collection rates in some MENA countries for year 2000.

Country	*Population (thousands)*			*Water consumption * (million m³/y)*			*Wastewater collection (% of population) ***			*Wastewater collection (million m³/y) ****		
	Urban	*Rural*	*Total*	*Urban*	*Rural*	*Total*	*Urban*	*Rural*	*Total*	*Urban*	*Rural*	*Total*
Algeria	18,969	12,502	31,471	831	319	1,150	90	47	73	598	120	718
Egypt	30,954	37,515	68,469	1,356	959	2,314	98	91	94	1,063	698	1,761
Iraq	17,756	5,359	23,115	778	137	915	93	31	79	579	34	613
Jordan	4,948	1,721	6,669	217	44	261	100	98	99	173	35	208
Lebanon	2,945	337	3,282	129	9	138	100	87	99	103	6	109
Libya	4,911	693	5,604	215	18	233	97	96	97	167	14	181
Oman	2,135	407	2,542	94	10	104	98	61	92	73	5	78
Saudi Arabia	18,526	3,081	21,607	811	79	890	100	100	100	649	63	712
Syria	8,783	7,342	16,125	385	188	572	98	81	90	302	122	423
Tunisia	6,281	3,305	9,586	275	84	360	97	48	80	214	32	246
Yemen	4,476	13,636	18,112	196	348	544	87	31	45	136	86	223

* Estimated based on 120 l/c/d for urban and 70 l/c/d for rural; it does not include commercial and industrial water.
** Sewerage and on-site collection systems (WHO, 2000).
*** Assumed that 80% of the water consumption is collected.

2.2.4 Wastewater treatment

Wastewater collected from communities and industries ultimately returns to receiving water bodies or to the land. Wastewater contains organic materials whose decomposition can lead to the production of large quantities of malodorous gases (Table 2.2). In addition, untreated wastewater usually contains numerous disease-causing microorganisms that dwell in the human intestinal tract. Wastewater also contains nutrients, which can stimulate excessive growth of aquatic plants and algae (eutrophication), and it may contain toxic compounds (Metcalf and Eddy, 1991). These contaminants have to be removed or reduced to a safe and environmentally sound level for environmental protection purposes in order that the water course can retain its utility (for fishing, bathing, etc.) downstream. In addition, if the wastewater can be treated to a high enough quality standard, it also provides for a badly needed non-conventional water resource. The level of required wastewater treatment is case-specific and directly related to the quality requirements associated with the end-use (Bouwer, 1991; Asano and Levine, 1996). The typical wastewater end-uses are: (i) discharge into the sea (with minimum disturbance of the existing ecosystem), (ii) discharge into surface water (ditto), (iii) discharge into groundwater aquifers (ditto), (iv) restricted agricultural irrigation, (v) unrestricted agricultural irrigation, (vi) aquaculture, (vii) non-potable domestic use, (viii) potable water use, and (ix) industrial use. In all these cases, wastewater treatment is a requisite.

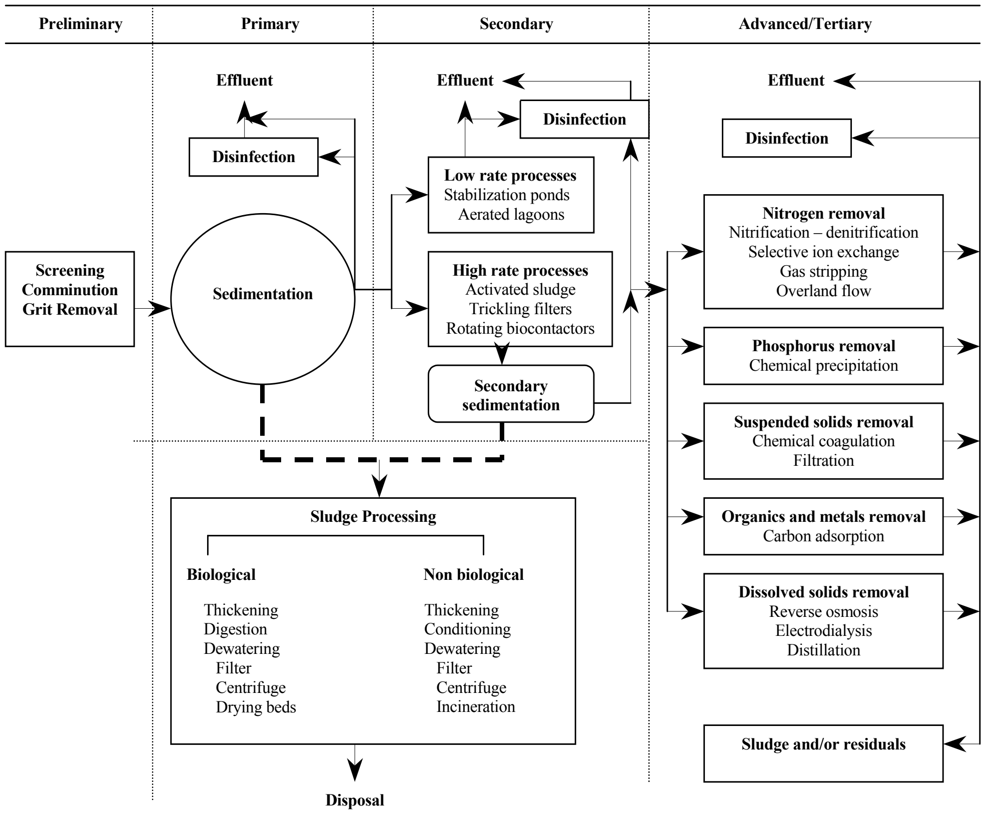
Table 2.2: Constituents of concern in reuse of reclaimed wastewater.

Constituent	*Measured parameters*	*Reason for concern*
Pathogenic microorganisms	Bacteria, viruses, helminthes, and protozoa	The presence of pathogenic microorganisms in wastewater creates the potential for adverse health effects and disease transmission where there is contact, inhalation, or ingestion.
Suspended solids	Suspended solids (SS), including volatile and fixed solids cause plugging in irrigation system	Organic contaminants, heavy metals, etc. are adsorbed on particulates. Suspended matter can shield microorganisms from disinfection.
Biodegradable organics	BOD, COD, and TOC	Aesthetic and nuisance problems. Organics provide food for microorganisms, adversely affect disinfection processes, make water unusable for some industrial or other uses, consume oxygen, and may result in acute or chronic effects if reclaimed wastewater is used for potable purposes.
Nutrients	N, P, and K	They are essential nutrients for plant growth, and their presence normally enhances the value of water for irrigation. When discharged to the aquatic environment, nitrogen and phosphorus can lead to the growth of undesirable aquatic life. When applied at excessive levels on land, nitrogen can also lead to nitrate build-up in groundwater.
Stable organics	Specific compounds (e.g., pesticides, chlorinated hydrocarbons)	Some of these organics tend to resist conventional methods of wastewater treatment. Some organic compounds are toxic in the environment, and their presence may limit the suitability of reclaimed water for irrigation or other uses.
Hydrogen ion concentration	pH	The pH of wastewater affects disinfection, coagulation, metal solubility, as well as alkalinity of soils. Normal range in municipal wastewater is pH = 6.5-8.5, but industrial waste can alter pH significantly.
Heavy metals	Specific elements (e.g., Cd, Zn, Ni, and Hg)	Some heavy metals accumulate in the environment and are toxic to plants and animals. Their presence may limit the suitability of reclaimed water for irrigation or other uses.
Dissolved inorganics	TDS, EC, and specific elements (e.g., Na, Ca, Mg, Cl, and B)	Excessive salinity may damage some crops. Specific ions such as chloride, sodium, and boron are toxic to some crops. Sodium may pose permeability problems.
Residual chlorine	Free and combined chlorine	Excessive amount of free available chlorine (>0.05 mg/l) may cause leaf-tip burn and damage some sensitive crops. However, most chlorine in reclaimed water is in a combine form, which does not cause crop damage. Some concerns are expressed as to the toxic effects of chlorinated organics in regard to groundwater contamination.

Pettygrove and Asano (1985) as cited in USEPA (1992).

Conventional wastewater treatment, typically, consists of a combination of physical, chemical, and biological processes and operations to remove solids, organic matter and, sometimes, nutrients from wastewater. General terms used to describe different degrees of treatment, in order of increasing treatment level, are preliminary, primary, secondary, and tertiary and/or advanced wastewater treatment (Figure 2.2). The conventional treatment systems tend to be expensive at small scale. Therefore, in rural and peri-urban environments, wastewater can be treated in alternative, low-cost treatment systems such as septic tanks with attached sub-drainage irrigation pipes, up-flow anaerobic tanks and ponds followed by furrow or pumped irrigation, etc. However, these systems are beyond the scope of this research.

The frequently used systems for urban wastewater treatment in the MENA are activated sludge systems (conventional activated sludge, oxidation ditch, and extended aeration), trickling filters, and lagoons (Bahri, 1998; Jamrah, 1999; Faruqui, 2000; Idelovitch, 2001). In some countries, disinfection to remove pathogens sometimes follows the last treatment step. These treatment systems are described in the forthcoming Sections.



Sources: Mujeriego and Asano, 1999 adapted from Asano, Smith and Tchobanoglous, 1985.

Figure 2.2: Typology of wastewater treatment processes.

2.2.4.1 Preliminary treatment

The objective of preliminary treatment is the removal of coarse solids and other large materials often found in raw wastewater. Removal of these materials is necessary to enhance the operation and maintenance of subsequent treatment units. Preliminary treatment operations typically include coarse screening, grit removal and, in some cases, comminution of large objects. In grit chambers, the velocity of the water through the chamber is maintained sufficiently high, or air is used, so as to prevent the settling of most organic solids. Grit removal is not included as a preliminary treatment step in most small wastewater treatment plants. Comminutors are sometimes adopted to supplement coarse screening and serve to reduce the size of large particles so that they will be removed in the form of sludge in subsequent treatment processes.

2.2.4.2 Primary treatment

The objective of primary treatment is the removal of settleable organic and inorganic solids by sedimentation, and the removal of materials that will float (scum) by skimming. Approximately 25-50% of the influent biochemical oxygen demand (BOD_5), 50-70% of the total suspended solids (TSS), and 65% of the oil and grease are typically removed during primary treatment (Pescod, 1992). Some organic nitrogen, organic phosphorus, and heavy metals associated with solids are also removed during primary sedimentation, but colloidal and dissolved constituents are not affected. The effluent from primary sedimentation units is referred to as primary effluent.

In many industrialized countries, primary treatment is the minimum level of pre-application treatment required for wastewater irrigation. It may be considered sufficient treatment if the wastewater is used to irrigate crops that are not consumed by humans or to irrigate orchards, vineyards, and some processed food crops. However, to prevent potential nuisance conditions in storage or flow-equalizing reservoirs, some form of secondary treatment is normally required in these countries, even in the case of non-food crop irrigation (Pescod, 1992).

Primary sedimentation tanks or clarifiers may be round or rectangular basins, typically 3-5 m deep, with hydraulic retention time between 2 and 3 hours. Settled solids (primary sludge) are normally removed from the bottom of tanks by sludge rakes that scrape the sludge to a central well from which it is pumped to sludge processing units. Scum is swept across the tank surface by water jets or mechanical means from which it is also pumped to sludge processing units.

In large sewage treatment plants, primary sludge is most commonly processed biologically by anaerobic digestion. In the digestion process, anaerobic and facultative bacteria metabolize the organic material in sludge, thereby reducing the volume requiring ultimate disposal, making the sludge stable and improving its dewatering characteristics. Digestion is carried out in covered tanks (anaerobic digesters), typically 7-14 m deep. The residence time in a digester may vary from a minimum of about 10 days for high-rate digesters (well-mixed and heated) to 60 days or more in standard-rate digesters. Gas containing about 60-65% methane is produced during digestion and can be recovered as an energy source. In small treatment plants, sludge is processed in a variety of ways including: aerobic digestion, storage in sludge lagoons, direct application to sludge drying beds, in-process storage as in stabilization ponds, and land application.

2.2.4.3 Secondary treatment

The objective of secondary treatment is the further treatment of the effluent from primary treatment to remove the residual organics and suspended solids. In most cases, secondary treatment follows primary treatment and involves the removal of biodegradable dissolved and colloidal organic matter using aerobic biological treatment processes. Aerobic biological treatment is performed in the presence of oxygen by aerobic microorganisms (principally bacteria) that metabolize the organic matter in the wastewater, thereby producing more microorganisms and inorganic end-products (principally CO_2, NH_3, and H_2O). Several aerobic biological processes are used for secondary treatment differing primarily in the manner in which oxygen is supplied to the microorganisms and in the rate at which organisms metabolize the organic matter.

High-rate biological processes are characterized by relatively small reactor volumes and high concentrations of microorganisms compared with low rate processes. Consequently, the growth rate of new organisms is much greater in high-rate systems because of the well controlled environment. The microorganisms must be separated from the treated wastewater by sedimentation to produce clarified secondary effluent. The sedimentation tanks used in secondary treatment, often referred to as secondary clarifiers, operate in the same basic manner as the primary clarifiers described previously. The biological solids removed during secondary sedimentation, called secondary or biological sludge, are normally combined with primary sludge for sludge processing.

Common high-rate processes include the activated sludge processes, trickling filters or biological filters, and rotating biological contactors (RBC). A combination of two of these processes in series (e.g., trickling filter followed by activated sludge) is sometimes used to treat municipal wastewater containing a high concentration of organic material from industrial sources. These processes are described as follows:

i) Activated sludge systems

In the activated sludge process, the dispersed-growth reactor is an aeration tank or basin containing a suspension of the wastewater and microorganisms, the mixed liquor. The contents of the aeration tank are mixed vigorously by aeration devices which also supply oxygen to the biological suspension. Aeration devices commonly used include submerged diffusers that release compressed air and mechanical surface aerators that introduce air by agitating the liquid surface. Hydraulic retention time in the aeration tanks usually ranges from 3-8 hours but can be higher with high BOD_5 wastewaters. Following the aeration step, the microorganisms are separated from the liquid by sedimentation and the clarified liquid is secondary effluent. A portion of the biological sludge is recycled to the aeration basin to maintain a high mixed-liquor suspended solids (MLSS) level. The remainder is removed from the process and sent to sludge processing to maintain a relatively constant concentration of microorganisms in the system. Several variations of the basic activated sludge process, such as extended aeration and oxidation ditches, are in common use, but the principles are similar. Depending on the loading and process circumstances, the efficiency is about 90-95% removal of BOD (Alaerts *et al*., 1990; Metcalf and Eddy, 1991; Pescod, 1992).

ii) Trickling filters

A trickling filter or biological filter consists of a basin or tower filled with support media such as stones, plastic shapes, or wooden slats. Wastewater is applied intermittently, or sometimes continuously, over the media. Microorganisms (bacteria, fungi, and algae) become attached to the media and form a biological layer or fixed film. Organic matter in the wastewater diffuses into the film, where it is metabolized. Oxygen is normally supplied to the film by the natural flow of air either up or down through the media, depending on the relative temperatures of the wastewater and ambient air. Forced air can also be supplied by blowers but this is rarely necessary. The thickness of the biofilm increases as new organisms grow. As the biomass grows, the influent wastewater flow sloughs off the excess, which settles out in a secondary sedimentation tank and discharged to sludge processing. There is no recycling of sludge for a trickling filter, but there is usually a high effluent recycle ratio to improve hydraulic distribution of the wastewater over the filter (Pescod, 1992).

iii) Lagoons

Lagoons, also called waste stabilization ponds, are often used in moderate or warm climates to remove pollutants such as BOD, nutrients, suspended solids, and pathogens. There are many types of lagoons (Arthur, 1983; Alaerts *et al*., 1990; Saqqar and Pescod, 1990; Pescod, 1992; Mendes *et al*., 1995; Oragui *et al*., 1995; Mayo, 1996):

- *Aerated lagoons* use mechanical equipment to maintain aerobic conditions. Organic matter is degraded by organisms that use oxygen.
- *Anaerobic lagoons* usually are without oxygen for their entire depth. They are the deepest and most heavily loaded (in terms of pollutants) of all the lagoons.
- *Facultative lagoons* usually have longer detention times than aerated lagoons. They are not mechanically aerated. Oxygen is provided through photosynthetic growth of algae in the surface layer of the lagoons. They are designed so that the top of the lagoon is aerobic, while the bottom layers are anaerobic.
- *Maturation ponds* are designed for pathogen removal. Maturation ponds are most effective as a series of ponds in succession.
- *High rate algae ponds* are shallow ponds used as part of an integrated pond system which may include paddle-wheel or axial flow pump mixers to encourage algae growth.
- *Advanced integrated pond system* uses a combination of anaerobic, facultative, high rate algae, settling, and maturation ponds with effluent recirculation to the anaerobic units.

Lagoons are designed to achieve different forms of treatment in up to three stages in series, depending on the organic strength of the influent and the effluent quality objectives. For ease of maintenance and flexibility of operation, at least two trains of ponds in parallel are incorporated in any design. Strong wastewaters (with >300 mg/l BOD_5) will frequently be introduced into first-stage anaerobic ponds, which achieve a high volumetric rate of removal. Weaker wastes or, where anaerobic ponds are environmentally unacceptable, even stronger wastes (e.g. up to 1,000 mg/l BOD_5) may be discharged directly into primary facultative ponds. Effluent from first-stage anaerobic ponds will overflow into secondary facultative ponds which comprise the second-stage of biological treatment. If further pathogen reduction is necessary, maturation ponds will be introduced following primary or secondary facultative ponds to provide tertiary treatment.

Anaerobic lagoons remove about 40-60% of influent BOD. The other types of lagoons can reliably achieve an effluent BOD concentration of 30 mg/l, and even better if designed well. Suspended solids (SS) concentrations are typically higher than 30 mg/l. Some lagoons can achieve final SS concentrations of 20-30 mg/l, however, most can only achieve effluent SS concentrations of 30-90 mg/l. Effluent faecal coliform concentration varies greatly. Detention time, exposure to sunlight, pH, and lagoon geometry all affect coliform removal. If maturation ponds are used as a polishing step, faecal coliform counts as low as 200-400/ml can be reliably achieved without chlorination. Some nitrogen removal is achieved through uptake in algae, and through nitrification and denitrification.

Lagoons are often preferred in developing countries where land is available at reasonable opportunity cost, skilled labor is in short supply, and receiving water effluent quality limitations are not severe (Arthur, 1983; Pescod, 1992). A World Bank report came out strongly in favor of lagoons as the most suitable wastewater treatment system for effluent use in agriculture (Shuval *et al*., 1986). Table 2.3 provides a comparison of the advantages and disadvantages of lagoons with those of activated sludge and trickling filter systems.

Table 2.3: Advantages and disadvantages of various wastewater treatment systems (Arthur, 1983).

Criteria	*Activated sludge systems*			*Trickling filter system*	*Lagoon systems*	
	Activated sludge	*Extended aeration*	*Oxidation ditch*		*Aerated lagoon*	*Waste stabilization pond*
BOD removal	F	F	G	F	G	G
FC removal	P	F	F	P	G	G
TSS removal	G	G	G	G	F	F
Helminth removal	F	P	F	P	F	G
Virus removal	F	P	F	P	G	G
Simple and cheap construction	P	P	F	P	F	G
Simple operation	P	P	F	F	P	G
Land requirement	G	G	G	G	F	P
Maintenance costs	P	P	P	F	P	G
Energy requirement	P	P	P	F	P	G
Sludge removal costs	F	F	P	F	F	G

G = good; F = fair; P = poor.

2.2.4.4 Tertiary and/or advanced treatment

Tertiary and/or advanced wastewater treatment is defined as the additional treatment needed to remove suspended solids and dissolved substances remaining after conventional secondary treatment (Metcalf and Eddy, 1991). As shown in Figure 2.2, individual treatment processes are necessary to remove nitrogen, phosphorus, additional suspended solids, refractory organics, heavy metals, and dissolved solids. Because advanced treatment usually follows high-rate secondary treatment, it is sometimes referred to as tertiary treatment. However, advanced treatment processes are sometimes combined with primary or secondary treatment (e.g., chemical addition to primary clarifiers or aeration basins to remove phosphorus) or used in place of secondary treatment (e.g., overland flow treatment of primary effluent). The principal tertiary treatment processes for wastewater reclamation are (USEPA, 1992): filtration, nitrification-denitrification, phosphorus removal, coagulation-sedimentation, carbon adsorption, and others.

In many situations, where the risk of public exposure to the reclaimed water or residual constituents is high, the objective of the treatment is to minimize the probability of human exposure to enteric viruses and other pathogens. Effective disinfection of viruses is believed to be inhibited by suspended and colloidal solids in the water. Therefore, these solids must be removed by advanced treatment before the disinfection step.

2.2.4.5 Disinfection

Disinfection normally involves the injection of a chlorine solution at the head end of a chlorine contact basin. The chlorine dosage depends upon the strength of the wastewater and other factors, but dosages of 5-15 mg/l are common. Ozone and ultra violet (UV) irradiation can also be used for disinfection but these methods of disinfection are not in common use (Pescod, 1992). Chlorine contact basins are usually rectangular channels designed to provide a contact time of about 30 minutes. However, to meet advanced wastewater treatment requirements, a chlorine contact time of as long as 120 minutes is sometimes required for specific irrigation uses of reclaimed wastewater. The bactericidal effects of chlorine and other disinfectants are dependent upon pH, contact time, organic content, and effluent temperature.

2.2.5 Wastewater reuse

2.2.5.1 General

The collected wastewater must be treated to adjust its quality to any of the following end-uses uses: (i) irrigation, (ii) artificial recharge, (iii) potable water supply, (iv) toilet flushing, and (v) industrial water supply. Reuse of wastewater has been practiced in many areas worldwide for thousands of years. Jordan, Israel, Egypt, Arab Gulf States, Iraq, south western parts of the USA, Greece, Cyprus, Germany, South America, Australia, Poland, Namibia, South Africa, Tunisia, China, and India are countries where wastewater is reused (Mara and Cairncross, 1989). There are two strong economic incentives to reuse reclaimed wastewater: (i) augmentation in regions with water scarcity, and/or (ii) avoiding the cost of the deterioration of the water resources and the environment that would be polluted when receiving un- or partly treated wastewater.

As far as possible, the wastewater from rural and small communities should be reused as well. In those cases, on-site and low cost systems can provide for decentralized collection and treatment of the wastewater. However, in practice in most cases, cesspits and permeable septic tanks are used whose effluents infiltrate into the surrounding soil indiscriminately polluting groundwater, thus jeopardizing public health (Bakir, 2000). Although their effluent is often indirectly partially "reused", this flow must not be accounted for as this practice is not sound. Likewise, direct or indirect irrigation with raw wastewater must not be accounted for as this practice is not in accordance with national and international sound reuse standards (WHO, 1989; EPA, 1991; Rowe and Abdel-Magid, 1995).

2.2.5.2 Reuse for agricultural irrigation

Since the beginning of the 1980s many countries have been using untreated or partially treated wastewater for agricultural irrigation (Thanh and Visvanathan, 1991; Pescod, 1992). Treated wastewater is used for agricultural irrigation directly and indirectly. In direct reuse, the treated effluent is taken from the wastewater treatment plants (WWTPs) to the irrigation site. For example, part of the treated effluents in Tunisia is used to irrigate about 6,750 ha of orchards (citrus, grapes, olives, peaches, pears, apples, and pomegranate), fodder, cotton, cereals, golf courses and lawns. In indirect reuse, the treated effluent is discharged into surface water or groundwater aquifers. The effluents, thus, are deliberately blended with freshwater available in the wadis, dams, rivers, and aquifers and used, on purpose or not, by downstream farmers. In most cases it is used for unrestricted irrigation; reclaimed wastewater can be used for all crops even those consumed raw or uncooked. For example, most of the treated wastewater in Jordan is blended with freshwater from the King Talal Reservoir and used downstream in the Jordan Valley for unrestricted irrigation (Shatanawi and Fayyad, 1996; Faruqui, 2000). In the Dan Region Project of Israel, more than 100 million m^3 of treated wastewater are leached annually to the groundwater aquifer. Water is then pumped by production wells to the main conveyance system and to the distribution network to be used for unrestricted irrigation (Shelef and Azov, 1996; Idelovitch, 2001).

2.2.5.3 Reuse for municipal uses

Municipal wastewater reuse can be divided into three categories: (i) direct potable use, (ii) indirect potable use, and (iii) non-potable use.

i) *Direct potable reuse*. Wastewater is treated to a level that is acceptable for human consumption. Wastewater for direct potable use usually goes through two subsequent treatment processes, conventional and advanced. The city of Windhoek, Namibia, is one of the very few examples of direct reuse, and has had a wastewater reuse program for direct potable use for 25 years. Despite the viability of the treatment technology to produce an acceptable drinking water quality from wastewater, it is unlikely that it will be widely adapted because of the high cost and low public acceptance.

ii) Indirect potable reuse. It is very common and applied through the disposal of treated wastewater into surface or groundwater, which is used downstream as a potable water supply source. Many of the large cities and towns that are located along the major rivers and lakes depend on water from those water bodies for their domestic water supply. These water bodies at the same time receive treated and raw sewage from upstream cities and industries. For instance, the lower reaches of the river Rhine in Germany - which serves as a raw water source for about 600,000 people - often contains 40% of treated wastewater which may rise up to 100% during very low flow periods (Al-Hamdi, 2000). Groundwater recharge with treated wastewater is used in many places in the world, such as Los Angeles and Orange County, California, and El Paso, Texas. The recharged aquifers are usually used as a water supply source (Metcalf and Eddy, 1991).

iii) Non-potable reuse. This includes reuse of reclaimed wastewater for irrigation of landscape, greenbelts, golf courses, public parks, sport fields, in addition to fire fighting, and toilet flushing. The use of reclaimed wastewater for irrigation of landscape, public parks, sport fields, and recreational sites has become a widespread practice. Kuwait uses about 60,000 m^3/d of treated wastewater to irrigate shelterbelts, forestry lots, and greens along the roads (Arar, 1991). Treated wastewater from the city of Abu Dhabi, United Arab Emirates, has been used for irrigation of municipal areas since 1976. In the city of Fukuoka, Japan, an average of 3,300 m^3/d of treated wastewater was used to supply 215 installations with toilet flushing water during 1994 (Asano *et al*., 1996; Maeda *et al*., 1996). In Tunisia, secondary treated effluents are used to irrigate about 900 ha of golf courses, green belts, public parks, and hotel gardens (ONAS, 2001).

2.2.5.4 Reuse for industrial and environmental uses

The availability of well-treated wastewater at comparatively low cost and the scarcity of good-quality natural water are strong incentives for innovative reclamation projects. Reclaimed wastewater is ideal for many industries where processes do not require water of potable quality. Also, industries are often located near populated areas where centralized WWTPs already generate an available source of reclaimed wastewater. Wastewater reuse for industrial purposes is widely practiced in the world. For instance, in the United States, the Bethlehem Steel Company in Baltimore, Maryland, uses approximately 4,380 l/s of treated wastewater for processing and cooling (USEPA, 1992). In Japan, treated wastewater is used since 1951 in the paper industry (Asano *et al*., 1996). In Saudi Arabia, the Riyadh wastewater treatment plant produces over 250,000 m^3/d of effluent, which is among others used as cooling water, process water for crude oil desalting, and for boiler feed water (Arar, 1991).

Reuse of reclaimed wastewater for environmental purposes is becoming a common practice in arid and semi-arid areas, especially in the form of artificial recharge in order to protect groundwater from seawater intrusion. The problem of groundwater degradation resulting from seawater intrusion in Orange County, California, was solved by implementing an artificial recharge project using reclaimed wastewater (Asano, 1985). In the clean stream restoration project in Japan, reclaimed wastewater was supplied to restore the Nobidome irrigation channel. In total 12.4 million m^3 of treated wastewater from the Tomegawa-Joryu treatment plant was devoted to stream augmentation during 1993 (Maeda *et al*., 1996).

2.3 Quantification of achievements in wastewater utilization

2.3.1 Background

Water scarcity has made wastewater reuse more prominent in technical and policy literature as well as in national and international professional meetings. Several indicators are being used to quantify achievements and progress in wastewater reuse. However, until now no standard yardstick exists to measure overall reuse efficiency at a country’s level that meets the following criteria: (i) considers all wastewater production (collected and uncollected), (ii) recognizes the importance of each of these subsequent steps of production, collection, treatment, and use of the wastewater, (iii) allows comparisons within and among countries, and (iv) accounts for wastewater that is utilized through on-site and low cost means. The currently used yardsticks are based only on the amounts of urban wastewater and omit to take account of the wastewater that does not pass through conventional collection and treatment.

To quantify achievements in wastewater reuse, the commonly used indicators are: (i) flow rate (million cubic meters per year), (ii) as percentage of wastewater treated, (iii) as percentage of municipal sewage produced, (iv) as percentage of total tap water supplied, (v) as percentage of urban water supply, (vi) as percentage of agricultural water supply, (vii) as percentage of total area irrigated, and (viii) as area of land irrigated with reclaimed wastewater. For example, reuse efficiency in Israel is assessed in Freidler (2001) as 65% of the municipal sewage production, in Freidler (1999) as 80% of all irrigation water in the Jeezrael Valley, in Shelef and Azov (1996) as 24.4% of the total water supply, in Idelovitch (2001) as 250 million m^3 per year, as 60% of the total urban water supply, as 83% of the treated effluent, and as 20% of the irrigated area. Bahri and Brissaud (1996) assessed reuse efficiency in Tunisia as 6,500 ha of irrigated land and as 15% of the available treated wastewater. Other country examples are shown in Table 2.4. These indicators are useful but are inadequate to capture the potential for and achievements in efficiency improvement.

Table 2.4: Wastewater reuse rates for agricultural irrigation (Khouri *et al*., 1994; Al-Hamdi, 2000).

Location	*Volume reused (million m^3/y)*	*As of total sewage (%)*	*As of total irrigation (%)*
Germany	100	3	10
China	10,000	27	-
Mexico	1,500	100	80
Santiago, Chili	190	100	70

In addition to the above mentioned indicators, the concept of "momentum" for reuse is used sometimes to provide a more qualitative assessment of wastewater reuse efficiency. Some authors reported that the "momentum" for wastewater reuse in the MENA region is still low compared to the potential (Bahri and Brissaud, 1996; Shelef and Azov, 1996; Angelakis *et al*., 1999). Others reported that wastewater reuse in the region is gaining momentum (Thanh and Visvanathan, 1991). The meaning of momentum, in origin, is mass in motion, which refers to a body in a steady state movement; i.e., without acceleration. However, the concept of momentum is used, in those cases, to describe increasing rate of wastewater reuse; i.e., the momentum for reuse is defined as the change in the rate of wastewater being reused. Thus, if no new reuse schemes are implemented, the momentum for reuse will be zero. Likewise, if a high level of reuse has been reached by utilizing most of the produced wastewater, the momentum will be reported as very low. Clearly, this definition is confusing and cannot be used for valid comparisons. For the purpose of policy development and planning, a better indicator would be welcome.

In the above cases also, the "potential" for reuse refers to the amounts of urban wastewater that is being collected and treated through conventional means and possibly would be added to the national water balance (Angelakis *et al*., 1999; Hussain and Al-Saati, 1999; Angelakis and Bontoux, 2001). In our study, the "potential" for reuse is defined as the actual hydraulic capacity of the wastewater resource – i.e., total amount of wastewater production (urban and rural) – combined with the existing enabling environment – i.e., technical, financial, regulatory, institutional, and socio-cultural capacity – to utilize this resource. Quantifying this potential implies assessing the:

- Total production of wastewater.
- Availability of demand/market/users for the reclaimed wastewater.
- Availability of technical skills and financial resources needed to design, construct, operate, and maintain the collection, treatment, and reuse facilities.
- Effectiveness of the regulatory and administrative frameworks.
- Availability of socio-cultural endorsement.

2.3.2 Wastewater Reuse Index (WRI)

An indicator with more potential is the *Wastewater Reuse Index* (*WRI*) which quantifies the total amount of reused wastewater as percentage of the total hydraulic capacity of the wastewater resources (total production of wastewater). It can be used to quantify the gap between achievements in wastewater reuse at different junctures; thus, highlights the way forward for improving the reuse efficiency:

G = total wastewater generation (urban, rural, commercial, and industrial) (million m^3/year),
C = amount of wastewater collected (by sewerage and on-site systems) (million m^3/year),
T = amount of wastewater treated (as effluent from WWTPs and appropriate on-site systems) (million m^3/year),
R = amount of wastewater reused (through irrigation, groundwater recharge, industrial use, potable use, toilet flushing, and acceptable on-site reuse) (million m^3/year),
WRI = Wastewater Reuse Index (%)
x = collection as percentage of total production,
y = treatment as percentage of total collection,
z = reuse as percentage of total treatment.

$$G = f(population,\ specific\ consumption,\ leakage) \quad (2.1)$$

$$C = \frac{x.G}{100} \quad (2.2)$$

$$T = \frac{y.C}{100} \quad (2.3)$$

$$R = \frac{z.T}{100} \quad (2.4)$$

$$WRI = f(R, G) \quad (2.5)$$

$$WRI = \frac{R}{G}.100 \quad (2.6)$$

Combining Equations 2.2 – 2.6,

$$WRI = \frac{z.T}{100.G}.100 = \frac{z.T}{G} = \frac{z.(y.C)}{100.G} = \frac{y.z.(x.G)}{G.10^4} = \frac{x.y.z}{10^4} \quad (2.7)$$

$$WRI = \frac{R}{G}.100 = \frac{x.y.z}{10^4}, \qquad 0 \le WRI \le 100 \quad (2.8)$$

Figure 2.3 gives *WRI* for all possible collection and treatment percentages at four different hypothetical reuse rates (z = 10, 40, 70 and 100%). Low values can be reached with an unlimited number of combinations of x, y, and z (collection, treatment, and reuse rates, respectively). Higher values of *WRI* can be reached only through higher rates of collection, treatment, and reuse, as these three factors are of equal importance in Equation 2.8.

In many MENA countries, the total collection rate through sewerage networks and on-site systems exceeds 90%, except in a few where it is around half this rate (Tables 2.1 and 2.5). Table 2.5 compares the *WRI* in selected MENA countries. Israel has reached a high collection rate of about 95% with 68% treatment of the collected wastewater and 83% reuse of the treated flow (Idelovitch, 2001), thus, with a *WRI* of 53.7%. Potentially, Israel can increase its *WRI* to 95% by increasing the treatment from 68% to 100% and reuse from 83% to 100%, assuming that the production and collection rates are unchanged. If Israel reuses all of its currently treated wastewater, its *WRI* will reach about 65%. High *WRI* values can be reached if the treatment and reuse rates are increased to a level closer to that of collection. For example, Jordan, Tunisia, and Saudi Arabia, respectively, could reach a *WRI* of 99%, 80%, and 100% if all their collected wastewater is treated and reused; Saudi Arabia currently is lagging behind whereas Tunisia and Jordan take a middle position, and Israel is achieving slightly above half of its potential (Table 2.5). All these countries have high collection rates but need to increase their treatment and reuse efficiencies in order to reach such high *WRI* values. This can be achieved by constructing treatment plants and by encouraging on-site management of wastewater at household and community levels in peri-urban and rural areas.

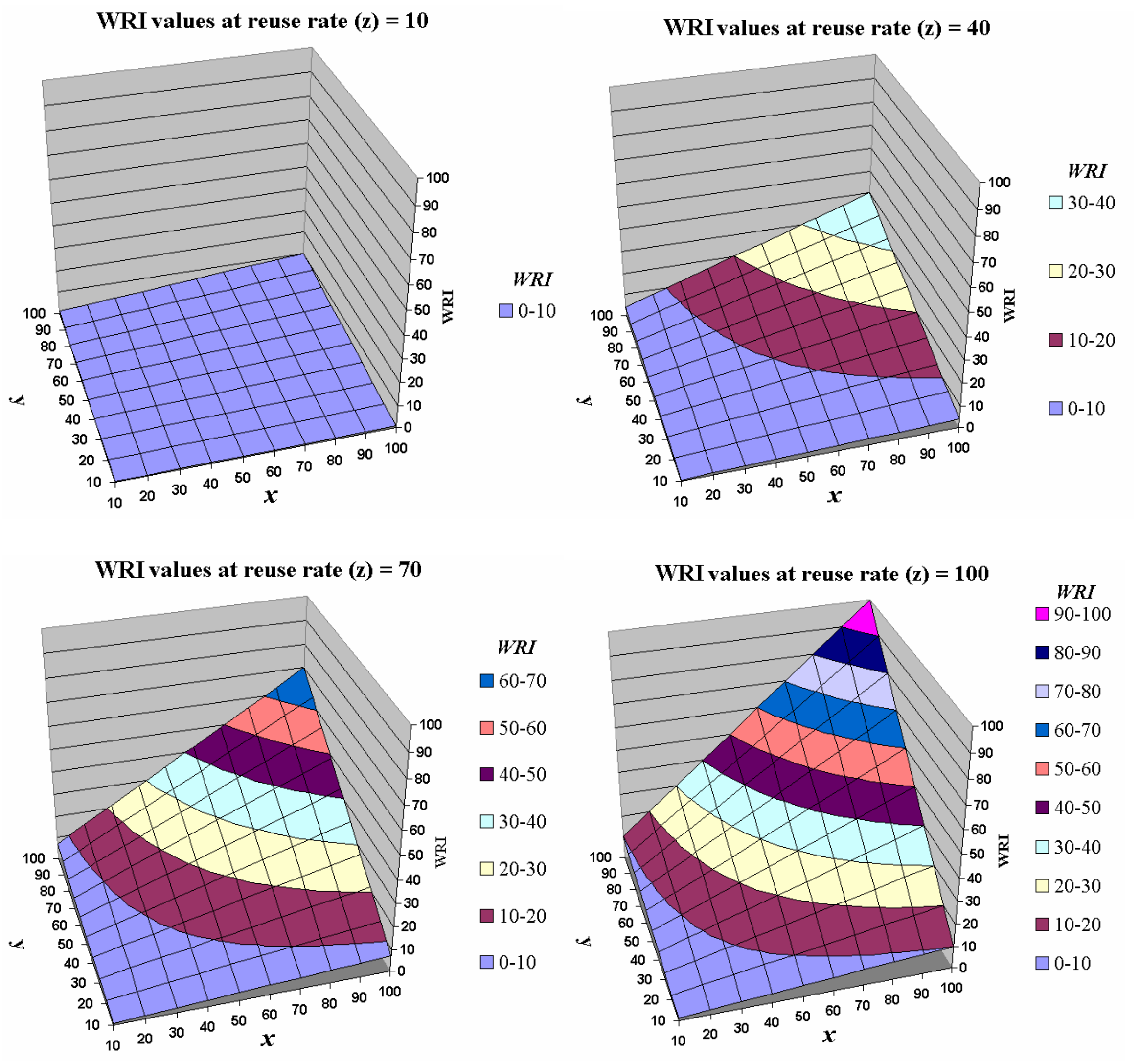


Figure 2.3: Graphical representation of the *WRI* at reuse rates of 10, 40, 70, and 100, respectively.

Table 2.5: *WRI* in selected MENA countries (MWI, 1999; Abu Rizaiza, 1999; Idelovitch, 2001; ONAS, 2001) (flow rates per annum).

Country	*G* (*million* m^3)	*C* (*million* m^3)	*T* (*million* m^3)	*R* (*million* m^3)	*x = C/G* (*%*)	*y = T/C* (*%*)	*z = R/T* (*%*)	*WRI* (*%*)
Israel	464	440	300	249	95	68.2	83.0	53.7
Jordan	241	239	80	67	99	33.5	83.8	27.8
Tunisia	395	316	148	50	80	46.8	33.8	12.7
Saudi Arabia	1,347	1,347	292	92	100	21.7	31.5	6.8

G: production; C: collection; T: treatment; R: reuse; WRI: Wastewater Reuse Index.

The major features of the *WRI* are: (i) it includes the early-mentioned criteria for a standard yardstick, (ii) it enables water resource managers and policy makers to put a figure on the gap between achievements at different junctures, and (iii) it recognizes water saving efforts such as low water consumption and reducing losses.

2.4 The incentive systems for improved utilization of reclaimed wastewater

As mentioned previously, most countries of the region have reasonably high rates of wastewater collection, which is driven by urbanization, public health, and environmental incentives. Thus, the low *WRI* values and the imbalance (failure) in the reclaimed-wastewater market are mainly due to low rates of wastewater treatment and/or reuse. For reuse, however, disincentives tend to be stronger than incentives because reuse offers direct benefit to a lower number of groups only, i.e., farmers and water resource managers.

This study, therefore, will focus on the factors (incentive systems) that may influence the decision making on wastewater treatment and reuse in irrigated agriculture and, thus, contribute to balancing the reclaimed-wastewater market in the MENA countries (Figure 2.4). Theses incentives and disincentives may be of one or more of the forms shown in Table 2.6, which are investigated in the forthcoming Chapters. It is worth mentioning that the "externalities" [2] that are defined by economists in reference to market failures are part of the incentive systems (Bowers and Young, 2000; Young, 2000; Simpson, 2003).

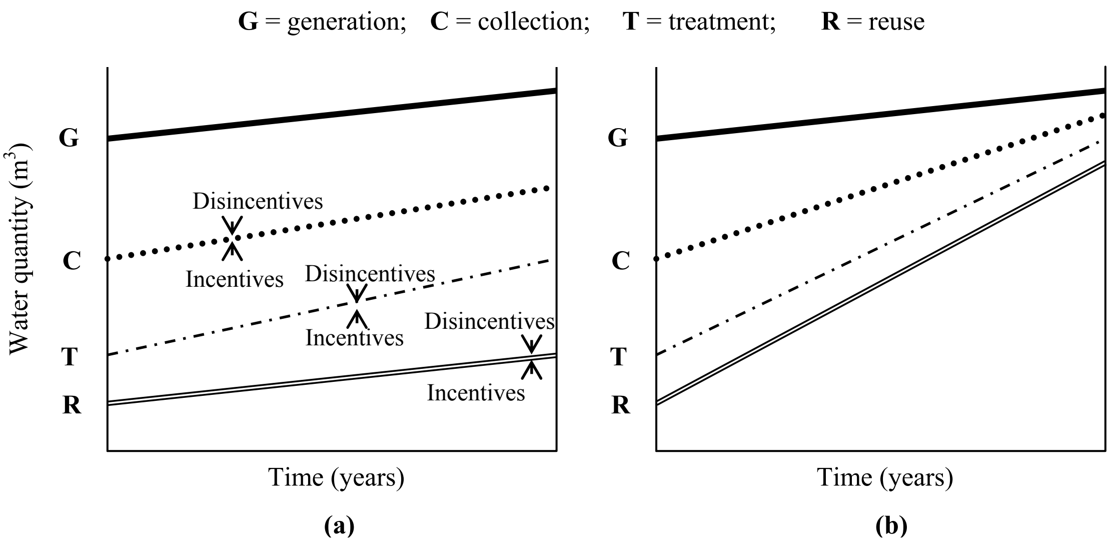


Figure 2.4: Effect of incentives and disincentives on the rates of collection, treatment, and reuse; (**a**) low *WRI* or unbalanced market; (**b**) high *WRI* or balanced market.

[2] An externality is defined as a cost or benefit that arises from an economic transaction that falls on people who do not participate in the transaction; activity that creates side-effects ignored by the producer (Jordan, 1998; Mc Taggart *et al*., 1999; Van Bueren and MacDonald, 2004). The recipient of the externality is neither compensated for the cost imposed on him, nor does he pay for the benefit bestowed upon him. These costs and benefits are labeled "externalities" because the people who experience them are outside or external to the transaction to buy and sell the good or service (Simpson, 2003).

Table 2.6: Typical (dis)incentives that may influence wastewater treatment and/or reuse.

Technical
• (In)capability to design and provide O&M for different treatment and reuse systems • Performance of the wastewater treatment systems • Availability/lack of materials and skills • Availability/lack of external support • Availability/lack of seasonal storage of water for irrigation • Availability/lack of infrastructure for conveyance and distribution of the reclaimed wastewater • Effects on quality of crops and soil • Effects on irrigation equipment
Financial
• Capital and operational costs • Availability/lack of funds • Effectiveness of cost recovery • Cost and tariff of reclaimed wastewater and freshwater • Fertilizer saving • Profitability to farmers
Economic
• Employment opportunities • Avoided costs from environmental degradation • Better land use • Saving some water from agriculture for municipal and industrial uses • Availability/lack of subsidies • Reliance on imports
Public health
• Health risks to workers, farmers, public, and crop consumers
Environmental
• Public nuisance due to smell/odor • Effects on water resources and aquaculture • Farmers may use excess fertilizers
Socio-cultural and religious
• The Islamic religion imposes restrictions against the wastewater handling without proper treatment • Farmers and crop consumers may accept or reject to use reclaimed water and related crops, respectively • Reuse may require changing farming traditions • Farmers irrigating with treated wastewater may face public criticism • Availability/lack of farmers' and public awareness
Regulatory, legislative, and Institutional
• Stringency/flexibility of quality standards and cropping restriction/freedom • Number, responsibility, and strength/weakness of the managing institutions • Availability/lack of enforcement that abandon irrigation with freshwater within the reuse area • Availability/lack of farmers' associations and farmers' involvement • Role of influencing people in the community • Level of private sector involvement
Political
• Location of the WWTPs • Regional sharing of water resources • Role of local politics on cost recovery and reallocation of water resources

2.5 Conclusions and recommendations

To better understand the research problem, wastewater is considered as a commodity whose market comprises (i) a supply side that refers to wastewater production, collection, and treatment, (ii) a demand side that refers to wastewater reuse, and (iii) market control and monitoring that refer to the regulatory and institutional framework. In most countries of the region, the reclaimed-wastewater market is unbalanced. The supply is growing – demonstrated by high rates of wastewater production and collection, and medium rates of treatment – against a stagnant demand – demonstrated by the large proportions of treated wastewater that are discharged into the water bodies. The high rates of collection are driven by urbanization, health, and environmental incentives. Thus, improved wastewater utilization and balancing the reclaimed-wastewater market are conditional to maximized rates of treatment and reuse.

The currently-used indicators to quantify achievements in wastewater reuse account for only the reused amounts of wastewater from urban treatment plants and omit to include that from rural communities. They do not enable valid comparisons between and within countries. The concept of "momentum" for wastewater reuse that is sometimes used to provide a semi-quantification of reuse can be misleading. Likewise, the concept of "potential" for wastewater reuse often refers to the amount of wastewater that could be included in the water resources management. In this study, the potential for wastewater reuse refers to total hydraulic capacity of the wastewater resources – which is the total production of wastewater from urban and rural areas – combined with the enabling environment for the utilization of the produced wastewater.

Here, we suggest another indicator that is more inclusive and takes into account the contribution of each component in a reuse scheme: collection, treatment, and reuse. This indicator is called Wastewater Reuse Index (*WRI*) which quantifies reuse as a percentage of the total production of wastewater. In the MENA region, Saudi Arabia has a low *WRI*, while Tunisia and Jordan have a medium *WRI*. Although Israel has the highest *WRI* it is still only half of its potential. Each component of the *WRI* depends upon a large number of incentives and disincentives that will be assessed and analyzed in forthcoming chapters.

2.6 References

Abu Rizaiza, O. (1999). Modification of the standards of wastewater reuse in Saudi Arabia. *Wat. Res.*, **33**(11): 2601-2608.

Alaerts, G., Blair, T., and Hartvelt, F. (1991). A Strategy for water sector capacity building. IHE report series 24, Delft, The Netherlands.

Alaerts, G., Veenstra, S., Bentvelsen, M., van Duijl, L. A., *et al.* (1990). Feasibility of anaerobic sewage treatment in sanitation strategies in developing countries. IHE report series no. 20, Delft, The Netehrlands.

Al-Hamdi, M. (2000). Competition for scarce groundwater in Sana'a plain, Yemen: a study on the incentives system for urban and agricultural water use. PhD thesis, IHE-Delft, The Netherlands.

Angelakis, A. and Bontoux, L. (2001).Wastewater reclamation and reuse in Eureau countries. *Water Policy*, **3**: 47-59.

Angelakis, A., Marecos, M., Bontoux, L. and Asano, T. (1999). The status of wastewater reuse practice in the Mediterranean basin: Need for guidelines. *Wat. Res.*, **33**(10): 2201-2217.

Arar, A. (1991). Wastewater reuse for irrigation in Near East region. *Wat. Sci. Tech.*, **23**: 2127-2134

Arthur, J. P. (1983). Notes on the design and operation of waste stabilization ponds in warm climates of developing countries. Urban Development Technical Paper no. 7. World Bank, Washington, D.C.

Asano, T., Maeda, M., and Takaki, M. (1996). Wastewater reclamation and reuse in Japan: overview and implementation examples. *Wat. Sci. Tech.*, **34**(11): 219-226.

Bahri, A. (1998). Fertilizing value and pollution load of reclaimed water in Tunisia. *Wat. Res.*, **32**(11): 3484-3489.

Bahri, A. and Brissaud, F. (1996). Wastewater reuse in Tunisia: Assessing a national policy. *Wat. Sci. Tech.*, **33**(10-11): 87-94.

Bakir, H. (2000). Guiding principles and options for accelerated extension of wastewater management services to small communities in EMR countries. World Health Organization. Regional Office for the Eastern Mediterranean. Regional Center for Environmental Health Activities (CEHA). December 2000, Amman, Jordan.

Bowers, J. and Young, M. (2000). Valuing externalities: A methodology for urban water use. Ref. 01/1323, Task 1.3.2 Externalities, Policy and Economic Research Unit, CSIRO Urban Water Program.

Faruqui, N. (2000). Wastewater treatment and reuse for food and water security. IDRC. Ottawa, Canada. www.idrc.ca/waterdemand/SpecialPapers_e.html

Freidler, E. (1999). The Jeezrael Valley project for wastewater reclamation and reuse, Israel. *Wat. Sci. Tech*., **40**(4-5): 347-354.

Freidler, E. (2001). Water reuse – an integral part of water resources management: Israel as a case study. *Water Policy*, **3**: 29-39.

Hussain, G. and Al-Saati, A. (1999). Wastewater quality and its reuse in agriculture in Saudi Arabia. *Desalination*, **123**: 241-251.

Idelovitch, E. (2001). Wastewater reclamation for irrigation: The Dan Region Project in Israel. Prepared for the World Bank, Washington.

Jamrah, A. (1999). Assessment of characteristics and biological treatment technologies of Jordanian wastewater. *Bioprocess Engineering*, **21**: 331-340.

Jordan, J. (1998). An introduction to water: Economic concepts, water supply and water use in the US. Georgia Water Series, Issue 1, Faculty Series 98-13, Department of Agricultural & Applied Economics, University of Georgia.

Khouri, N., Kalbermatten J., and Bartone, C. (1994). The reuse of wastewater in agriculture: A guide for planners. UNDP - World Bank Water and Sanitation Program. Washington, DC., The World Bank.

Maeda, M., Nakada, K., Kawamoto K., and Ikeda, M. (1996). Area-wide use of reclaimed water in Tokyo, Japan. *Wat. Sci. Tech*., **33**(10-11): 51-57.

Mara, D. and Cairncross, S. (1989). Guidelines for the safe use of wastewater and excreta in agriculture and aquaculture: Measures for public health protection. WHO, Geneva.

Mayo, A.W. (1996). BOD_5 removal in facultative ponds; experience in Tanzania. *Wat. Sci. Tech*., **34**(11).

Mc Taggart, D., Findlay, C., and Markin, M. (1999). Economics. 3rd Edition, Addison Wesley Longman, South Melbourne.

Mendes, B. S., Nascimento, M. J., Pereira. I. M., Bailey, G., Lapa, N., Morais, J., and Oliveira, J. S. (1995). Efficiency of removal in stabilization ponds I: Influence of climate. *Wat. Sci. Tech.*, **31**(12): 219-229.

Metcalf and Eddy Inc. (1991). Wastewater engineering: Treatment, disposal, and reuse. McGraw-Hill International. Third Edition.

Mills, R. and Asano, T. (1996). A retrospective assessment of water reclamation projects. *Wat. Sci. Tech*., **33**(10-11): 59-70.

MWI. (1999). Annual report of the Ministry of Water and Irrigation. Amman.

ONAS. (2001). Annual report of the National Agency for Sewerage. Tunisia.

Oragui, J., Arridge, H., Mara, D. D., Pearson, H. W., and Silva, S. A. (1995). Rotavirus removal in experimental waste stabilization pond systems with different geometrics and configurations. *Wat. Sci. Tech.*, **31**(12): 285-290.

Oron, G., Campos, C., Gillerman, L., and Salgot, M. (1999). Wastewater treatment and reuse for agricultural irrigation in small communities. *Agricultural Water Management*, **38**: 223-234.

Pescod, M. B. (1992). Wastewater treatment and use in agriculture. FAO irrigation and drainage paper no. 47. Food and Agriculture Organization of the United Nations, Rome, Italy.

Rowe, D. R., and Abdel-Magid, I. M. (1995). Handbook of wastewater reclamation and reuse. Lewis Publishers, USA.

Saqqar, M. M. and Pescod, M. B. (1990) Microbiological performance of multi-stage stabilization ponds for effluent use in agriculture. *Wat. Sci. Tech*., **23**:1517-1524.

Shatanawi, M. and Fayyad, M. (1996). Effect of Khirbet As-Samra treated effluent on quality of irrigation water in the Central Jordan Valley. *Wat. Res*., **30**(12): 2915-2920.

Shelef, G. and Azov, A. (1996). The coming era of intensive wastewater reuse in the Mediterranean region. *Wat. Sci. Tech*., **33**(10-11): 115-125.

Simpson, B. (2003). Why externalities are not a case of market failure. A paper based on a chapter of a forthcoming book titled Markets Don't Fail, National University, Department of Business, La Jolla.

Tchobanoglous, G. and Burton, F. (1991). Wastewater engineering: treatment, disposal, and reuse. Metcalf and Eddy, Inc. McGraw-Hill, Inc.

Thanh, N. and Visvanathan, C. (1991). Wastewater reuse gains momentum in Mediterranean and Middle East regions. Wastewater: 19-26, WWI/February 1991.

USEPA. (1991). Alternative wastewater collection systems: Manual. US Environmental Protection Agency, U.S. Agency for International Development, Washington, DC. USA.

Van Bueren, M. and MacDonald, D. (2004). Addressing water-related externalities: Issues for consideration. Paper presented at a Water Policy Workshop convened by the Australian Agricultural and Resource Economics Society, 10th February 2004, Melbourne.

WHO. (1989). Health guidelines for use of wastewater in agriculture and aquaculture. Report of a WHO scientific group. Technical report series, no. 778. WHO, Geneva.

WHO. (2000). Global water and sanitation assessment 2000. Report.

Young, M. (2000). Managing externalities: Opportunities to improve urban water use. Ref. 01/1324, Task 1.3.2 Externalities, Policy and Economic Research Unit, CSIRO Urban Water Program.

Chapter 3: The Study Area

3.1 Jordan

3.1.1 Population, topography, and climate

The population of the Hashemite Kingdom of Jordan was approximately 4.5 millions in 1998, with a comparatively high growth rate of about 3.6%. Jordanians are Arabs, except for a few small communities of Circassians, Armenians, and Kurds, which have adapted to Arab culture. The official language is Arabic, but English is used widely in commerce and government. About 70% of Jordan's population is urban; less than 6% of the rural population is nomadic or semi-nomadic. About 1.5 million Palestinians are registered as refugees and displaced persons residing in Jordan. About 95% of the Jordanians are Sunni Muslims, while 5% are Christians. The settlement pattern is heavily influenced by the uneven distribution of natural water resources. About 91% of the total population lives in the northwestern part of the country, with 52% living in Amman and Zarqa area (NIS, 2003). The development indicators for Jordan are given in Annex B.2.

Jordan is an arid to semi-arid Middle Eastern country with a land area of 89,556 km^2. It is bordered by Syria in the north, Iraq in the northeast, Saudi Arabia and the Gulf of Aqaba in the east and south, and Israel, West Bank (disputed), and the Dead Sea in the west. Jordan's topographic features vary. A mountainous chain runs from the north to the south of the country. To the east of these mountains, gentle slopes lead to the eastern deserts. To the west, the land declines steeply towards the Jordan Rift valley. The Jordan Rift valley extends from Tiberias Lake in the north, at ground elevation of -220 m, to the Red Sea at Aqaba. The southern Ghors and Wadi Araba, south of the Dead Sea, form the southern part of the Rift valley. To the south of Wadi Araba region a coastline of 25 km stretches along the northern shores of the Red Sea (Al-Weshah, 2000; MWI, 2000; EMWIS, 2001; NIS, 2003). The map of Jordan is provided in Annex A.3.

The climate of Jordan is marked by sharp seasonal variations in both temperature and precipitation. Summer's maximum temperatures average 32 ^oC for the highlands and 38 ^oC for the Jordan Valley and the eastern deserts. Winter's maximum temperatures average 14-17 ^oC in the highlands and the desert areas, and 21 ^oC in the Jordan Valley. Winter's minimum temperatures average is 1-4 ^oC in the highlands and desert area with occasional snowfalls on the highlands, while it rarely falls below 8 ^oC in the Jordan Valley (MWI, 2000; NIS, 2003).

Due to the variable topographic features of Jordan, the distribution of rainfall varies considerably with location. Rainfall intensities vary from 600 mm in the northwest to less than 200 mm in the eastern and southern deserts that form about 91% of the surface area. The average total quantity of rainfall that falls on Jordan is about 7,200 million m^3/year, but this varies between 6,000 and 11,500 million m^3/year. About 15% of the rainfall reaches rivers and wadis as flood flows and groundwater recharge, while 85% of the rainfall evaporates.

Groundwater recharge is about 4% of the total rainfall, while surface water is about 11% of the rainfall (MWI, 2000).

3.1.2 Water resources

3.1.2.1 General

Jordan is facing a chronic imbalance between its the population and water demand on one side, and the water resources on the other. The per capita water availability was 160 m^3 in 1997 (MWI, 1998; Al-Weshah, 2000; EMWIS, 2001). Renewable water resources include 277 million m^3/year of groundwater and 692 million m^3/year of surface water. An additional 143 million m^3/year is estimated to be available from fossil aquifers. Brackish aquifers are not yet fully explored but at least 50 million m^3/year is expected to be accessible for urban uses after desalination. The renewable water resources fall short of meeting actual demand, as seen from the increase in food imports; in 1996 the deficit in food balance reached US$ 110/capita (MWI, 1998). Despite the huge investment in the water sector, the water deficit will still be considerable in the coming years. The projected water deficit for all uses is 408 million m^3 in 2020 (Table 3.2). Agricultural irrigation dominates water use with 71% of the existing water resources as shown in Figure 3.1 and Table 3.1.

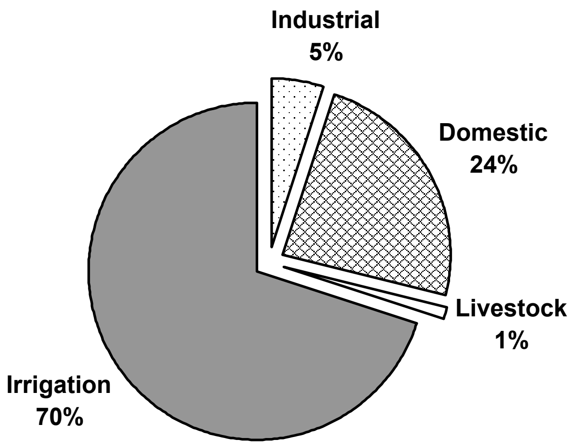


Figure 3.1: Sectoral distribution of water consumption in Jordan during 1998 (Jaber and Mohsen, 2001).

Table 3.1: Sources of water used in Jordan in 1997 (EMWIS, 2001; MWI, 2003).

Source	*Uses (million m^3)*				*Total uses (million m^3)*
	Domestic	*Industrial*	*Irrigation*	*Livestock*	
Surface water:	*58.0*	*1.9*	*264.5*	*4.0*	*328.5*
- Jordan Rift Valley	38.4	1.9	194.5	0.0	234.8
- Springs	19.6	0.0	* 30.0	0.0	49.6
- Flood	0.0	0.0	* 40.0	* 4.0	44.0
Groundwater:	*177.6*	*35.3*	*266.2*	*7.1*	*486.2*
- Renewable	168.7	31.6	207.1	6.0	413.4
- Nonrenewable	8.9	3.8	59.1	1.1	72.9
Reclaimed wastewater:	*0.00*	*0.0*	*61.0*	*0.0*	*61.0*
- Registered	0.00	0.0	57.3	0.0	57.3
- Not registered	0.00	0.0	3.7	0.0	3.7
Total	*235.6*	*37.2*	*591.7*	*11.1*	*875.7*

* Estimated.

Table 3.2: Projected water supply, demand, and deficit (million m^3) (EMWIS, 2001).

Year	*Supply*	*Demand*	*Deficit*
1995	882	1,104	222
2000	960	1,257	297
2005	1,169	1,407	238
2010	1,206	1,457	251
2015	1,225	1,550	325
2020	1,250	1,658	408

Jordan shares some of its most important water resources with neighboring countries such as Israel, Palestine (disputed), Lebanon, and Syria. These resources form a large percentage of the presently exploited water resources, on which the country depends for meeting present and future demands. One of the most important shared surface water resources is the Jordan River system. The Jordan River, which forms Jordan's border with Israel and the West Bank (disputed), is the heart of the country's drainage system. The river rises in Syria and flows straight south into the Dead Sea. Most of Jordan's freshwater is supplied by the Jordan River, which is also an important source of water for Israel and Lebanon. Before the Six-Day War with Israel in 1967, Jordan controlled the West Bank that is irrigated by underground springs and aquifers. After this war, Jordan lost this important source of water and half of its arable farmland. Plans to irrigate other parts of the country by diverting the Jordan River were abandoned after the West Bank was occupied by Israel. However, Jordan began to cooperate with neighboring countries to manage the region's water resources. In 1994, the leaders of Jordan and Israel signed a comprehensive peace treaty. As part of the agreement, Israel committed to supply Jordan with 50 million m^3/year of water, mostly by diverting flows from the Jordan River.

Another important shared water resource includes the groundwater of north Jordan (Azraq, Yarmouk, Amman, and Zarqa basins), where a large percentage of the natural recharge occurs in the Syrian territories.

3.1.2.2 Surface water

At present, surface water resources average about 692 million m^3 distributed unevenly in 15 basins, with high inter-seasonal and inter-annual variations. The average base flow for all basins is about 359 million m^3/year, while flood flow is estimated at 334 million m^3/year. The Yarmouk River Basin accounts for about 40% of the annual total surface water. This river is the major supplier of water to the King Abdullah Canal (KAC) that is the backbone of the irrigation system in the Jordan Valley. KAC was built in several stages from 1959 to 1989 and stretches over a total length of 110 km from the Yarmouk River at Adassiya to almost at the shores of the Dead Sea. KAC is basically lined and open canal, with a maximum width of 11.30 m, a maximum water depth of 2.80 m, and a maximum conveyance capacity of approximately 20 m^3/s. The canal irrigates about 23,710 ha of arable land. The water resources for KAC comprise from the Yarmouk River (48%), from the conveyer from Lake Tiberias (24%), from King Talal Dam (KTD) (15%), from Mukheibeh wells (5%),from the side wadis in the northern part of the valley (4%), and from the side wadis in the southern part of the valley (4%). In addition, about 745 ha are irrigated directly from other sources such as KTD and Hisban Kafrin Dam (Shatanawi and Salman, 2002; MWI, 2003).

In the rivers and wadis delivering the water resources to the conveyance system, there are six retention reservoirs, with a total storage capacity of 165 million m^3. Five of these reservoirs hold the surplus discharge of their respective rivers and have a total storage capacity of 110 million m^3. The sixth is the Karamah Dam (55 million m^3), which is an intermediate reservoir that is filled with surplus water from other water sources conveyed by the KAC in winter.

Other surface resources include the Zarqa River and several wadis that run west from the highlands to the Jordan Rift area. The Zarqa River flow is augmented by treated wastewater from Al-Samra and other plants serving Amman and Zarqa areas. In 2000, about 500 million m^3 of surface water had been developed for irrigation, municipal, and industrial uses. Full development has been impeded by regional political considerations, riparian water use rights of the Yarmouk River, and the high cost to develop and transport the remaining sources of water. The Jordanian Government has extensively developed surface water resources in Jordan with the priority being given to the construction of dams and irrigation projects for maximizing the utilization of its water resources before they get discharged into the Dead Sea and the Jordan River (Taha and Bataineh, 2002). Table 3.3 shows the characteristics of the major dams in the Jordan Valley. There are many other dams in the uplands that in total have a capacity of about 32 million m^3.

Table 3.3: Major dams in the Jordan Valley (MWI, personal contact).

Dam	*King Talal*	*Wadi Arab*	*Kafrein*	*Shueib*	*Ziglab*	*Karameh*	*Tannur*
Location	Eastern Heights	JV	JV	JV	JV	JV	Southern Ghours
Completion date	1977-87	1986	1967-97	1969	1967	1997	2001
Height (m)	108	83.5	37	32	48	44.5	60
Length at crest (m)	350	434	552	730	745	2150	270
Width at crest (m)	11.5	8.5	6	5	6	10	8
Elevation at crest (msl)	185	-101	-117.5	-165	-129	-294.5	400
Storage capacity (million m^3)	*86*	*20*	*11*	*2.3*	*4.3*	*55.1*	*16.8*
Water use	Irrigation, electricity	M&I, irrigation	Irrigation	Irrigation, recharge	Irrigation	Irrigation	Irrigation
Total cost (million JD)	*34*	*20*	*9.3*	*0.56*	*0.9*	*55*	*23.3*

3.1.2.3 Groundwater

Groundwater is considered to be a major source of water in Jordan, and the only source in some areas of the country. Twelve groundwater basins have been identified in Jordan. Most basins are comprised of several groundwater aquifer systems. Approximately 80% of Jordan's known groundwater reserves are contained in three main aquifer systems: (i) Amman-Wadi Sir, (ii) Basalt, and (iii) Rum (MWI, 2003).

The long-term safe yield of renewable groundwater resources has been estimated at 277 million m^3/year. Some of the renewable groundwater resources are presently exploited to their maximum capacity and in some cases beyond safe yield. Overexploitation of groundwater aquifers, beyond the annual replenishable quantities, has and will contribute significantly to the degradation of groundwater quality and/or quantity in the exploited aquifers, and endangers the sustainability of these resources for future use. The main non-renewable groundwater resource in Jordan exists in the Disi aquifer in the South, with a safe yield of 125 million m^3/year for 50 years. Other non-renewable groundwater resources are estimated at an annual safe yield of 18 million m^3 (Taha and Bataineh, 2002).

Irrigated agriculture in Jordan depends on groundwater, particularly in the uplands where most agricultural wells exist. Exploitation of groundwater for agricultural purposes in Jordan has been in practice since the 1960s. At the beginning, pilot wells were dug by government authorities. Individual citizens and the private sector obtained licenses to dig wells and exploit groundwater for growing vegetables and trees in the desert lands at the expense of renewable and non-renewable groundwater resources. The Government's policy to permit the digging of agricultural wells was to encourage the citizens in the desert and villages to stay on their lands and engage in agriculture so as to limit migration to the main cities and seeking governmental jobs.

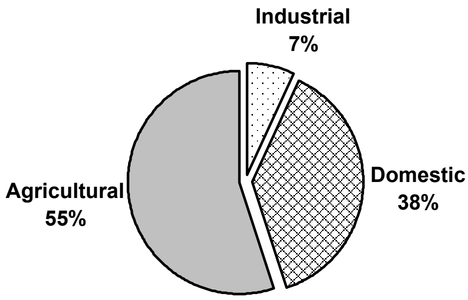


Figure 3.2: Groundwater use in Jordan (Bataineh *et al*., 2003).

Table 3.4: Groundwater extraction and number of operating wells in Jordan in 2000 (Hadidi, 2002).

Quantity of water 1,000 m^3	*Operating wells*		*Quantity of extracted water (million m^3)*
	Number	*%*	
<50	617	34.9	13.5
50-100	439	24.9	32.9
100-200	472	26.7	68.3
>200	235	13.3	105.8
Total	*1,763*	*100*	*220.5*

In the 1960s, digging was carried out randomly since geographical and hydrological information on most of aquifers was rare. Digging operations were carried out only in the areas where shallow groundwater exists such as the Jordan Valley and Al-Azraq basins. Later, digging of agricultural wells was brought under control when licenses were required and data was collected. This situation continued until 1977 when the Groundwater Control Regulation was issued to regulate the licensing of agricultural wells. In 1992, after studying and evaluating the status of water basins, digging agricultural wells was prohibited in all parts of the country. Nonetheless, the total number of agricultural wells, which was 1,627 in 1995, has increased to 1,763 in 2000 (Table 3.4). Since 1994, MWI has been installing water meters on most of the agricultural wells. Meters of the same type and origin have been installed so that maintenance and replacement can be easily made either at the cost of the Ministry or of the owners of these wells (Hadidi, 2002).

3.1.2.4 Non-conventional water resources

Different non-conventional water resources are considered for water supply in Jordan. These resources include reuse of treated wastewater, rainwater harvesting, importation of water from across the national border, and desalination of brackish and seawater. Moreover, water conservation and demand management options are being considered as a means to address the water crisis in the country. These resources can be briefly described as follows (Al-Jayyousi, 1995; MWI, 1999; Jaber and Mohsen, 2001):

- *Reclaimed wastewater*. Jordan is recognized as one of the pioneer countries in the region that utilize their wastewater efficiently. Out of 79.5 million m^3 that was treated at 17 WWTPs in year 1999, about 67 million m^3 was indirectly used for irrigation in different parts of the country. About 52 million m^3 was indirectly used for unrestricted irrigation in the Jordan Valley after blending with freshwater in wadis and KTD. About 15 million m^3 was directly used for restricted irrigation indoor and within the surroundings of existing WWTPs.
- *Rainwater harvesting*. Rainwater collection and storage schemes on large and/or small scale play an important role in securing sustainable water supplies in the Kingdom. It is estimated that about 6 million m^3 were collected in 2000, which is expected to reach about 9 million m^3 in 2010.
- *Water import*. Preliminary studies have been conducted to assess the possibilities of importing water to Jordan. A study was completed in 1983 to import 160 million m3 from the Euphrates River in Iraq to supply the northern part of the country. Another major water import project is the Turkish Peace Pipeline, which is intended to divert the water of the Ceyhan and Seyhan Rivers in southern Turkey to supply Jordan and other countries with the freshwater. The major concerns with regard to water import are political uncertainty and security of supply as well as high capital expenditures encountered in such multi-national projects.
- *Desalination*. Two main sources are available to be desalted: the Gulf of Aqaba and the brackish water in some closed basins. Preliminary studies showed that by the year 2010 more than 20 million m^3 of brackish water would be developed in central Jordan. This figure would reach 70 million m^3 in 2040.

3.1.3 Agriculture

Only four percent of Jordan's land is arable but agricultural production is constrained by water shortage. The potential land area suitable for irrigated cultivation is estimated at around 840,000 ha. However, the potentially available water resources, limit the irrigation potential to about 85,000 ha, including the area currently irrigated. Although irrigation has been reported to be used in Jordan for a very long time, particularly in the Jordan Valley, intensive irrigation projects have been implemented only since 1958 when the Government decided to divert part of the Yarmouk River water and constructed the KAC. The construction of dams on the side wadis and the diversion of the flows from other wadis have allowed the development of irrigation over a large area. At the same time, wells were drilled in the Jordan Valley to abstract groundwater, not only for domestic purposes but also for irrigation (FAO, 1997).

Apart from in the Jordan Valley, irrigation is also reported to take place in the highlands. The irrigation system there relies on wells (100-5,000 m deep) and pumps which deliver water to the agricultural land (FAO, 1997). There are three types of irrigated farming entities in these areas:

- Private holders who have received loans from the Agriculture Credit Corporation for drilling, pumps, and farm irrigation systems.
- Bedouin settlement irrigation projects operated and maintained by the Ministry of Agriculture and the Water Authority.
- Private companies operating large-scale projects in the southeast of the country.

All types of horticulture can be found in Jordan. Cultures under plastic greenhouses and in the open (vegetables, strawberry, flowers) as well as citrus, banana, grapes, and date palm, are all concentrated in the Jordan Valley. Fruit trees, mainly olives, grapes, peaches, apples, and figs are grown in the uplands along the eastern mountains and in the eastern and southeastern parts of the country. Vegetable growing is practiced in all regions. Table 3.5 summarizes the irrigated areas in the Jordan Valley and the uplands.

Table 3.5: Irrigated and non-irrigated areas under tree crops, field crops, and vegetables in Jordan (in 2000).

Crops	*Total area (1,000 ha)*			*Irrigation area (1,000 ha)*			*Non-irrigated area (1,000 ha)*		
	*JV**	*Uplands*	*Jordan**	*JV*	*Uplands*	*Jordan*	*JV*	*Uplands*	*Jordan*
Tree crops	11.16	75.78	86.95	11.00	23.82	34.82	0.16	51.97	52.13
Field crops	4.00	108.67	115.58	3.80	4.33	11.03	0.21	104.34	104.55
Vegetables	17.36	15.52	32.88	17.18	13.88	31.06	0.18	1.64	1.82

* JV: Jordan Valley; summations do not match due to rounding.
Source: Department of Statistics, 2001.

Agriculture contributed substantially to the economy at the time of Jordan's independence, but it subsequently suffered a decades-long steady decline. In the early 1950s, agriculture constituted almost 40% of GDP; after the 1967 War, it was 17% and by mid 1980s, it was only about 6%. Several factors contributed to this downward trend: (i) loss of prime farmland after the Israeli occupation of the West Bank, (ii) labor emigration in the mid-1970s, (iii) population increase and urban expansion, that reduced the area of land available of agriculture, and (iv) land tenure being not an important concern in Jordan, more than 150,000 foreign laborers, mainly Egyptians, worked in farming in 1988. After irrigating the Jordan Valley in the early 1960s and subdividing plots of larger than 20 ha into 3-5 ha plots, the contribution of agriculture to the economy started to increase. Nowadays, agriculture contributes less than 10% of GDP, and agro-business in general contributes 20% of GDP (Abuirmeileh, 1987; Al-Weshah, 2000).

Although the agricultural sector's share of GDP declined in comparison with other sectors of the economy, farming remained economically important and production grew in absolute terms. Between 1975 and 1985, total production of cereals and beans rose by almost 150%, and production of vegetables rose by more than 200%, almost all of the increase occurred between 1975 and 1980. Production of certain cash export crops, such as olives, tobacco, and fruit, more than quadrupled. Because farming had remained labor intensive, about 20-30% of the male work force continued to depend on farming for its livelihood (Abuirmeileh, 1987). Even with increased production, the failure of agriculture to keep pace with the growth of the rest of the economy resulted in an insufficient domestic food supply. Jordan thus needed to import agricultural products such as cereals, grains, and meat. Wheat imports averaged about 350,000 tons/year, 10-20 times the amount produced domestically. Red meat imports cost more than JD 30 million/year, and onion and potato imports cost between JD 3-4 million/year. Between 1982 and 1985, the total food import bill averaged about JD180 million/year, accounting for more than 15% of total imports during this period. At the same time, cash crop exports, for example, export of 7,000 tons of food to Western Europe in 1988, generated about JD 40 million/year, yielding a net food deficit of JD 140 million. One emerging problem in the late 1980s was the erosion of Jordan's traditional agricultural export market. The wealthy oil-exporting states of the Arabian Peninsula started to replace imports from Jordan with food produced domestically using desalinated water.

3.1.4 Water supply, sanitation, and reuse

3.1.4.1 Water supply

The average domestic water consumption is low, ranging from 20-50 l/c/d in rural areas to 53-120 l/c/d in urban and peri-urban areas. Almost 95% of the population in 2000 has connections to municipal water network. The non-served five percent is mostly in rural areas that rely on rainwater harvesting (cisterns), private water vendors (tankers), public taps, and springs (Table 3.6). In urban areas network connections served a population of 3.75 million and covering 98% of the urban households while in rural areas it served a population of about one million covering 88% of the rural households. Intermittent water supply prevails in most parts of the country as a result of water shortage. This has increased the interest in other water supply systems such as rainwater collection from the roofs in winter so as to be used in summer (hot and dry). Moreover, private water vending via tankers is a growing business in Jordan. Private tankers buy water from neighboring freshwater sources and sell it to individual households that store it their cisterns and roof tanks[3].

Table 3.6: Water supply methods in Jordan (Bataineh *et al*., 2002).

Water supply method	*% of population*		
	Total	*Rural*	*Urban*
Network	94.4	87.3	97.6
Cisterns	0.5	1.4	0.2
Tankers (vendors)	3.0	8.3	1.2
Public taps	0.34	0.35	0.33
Others	1.0	2.7	0.4

3.1.4.2 Wastewater collection

Most of Jordan’s wastewater is collected in one way or another. About 51% of Jordan’s population, which is 65.5% of the urban population, is served with sewerage systems (Table 3.7). Households having no access to the municipal sewers use either cesspits or watertight tanks. In the case of cesspits, less emptying is required depending upon storage capacity and permeability of soil. However this old-fashioned system is not allowed in the country

[3] Each household has a storage tank of 1-2 m^3 to cope with water shortage and intermittent supply. These tanks are usually located on roofs of the buildings, but sometimes they are on/in the ground necessitating the use of pumps.

anymore because the collected wastewater seeps into the ground causing pollution of water resources. As an alternative, watertight tanks that do not allow seepage of wastewater into the ground are strongly recommended and enforced by recent regulations. Such systems are more expensive since they are made of reinforced concrete and imply frequent emptying. Emptying of cesspits or watertight tanks costs about JD 1-2/m^3 (US$ 1.4-2.8) depending on the disposal area and distance. The average cost of building a cesspit or a watertight tank is about JD 105/person (US$ 150), depending on its storage capacity and type of soil (Bataineh *et al*., 2002). Septage is usually transported through private tankers to the nearest treatment plant or to a special dumping areas operated by municipalities.

Table 3.7: Wastewater collection systems in Jordan (Bataineh *et al*., 2002).

Sanitation method	*% of population*		
	Total	*Rural*	*Urban*
Public systems	51.3	5.0	65.5
Cesspits	48.0	93.5	35.0
Others	0.7	1.5	0.3

3.1.4.3 Wastewater treatment

The first WWTP goes back to the late 1960s at Ain Ghazal when a conventional activated sludge system was built for treating wastewater of Amman city. Since then the government extended this practice to almost every major city. In 2000, seventeen WWTPs were in operation producing about 80 million m^3 of secondary treated effluent, which is about 51% of the total amount of sewered wastewater and 34% of total wastewater production. The frequently used systems for wastewater treatment are activated sludge, trickling filters, and lagoons. About 76% of the treated wastewater in Jordan is produced at Al-Samra lagoon system that serves a population of about two million in Amman and Al-Zarqa areas. Performance and characteristics of 13 surveyed WWTPs (Chapter 1) are discussed in Chapter 4 and Annex C.

Treated effluents constitute a significant portion of the major receiving streams. These streams are not used for bathing or fishing. Much of Amman's treated effluent is discharged in the Zarqa River and is impounded by the KTD where it gets blended with fresh floodwater and is subsequently released for irrigation in the Jordan Valley.

3.1.4.4 Wastewater reuse

Direct reuse of reclaimed wastewater in Jordan is limited to the site and surroundings of the existing treatment plants (Table 3.9). The total number of farms that are directly irrigated with reclaimed wastewater in a sanctioned manner[(4)] is about 20, distributed in different parts of the Kingdom. The total land area of these farms is about 1,405 ha of fodders, fruit trees, and forestry, utilizing 15 million m^3 of reclaimed wastewater (Tables 3.9 and 3.10). Due to the topography and the concentration of the urban population above the Jordan Valley escarpment, the majority of treated wastewater is discharged into various watercourses and

[4] Each farmer signs a contract with the MWI for irrigation with reclaimed wastewater. According to this contract, land area, irrigated crops, irrigation system, amount of water, and water price are determined. Moreover, the farmer has to provide a financial guarantee, which is normally issued by a bank.

flows downstream to the Jordan Valley. Treated or poorly treated effluents mix with the fresh surface water. Thereafter, blended water is used for unrestricted irrigation utilizing about 52 million m^3 of reclaimed wastewater.

Table 3.8: Total land area irrigated with reclaimed wastewater in Jordan (Bataineh *et al*., 2002).

Irrigation restriction	*Total area (ha)*	*Area of irrigated crops (ha in year 2000)*			
		Fodder [a]	*Forestry* [b]	*Fruit* [c]	*Vegetables* [d]
Restricted irrigation	1,405	851	328	226	-
Unrestricted irrigation after blending	9,100	650	100	2,500	5,850
Total	*10,505*	*1,401*	*428*	*2,726*	*5,850*

[a] barley, Sudan grass, alfalfa, berseem, maize (forage);
[b] Acacias, Casuarinas, and Eucalyptus;
[c] olive, citrus, banana, peaches, apricots, and others;
[d] different vegetables.

Table 3.9: Direct wastewater reuse in Jordan (MWI, 2001; Bataineh *et al*., 2002).

WWTP	*Area of irrigated crops (ha in year 2000)*			
	Total	*Fodder*	*Forestry*	*Fruit*
Abu-Nuseir	0.7	-	0.2	0.5
Al-Samra	1,000	700	150	150
Aqaba	155	-	150	5
Baq'a	0.5	-	0.5	-
Fuheis	20	-	10	10
Irbid	0.7	-	0.5	0.2
Jerash	0.5	-	0.5	-
Karak	50	-	1.5	48.5
Kufranja	9	7	1	1
Ma'an	12	5	5	2
Madaba	63	60	2	1
Mafraq	29.5	25	1.5	3
Ramtha	52	50	1.5	0.5
Salt	5.5	4	0.5	1
Tafila	1.5	-	-	1.5
Wadi Seer	5	-	3	2
Total (ha)	*1,405*	*851*	*328*	*226*

Table 3.10: The surveyed reuse schemes in Jordan.

Scheme	*No. of surveyed farms **	*Area (ha)*
Restricted irrigation with reclaimed wastewater:		
Al-Samra	2 (3)	170.8
Madaba	5 (7)	31.0
Mafraq	1 (1)	15.0
Ramtha	1 (1)	47.0
Kufranja	1 (2)	5.2
Salt	1 (1)	1.6
Unrestricted irrigation with reclaimed wastewater after mixing with freshwater: The Jordan Valley	10	45.0
Irrigation with fresh surface water: The Jordan Valley	15	19.8
Irrigation with fresh groundwater: Baq'a	10	60.1

* Between brackets is the total number of farmers that officially use reclaimed wastewater.

The Wastewater Reuse Index (*WRI*) that has been discussed in Chapter 2 is used to compare wastewater reuse in Jordan during the period 1988-1999 (Figure 3.3). Results show that reuse is increasing slowly compared with wastewater produced and with wastewater collected and treated.

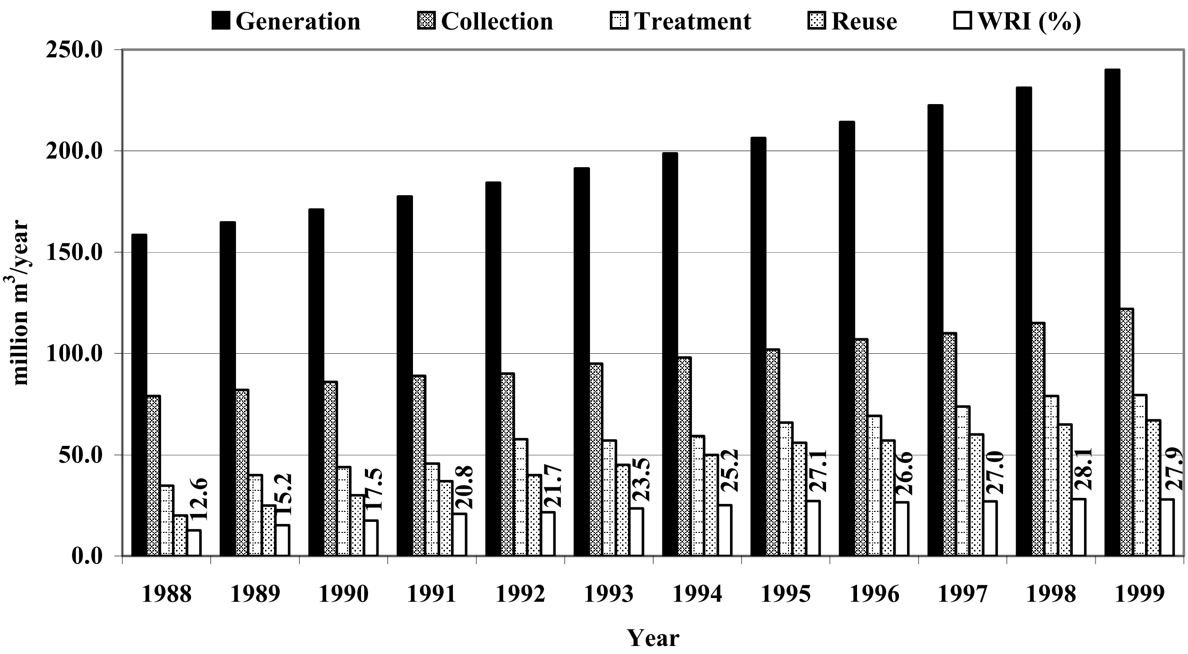


Figure 3.3: Status of wastewater reuse in Jordan (JWA, 1999).

3.1.4.5 Water and sanitation tariffs

A block tariff structure is adopted for pricing of water supply and sanitation in order to recover the O&M cost and part of the capital cost. The average tariff of domestic water is JD 0.36/m^3 (US$ 0.5) while it is JD 1.0/m^3 (US$ 1.42) for industrial, commercial, and touristic purposes (Table 3.11). The price charged for irrigation with reclaimed wastewater is fixed at JD 0.010/m^3 (US$ 0.014), while it varies JD 0.008-0.035/m^3 (US$ 0.011-0.05) for irrigation with freshwater.

Table 3.11: Water and sanitation tariffs in Jordan (MWI, 1999; Taha and Bataineh, 2002).

Block (m^3)	*Meter charge (JD)*	*Water supply tariffs (JD)*	*Wastewater tariffs (JD)*
Amman residential areas (started Oct.1st-1997)			
0 - 20	0.300	2.000	0.600
21 - 40	0.300	(0.14q)-0.8	(0.04 q) - 0.2
41 - 130	0.300	0.006556(q)^2 - 0.12224(q)	0.002889(q)^2 - 0.07556(q)
131 - more	0.300	0.85(q)	0.35(q)
Governorates residential areas (started Oct.1st-1997)			
0 - 20	0.300	1.300	0.600
21 - 40	0.300	(0.075q)-0.2	(0.035 q) - 0.1
41 - 130	0.300	0.004517(q)^2 - 0.10568(q)	0.001828(q)^2 - 0.038103(q)
131 - more	0.300	0.85(q)	0.35(q)
Commercial, industrial, and touristic uses (minimum consumption = 5 m3)			
6 - more	0.300	1 (q)	0.5(q)
Agricultural irrigation			
Treated wastewater: flat rate		0.010 JD/m^3	-
Freshwater: surface water, sometimes blended with reclaimed wastewater			
0 - 2,500	-	0.008 JD/m^3	-
2,500 - 3,500	-	0.015 JD/m^3	-
3,500 - 4,500	-	0.020 JD/m^3	-
4,501 - more	-	0.035 JD/m^3	-

q = Quantity; One JD = 1.4 US$.

Households that are connected to the sewer system pay for the service as follows (Bataineh *et al*., 2002):

- A connection fee, which is paid only once when the household is connected to the network. The amount paid varies from one household to another depending on the surface area of the household and the category under which it falls. Typically, it is 25% of the annual rental value.
- Three percent of the property tax paid annually depending on the previous factors.
- A regular bill, which depends on the amount of water consumed according to a block tariff structure; these tariffs drastically increase with increased water consumption[5] (Table 3.11).

3.1.4.6 Institutions in charge of wastewater reuse

Several public agencies are vested with primary responsibility for water and wastewater in Jordan such as the Ministry of Water and Irrigation (MWI), the Water Authority of Jordan (WAJ) and the Jordan Valley Authority (JVA) in addition to other governmental and non-governmental institutions. The role of these institutions can be summarized as follows:

- *MWI*, was empowered in 1992 to be responsible for the formulation and implementation of water and wastewater development programs. Its main functions are to formulate policy and strategy, plan water resources development, carry out research and development, conduct socio-economic and environmental studies, procure financial resources, monitor water and wastewater projects, implement human resources development and public awareness programs, and establish information systems.
- WAJ was created in 1988 as a national government agency for provision of water and sewerage services, and water resources management.
- JVA was created in 1988 as the responsible organization for the Jordan Valley development. It is responsible for the development of water resources (irrigation, domestic, industrial, and municipal), design and construction of roads, water supply, sanitation, electricity, and other infrastructural facilities.
- *Ministry of Health* (MoH) is empowered to monitor the operation of the WWTPs and sewerage systems. It also has the authority to ensure the safety of drinking water and treated effluents discharged or reused for irrigation or recharge.
- *Ministry of Agriculture* (MoA) is responsible for the irrigation water quality. It works closely with MWI on standard settings.
- *Ministry of Industry* (MoI) is responsible for industrial pollution prevention and cooperates with MWI and MoH in setting industrial discharge standards and regulations.
- *Standards and Metrology Establishment* is responsible for standards setting and amendments in cooperation with the aforementioned institutions.

[5] The present block tariff structure encourages less water consumption. Most households are aware of the tariff structure and the consequences of increased water consumption, especially when exceeding 40 m^3 per quarter. For this reason, many households watch their water meters and avoid exceeding this limit. As an alternative, they use harvested rainwater from cisterns or buy water from private vendors or reduce consumption. However, it is very common that many households share one water meter. In this case the price they pay for their aggregated water consumption is exponentially high.

- Other institutions that carry out research projects, provide training and advisory services, and carry out awareness programs in cooperation with MWI are: the General Corporation for Environmental Protection (GCEP), the Royal Scientific Society (RSS), the Water and Environment Research Center (WERC) at the University of Jordan, the Royal Society for the Conservation of Nature (RSCN), the Jordanian Environmental Society (JES), and the National Center for Agricultural Research and Technology Transfer (NCARTT).

3.2 Tunisia

3.2.1 Population, topography, and climate

The Population of the Republic of Tunisia was approximately 9.4 millions in 1998, with a growth rate of about 1.43%. Although Arabic is the official language, French is widely used and has a strong influence. English is also used in commerce and government. About 64% of Tunisia's population is urban. Tunisians are mostly Arabs and Sunni Muslims (98%), with some Christians (1%) and Jews (1%). The settlement pattern is heavily influenced by the uneven distribution of natural water resources. The development indicators are available in Annex B.3.

Tunisia is located in North Africa with a land area of 164,418 km^2. It borders the Mediterranean Sea on the north and northeast, Libya on the southeast, and Algeria on the southwest and west (map is available in Annex A.4). Tunisia is divided into four main topographic regions from north to south. In the north, low-lying spurs of the Tell Atlas traverse the country in a southwest to northeast direction, with fertile valleys and plains interspersed among the mountains. Peaks range in elevation from about 610 to 1,520 meters. Southward, the mountains give way to a plateau that averages about 610 meters in elevation. Farther south, the plateau descends gradually to a chain of low-lying salt lakes (some below sea level) called *shatt*, or *chott*, which extend east to west across the country. On the south, the *shatt* adjoins the Sahara that comprises about 40% of Tunisia's land area.

The climate is Mediterranean ranging from humid and sub-humid in the north to semi-arid in the central areas and arid (desert) in the south. The coastal areas are influenced by the Mediterranean (cooler during summer and warmer during winter than the interior zones). The yearly average precipitation ranges from 1,000 mm in the north to 50 mm in the south. Most of the precipitation occurs during winter season. The average temperature is 11.4 °C in December and 29.3 °C in July.

3.2.2 Water resources

3.2.2.1 General

The potential water resources of the country are estimated at 4,670 million m^3/year. The total volume that can be accessed is 3,100 million m^3/year. The annual per capita water availability in Tunisia is about 489 m^3, which is below the threshold for water scarcity (1,000 m^3/year) (Al-Atiri *et al.*, 2002). Water resources are unevenly distributed across the country with about 60% located in the north, 18% in the center, and 22% in the south (Table 3.12). Salinity is one of the major problems that influence the Tunisian water resources. The water resources that have a salinity of less than 1.5 g/l are distributed as follows: 72% of surface water resources, 8% of shallow groundwater, and 20% of deep groundwater. The water resources in Tunisia are used predominantly for irrigation (80%) as shown in Table 3.13.

The water resources management and planning are outlined in the country's five-year development plans. The goals are to mobilize most of the surface water through construction of 42 dams, 203 hillside dams, 1,000 hillside lakes, and 4,000 recharge and floodwater diversion structures. In addition, the plans emphasize water harvesting and wastewater reuse (Bahri, 1998).

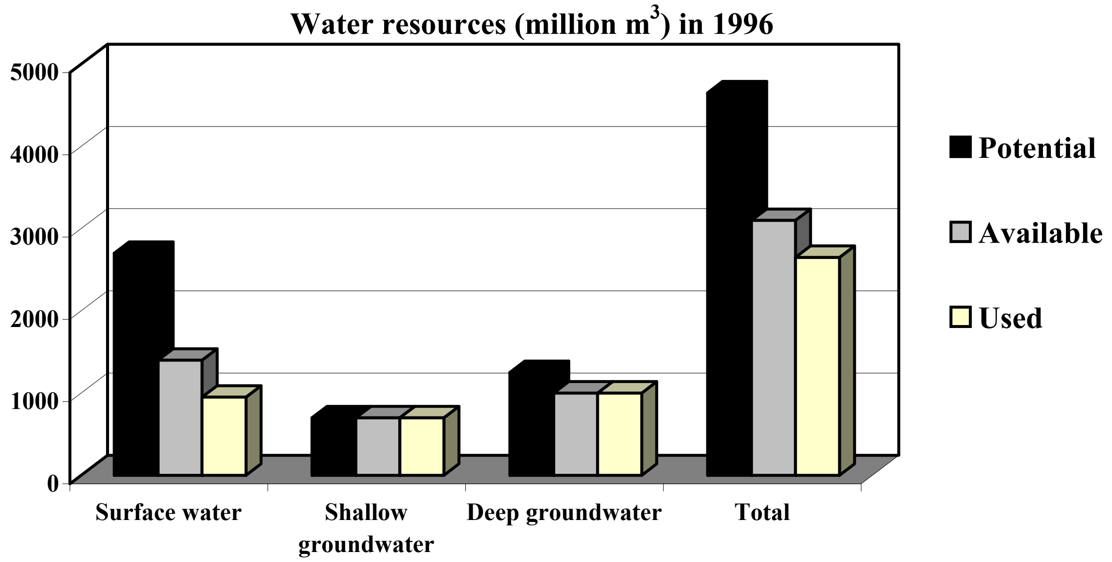


Figure 3.4: Available water resources in Tunisia (MoA, 1998).

Table 3.12: Distribution of surface water and groundwater in Tunisia (MoA, 1998).

Water resource	*North*		*Center*		*South*		*Total*	
	million m^3	*%*	*million m^3*	*%*	*million m^3*	*%*	*million m^3*	*%*
Surface water	2,190	78	320	38	190	19	*2,700*	*58*
Shallow groundwater	395	14	222	26	102	10	*719*	*15*
Deep groundwater	216	8	306	36	728	71	*1,250*	*27*
Total	*2,801*	*100*	*848*	*100*	*1,020*	*100*	*4,669*	*100*
% of total	*60*		*18*		*22*		*100*	

Table 3.13: Projected water demand in Tunisia (million m^3/year) (Bahri, 1998).

Water user	*1996*	*2010*	*2020*	*2030*
Domestic (urban + rural)	290	381	438	491
Tourism	19	31	36	41
Industry	104	136	164	203
Agriculture	2,115	2,141	2,082	2,035
Total	*2,528*	*2,689*	*2,720*	*2,770*

3.2.2.2 Surface water

Total annual rainfall is not sufficient to provide a year-round water source for agricultural crops and to satisfy other requirements. Hence, reservoirs, water transfer systems, and other hydraulic structures such as floodwater diversion are important to store rainwater and fill the gap between rainy and dry years. In order to store most of the potential surface water, many of these structures have already been completed and others are planned or under implementation. About 2,100 million m^3/year may be stored in large dams, hillside dams and hillside lakes. The existing 19 dams currently allow for utilizing 1,400 million m^3/year of surface water. The net development rate of surface resources is 52%. The construction of 24 projected dams will allow storage of about an additional 2,100 million m^3 in 2010. Other smaller structures such as hillside dams and lakes have been implemented to store surface water. These structures are also essential for flood control, conservation of soil and water, contribution to groundwater recharge, and they may extend the expected life of the dams by reducing reservoir silting. In total, 66 hillside dams (plus 45 under implementation) and 392 hillside lakes (3,300-500,000 m^3 capacity), collecting respectively 77 and 37 million m^3/year, are already in operation (CITET, 2003).

Surface water is affected by variability in space and time. One year out of two is dry and it may be considered that out of 2,700 million m^3/year of surface water, 2,230 million m^3 are available one year out of two, 1,500 one year out of five, and 1,250 one year out of ten. Such variability implies specific strategies and tools for surface water management in terms of capacity for inter-annual regulation. Reduction in capacity of the available surface water resources is due to silting (5-10% per decade) and water losses by evaporation (1-2 m/year). Water is piped and conveyed over long distances from inland to the coastal areas (150 km) or from north to south (300 km) through systems of open canals (Canal Madjerda-Cap Bon) and pipelines, reservoirs, and pumping stations. This is to supply the coastal cities with drinking water and to preserve some agricultural regions such as the Cap Bon (Bahri, 1998).

Salinity of surface water ranges between 0.5 and 4.5 g/l; about 72% of surface water resources have a salinity of less than 1.5 g/l.

3.2.2.3 Groundwater

The groundwater resources of the country are about 1,970 million m^3 of which 650 million m^3 are non-renewable and located in the south. About 1,250 million m^3 are in deep aquifers and 719 million m^3 in shallow ones (Table 3.12). The net rate of development of these aquifers is 93%; about 86% from 2,400 deep groundwater wells (100-400 m deep) and 14% from 123,000 shallow wells (<50 m deep).

Water pumped from shallow aquifers is mainly used for irrigation and to a lesser extent for drinking purposes. Deep groundwater is used for agriculture (74%), potable water supply (18%), and industry and tourism (8%). In the arid and semi-arid parts of the country where surface water is lacking, water is sometimes transported several kilometers to supply cities such as in Sousse and Sfax.

Groundwater resources are exposed to various types of pollution and deterioration, increasing their vulnerability and scarcity. Shallow aquifers are already over-exploited. Groundwater resources in coastal regions (Cap Bon, Sahel, and Mareth) and in the vicinity of salt lakes (Nefzaoua and Jerid) suffer from salinization problems due to seawater or saline water intrusion. As a result, the quality of these aquifers has deteriorated considerably. Pollution of some shallow aquifers by nitrates constitutes also a major risk for domestic water supply.

Generally, deep aquifers composition is rather stable over the year while that of shallow aquifers depends on location and season, and is often salt-affected. Thus, salinity of 8% of the shallow aquifers is less than 1.5 g/l, 71% of the wells range between 1.5 and 5 g/l, and 21% are above 5 g/l. Of the deep aquifers, 20% have a salinity of less than 1.5 g/l, 57% are between 1.5 and 3 g/l and 23% are above 3 g/l. In the south, there are three main fossil aquifers with different water qualities (1-7 g/l) (CITET, 2003).

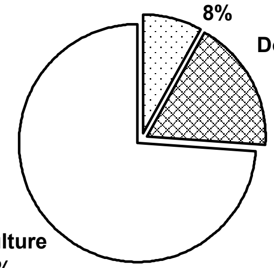


Figure 3.5: Use of deep groundwater in Tunisia.

3.2.2.4 Non-conventional water resources

Reclaimed wastewater and desalination of brackish and sea water are the major non-conventional water resources in Tunisia (Table 3.14). Moreover, there is growing interest in water conservation and demand management options as a means to cope with the water crisis in the country. These resources can be briefly described as follows:

- *Desalination*. Desalination of brackish groundwater (3.8 g/l) using reverse osmosis is in operation on Kerkennah Island and in the city of Gabes to supply the population with drinking water. It is under implementation for the cities of Zarzis and Jerba. About seven million m^3 of desalinated water was provided in 1996. This volume is projected to be around 49 million m^3 in 2030.
- *Reclaimed wastewater*. The volume of treated wastewater has increased from 78 million m^3 in 1988 to 148 million m^3 in 2000. In 1988, wastewater was treated in 26 WWTPs, mainly located on the coast to reduce sea pollution, and by 2000 the number of WWTPs was increased to 61. The amount of wastewater reused in 2000 was 43 million m^3 irrigating about 6,750 ha of fodder crops, cereals, fruit trees, and green belts. There is a growing national concern for maximizing the use of reclaimed wastewater.
- *Rainwater harvesting*. Rainwater is not taken into account in the water resources budget. However, many households in the rural and peri-urban areas have individual cisterns for collecting rainwater from the roofs.

Table 3.14: Potential non-conventional water resources (million m^3/year) in Tunisia (MoA, 1998).

Water source	*1996*	*2010*	*2020*	*2030*
Treated wastewater	120	200	290	340
Desalination	7	10	24	49
Total	*127*	*300*	*314*	*349*

3.2.3 Agriculture

The country's arable land area is estimated at five million ha, of which about 400,000 ha is irrigated. Agriculture accounts for 13.2% of the GDP (2000) and 9% of exports of goods, and provides work for 22% of the active population. The irrigated sector occupies 8% of the useful agricultural area of the country, but contributes significantly to the productivity of agriculture (Table 3.15). It accounts for 35% of the value of agricultural production, 20% of agricultural export and 27% of the labor force. Moreover, with regard to crops produced, Tunisian irrigated agriculture is diverse, with its oasis areas of the South, citrus fruit production areas of Cap-Bon, and market-garden areas of the Sahel and the Madjerda Valley. Generally, the irrigated lands comprise market-garden crops (33%), arboriculture (34%), cereals (13%), fodder crops (10%), and various crops (10%). Government encouragement for the development of dairy livestock has led to an increase in the irrigation of cereals and fodder crops. The irrigation sector contributes about 30-35% to the agricultural value of the country. The state manages large-scale public irrigation schemes while users associations manage medium-scale public irrigation schemes.

Table 3.15: Sources of irrigation water in 1996 (Bahri, 1998).

Water source	*Irrigated area in 1996 (ha)*
Intensive irrigation	345,500
Large dams and hillside-dams and lakes	128,000
Reclaimed wastewater	6,500
Deep groundwater wells (tube wells)	67,000
Shallow groundwater wells	130,000
Springs and intermittent streams	14,000
Complementary irrigation	50,000
Total	*395,500*

Many horticulture activities can be found in Tunisia: fruit growing (olive trees cover about 80% of the total fruit area), vegetables, and flowers. Olive tree growth (rain fed) is spread widely in the country. Citrus and grape production is located mainly in the Cap Bon area and dates are produced in the oases located in the south. Other fruit species are cultivated in the northern and the central areas. Vegetables production is spread along the coast and the inland irrigated perimeters in the north and central zones. Protected vegetables production is located along the coast, whereas the geothermal water sources are used for early vegetables production in the southern areas.

Surface irrigation techniques are mainly practiced on the schemes with complementary irrigation and some sprinkler irrigation is used on cereals in case of a severe rainfall deficit and on fruit trees during the early years of their development.

3.2.4 Water supply, sanitation, and reuse

3.2.4.1 Water supply

The National Company for Water Management and Distribution (SONEDE) provides the entire Tunisian territories with drinking water. It is a public enterprise of industrial and commercial nature. The non-agricultural water supply was 413 million m^3 in 1996 of which 290 million m^3 was for domestic uses, 104 million m^3 for industries, and 19 million m^3 for tourism. This is expected to reach 548 million m^3 by the year 2010 (with 71% for domestic and public purposes, 23% for industry, and 6% for tourism). Eighty eight percent of the population has access to piped water supply. In urban areas, almost full water supply service coverage has been achieved. In rural areas, 66% of the population is connected to a water supply network through house connections, and 34% rely on public standpipes and wells. The average urban water consumption is about 85 l/c/d (53-105). In the rural sector, the average water consumption is about 28 l/c/d (5-94). Industries use 37% from municipal water supply and 63% from other sources such as deep and shallow groundwater wells. In 1996, the industrial water consumption was 104 million m^3; of this amount, 75 million m^3 came from deep aquifers and 29 million m^3 from shallow aquifers (Limam, 2002). By 2010, the total water demand projection is estimated at 2,689 million m^3 distributed among the following uses: households 381 million m^3, tourism 31 million m^3, industry 136 million m^3, and irrigation 2,141 million m^3. Thus, the irrigation sector would continue to use most of available water resources.

The water consumption for tourism is about 7% of total municipal consumption (19 million m^3/year). The average water consumption is about 345 l/bed/d. Hotels in some areas such as Jerba and Zarzis, use other sources of water (deep wells, cisterns) in addition to the municipal water supply.

3.2.4.2 Wastewater collection

Sanitation coverage in the sewered cities is about 78%, which is 61% of the urban population (5.8 million). The connection rate of the urban and rural households to a sewerage network is 40%. The number of towns or villages which ONAS has taken charge of is 141 out of a total of 260. The percentage of towns served with sewerage system is shown in Table 3.16. Like in Jordan, the unsewered households rely on cesspits and septic tanks. Effluent from these structures either percolates into the ground or is transported to the neighboring WWTPs.

Table 3.16: Towns and cities connected to sewerage system in 2001 (Al-Atiri *et al*., 2002).

Towns and cities	*% of connected towns and cities*
< 5,000 inhabitants	4%
5,000-10,000 inhabitants	36%
10,000-50,000 inhabitants	84%
50,000-100,000 inhabitants	95%
> 100,000 inhabitants	100%

Table 3.17: Wastewater infrastructure in Tunisia (ONAS, 2000).

Year	*Length of sewage lines (km)*	*Pumping stations*	*Treatment plants*
1997	7,700	340	52
1998	8,200	355	55
1999	9,000	385	60
2000	9,650	417	61

3.2.4.3 Wastewater treatment

In 1988, about 78 million m^3 of wastewater was treated in 26 WWTPs. In 2000, this amount has increased to 148 million m^3, produced at 61 WWTPs (representing 77.1% of sewered wastewater and 46.8% of total wastewater production). Five treatment plants are located in the Tunis area, producing about 62 million m^3/year. Several of the plants are located along the coast to protect coastal resorts and minimize sea pollution; currently they discharge around 88% of the treated effluent. ONAS plans to extend its services to other towns (some have already been implemented) to protect the Sidi Salem dam that supplies municipal and irrigation water to the Tunis, Cap Bon, Sousse, and Sfax areas. Tunisia's major goal is to increase the reuse of treated effluents that are currently discharged into the sea. Wastewater in Tunisia is of mainly domestic origin (about 88%) which goes through secondary treatment. The commonly used systems for wastewater treatment include activated sludge, trickling filters, and lagoons. Performance and characteristics of 18 surveyed WWTPs (Chapter 1) are discussed in Chapter 4 and Annex C.

3.2.4.4 Wastewater reuse

Wastewater reuse for agriculture has always existed and remains nowadays a widespread practice, sometimes planned and more often not (Bahri and Brissaud, 1996). Wastewater reuse in agriculture has been practiced for several decades in Tunisia and now it is an integral part of the national water resources strategy. During the nineties, the amount of reused water tripled (Table 3.18). The total amount of wastewater reused was about 50 million m^3 in 2000, with about 38 million m^3 used for irrigation of about 6,750 ha of fodder crops (alfalfa, sorghum), cereals, fruit trees (citrus, olives, peaches, pears, apples, grenades, and vineyards), tobacco, cereals, golf courses, green belts and roadsides ("streets of the environment")[(6)] (Table 3.18). About 12 million m^3 were indirectly reused after mixing with freshwater. More than 60% of the area irrigated with reclaimed wastewater is located around Tunis. In some schemes, most of the treated water available for irrigation is being used, while in new projects the reclaimed water utilization rate is slowly increasing. Use of treated effluents in Tunisia is seasonal (spring and summer). During the irrigation season, 30-40% of the total effluent is reused which is 15-20% of the annually treated effluents.

Table 3.18: Schemes irrigated with reclaimed wastewater in Tunisia in 1992 and 2001.

Irrigation scheme	*Irrigated area in 1992 (ha) **	*Irrigated area in 2001 (ha) ***
Soukra	600	600
Cebala and Al-Taweel	430	2,200
Mornag	300	1,047
Nabeul	320	346
Hammamet	140	140
Sousse	160	205
Monstir:		
Maknine	100	100
Al-Wardanin	-	50
Sayada	-	50
Kairouan	150	240
Sfax	190	425
Quasrine	-	100
Qafsa	-	116
Gabes	-	200
Madnine	-	24
Others around WWTPs	-	300
Golf course	-	600
Total	*2,390*	*6,743*

* Bahri and Brissaud (1996); ** ONAS (2001) personal contact.

6 Each Tunisian city has one street that is locally called "street of the environment". The sides of these streets are kept clean and green by making use of reclaimed wastewater.

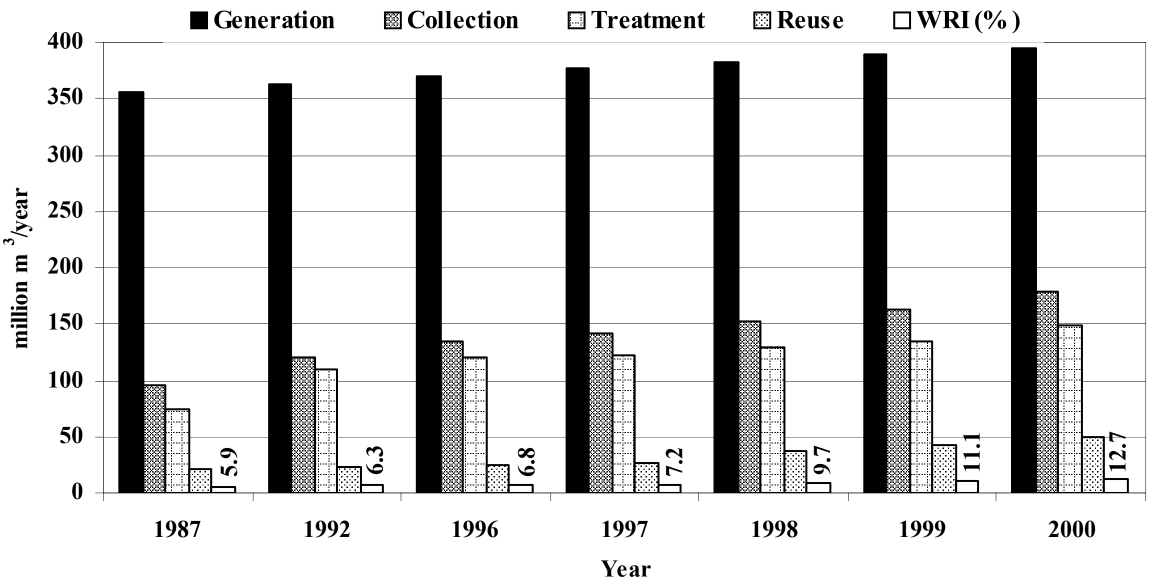


Figure 3.6: Status of wastewater reuse in Tunisia (ONAS, 1999, 2000).

The Wastewater Reuse Index (*WRI*) that has been discussed in Chapter 2 is used to compare Tunisia's progress for the period 1987-2000 (Figure 3.6). Results show that the reuse is increasing slowly compared with wastewater produced or even collected and treated. Bahri and Brissaud (1996) attributed the low utilization of wastewater to three main reasons: (i) irrigation is practiced only 6 months per year, (ii) as no treated wastewater can be stored, the irrigation rate is limited to that of the pumps withdrawing effluents from WWTPs, and (iii) which is the most important, only 40% of the area equipped to use treated wastewater is irrigated. However, farmers are taking steps to shift from rain fed to reclaimed water irrigated crops. In contrast, the utilization rate of treated effluents is high for golf irrigation: more than 11,000 m^3/ha per year are used at Hammamet, Sousse, and Monstir golf courses. Using reclaimed water for irrigation of golf courses, green belts, and hotel gardens would result in an optimization of both investment and operational costs. These users are never far from the treatment plants, they are large water consumers, they add considerably to GDP, and they are likely to pay a price that would allow recovering operation and maintenance costs (Bahri and Brissaud, 1996).

Cebala and Al-Taweel reuse scheme. It is located 8 km north of Tunis with an average rainfall of 450 mm/year; the rainy season stretches from October to March (Figure 3.7). The groundwater is very shallow (1-2 m depth) and unusable for irrigation due to high salinity levels. Wells located upstream of the scheme provide good quality water used for irrigation of cash crops. Cebala scheme has traditionally been devoted to large-scale dry farming. The traditional crops are wheat, barley, beans, and vetch-hay. In the outlying areas, farmers of the schemes irrigated with Madjerda water use to grow cash crops that bring them good income.

Table 3.19: The distribution of the land equipped for irrigation at Cebala and Al-Taweel scheme.

Plot category	*Total area (ha)*	*No. of farmers*
< 5 ha	435	516
5-50 ha	1,850	390
> 50 ha	1,500	11
Total	*3,785*	*917*

Source: RADC office at Cebala and Al-Taweel (personal contact).

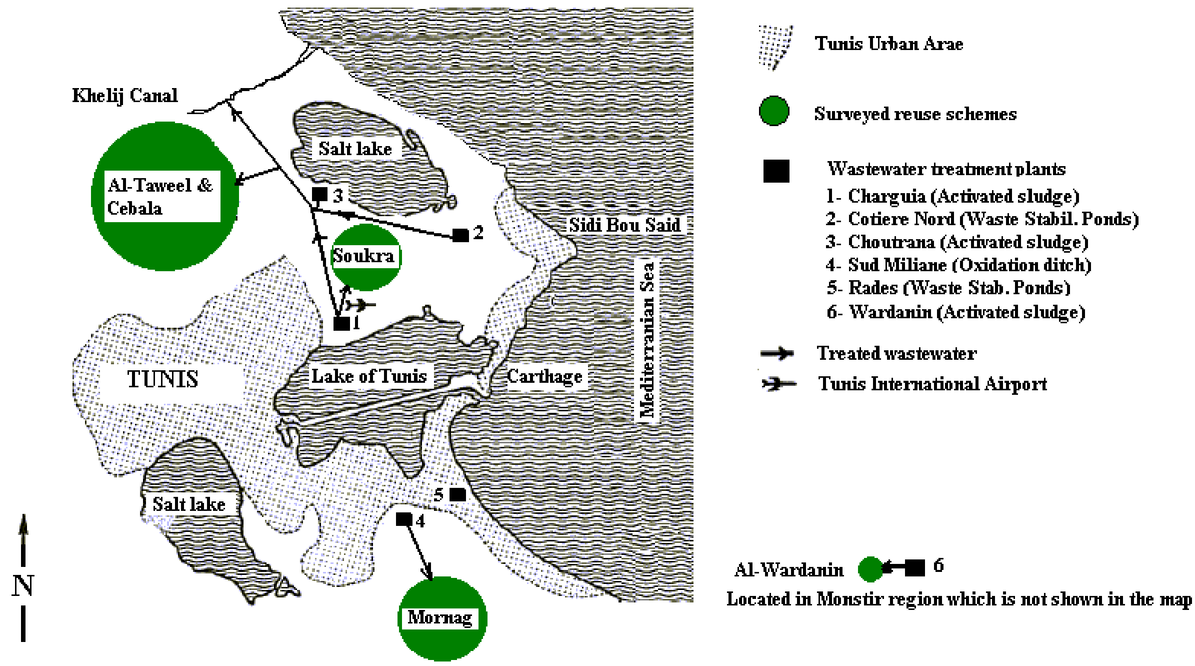


Figure 3.7: Location of the surveyed reuse schemes in Tunisia.

Table 3.20: Irrigated area (ha) at Cebala and Al-Taweel reuse scheme.

Crops	*Equipped area for irrigation*	*Season 1998/99*		*Season 1999/2000*		*Season 2000/2001*	
		Rainwater	*Treated WW*	*Rainwater*	*Treated WW*	*Rainwater*	*Treated WW*
Cereal fodders	1,480	1,302	276	801	687	600	700
Fodders	1,440	952	855	1,082	891	628	1,068
Industrial crops	800	-	170	-	360	-	420
Fruit trees	65	-	8	-	10	-	20
Total (ha)	*3,785*	*2,254*	*1,309*	*1,883*	*1,948*	*1,228*	*2,202*

Source: RADC office at Cebala and Al–Taweel (personal contact).

The Cebala scheme comprises about 2,200 ha of land irrigated with reclaimed wastewater, thus, it is the biggest reuse scheme in Tunisia (Figure 3.7; Tables 3.19 and 3.20). It started operation in 1989 and was designed to receive effluents from three WWTPs of Greater Tunis (Choutrana, Cherguia, and Cotiere Nord). Effluents from these plants are mixed at the output of the Choutrana plant and discharged to the sea through the ONAS and Khelij canals. Wastewater is pumped at 4 km downstream from Choutrana and conveyed to a regulation reservoir that has a capacity of 4,000 m^3 and located 120 meters higher than the irrigated farms. In 1992, three years after the project was implemented, the irrigated area did not exceed 16% of the equipped area (3,785 ha) and it used about 15% of the available treated wastewater. Winter farming essentially consists of cereals production (wheat, barley, and hay) and fodder crops (berseem, green barley, and vetch-hay). Land use intensity remains very low in summer with farmers growing cotton, grain, fodder corn, and fodder sorghum. Between the planning and implementation phases, it was decided to modify the distribution system so as to also enable sprinkling irrigation. The additional costs were limited because the high elevation of the regulation reservoir allowed dispensing with the pumping system. Most farmers yet keep to traditional gravity (furrow and canal) irrigation. Sprinkler irrigation remains limited to a few pilot plots.

The Cebala project was implemented upon the request of the Ministry of Agriculture. The project aimed at agricultural development based on intensification of cereals and fodder crops, the introduction of corn grain, and the promotion of veal fattening. The prohibition of vegetables and cash crops is particularly difficult to bear for the farmers located near the zone irrigated with Madjerda water who used to farm these crops before the project was implemented (Bahri and Brissaud, 1996).

Soukra reuse scheme. The Soukra scheme is 8 km northeast Tunis. The scheme was constructed in the early sixties for irrigation with the effluent from the Cherguia WWTP (Figure 3.8). The Cherguia activated sludge plant receives sewage from part of the Tunis metropolitan area. About 600 ha were originally irrigated although it was planned to irrigate 1,280. Nowadays, still only 500 ha are irrigated while 550 ha are rain fed and partly irrigated with shallow groundwater; freshwater is not available. Urban expansion causes less concern for agriculture and reduces the available irrigated land acreage. Hundred eighty two farmers out of 350 are connected to the treated effluent distribution system. Only 120 farmers are still using this water despite that 180 are equipped with water meters. The irrigated crops are citrus (300 ha), other fruits (80 ha), fodders (70 ha), golf courses and green belts (50 ha). Based on the experience of the Soukra scheme, a wastewater reuse policy (at national level) was launched in the early eighties to equip more than 6,500 ha for irrigation with reclaimed wastewater (Bahri and Brissaud, 1996). Water meters[7] are the only means of estimating the consumed water.

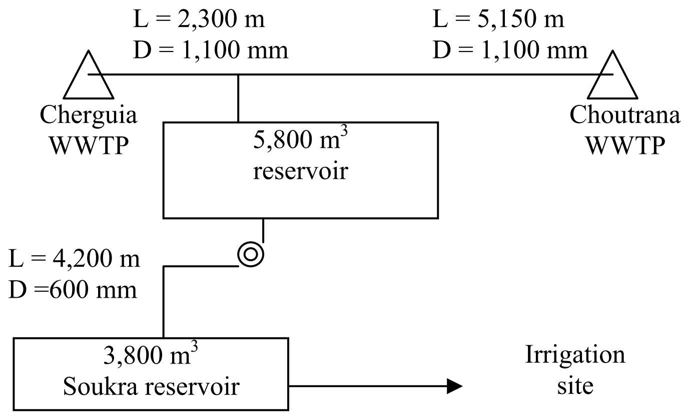


Figure 3.8: Layout of the Soukra reuse scheme.

[7] The ASTRA type of water meters is specially designed for treated wastewater. It costs TD 300 (US$ 210). Farmers pay TD 4/quarter (US$ 2.8) for rental of the water meter provided by the MoA.

Mornag reuse scheme. This irrigation scheme is located 30 km southeast of Tunis. The scheme was established in 1989 and comprised originally 1,087 ha of agricultural land irrigated with treated wastewater, which expanded to 731,930 m^3 in 2000; the water comes from the activated sludge treatment system at Sud-Melian. The treated effluent is pumped directly (without storage) from the treatment plant at Sud-Melian to the irrigated lands at Al-Resalah and Ouzarah via a pipeline (L = 13 km, D = 800 mm). The elevation difference between the pumping station and the highest consumption point is 134 m. At the beginning, the Tunisian government owned and managed most of the irrigated land, but later on the government divided the land into plots of 2 ha each and leased it to farmers (Table 3.21). The irrigated crops at Al-Resalah are fruit trees (peach, apple, pear, grape, and olive). Freshwater of good quality from the ground as well as from Madjerda canal is available at TD0.12/m^3 (US$0.084/$m^3$).

Table 3.21: Distribution of land irrigated with treated wastewater at the Mornag scheme.

Irrigation scheme	*Land area (ha)*	*Number of farmers*	*Average land area (ha/farmer)*
Al-Resalah	225	43	5.2
Ouzarah	862	69	12.5
Total	*1,087*	*112*	*9.7*

Source: RADC office at Mornag (personal contact).

A few farmers, irrigating 36 ha at the Ouzarah area, applied for permission to use the Madjerda water instead of reclaimed wastewater because they prefer to grow vegetables. Water meters are the standard since 1996, with the farmer paying TD 13.5-18/quarter (US$ 9.45-12.6) for the rental of the water meter, depending on the diameter of the supply pipeline (80-200 mm).

Al-Wardanin reuse scheme. This scheme is located 160 km southeast of Tunis and was constructed in 1996 for utilizing 800-1,000 m^3/d of treated effluent from Wardanin WWTP (activated sludge system) that is 3 km way. A reservoir with a capacity of 500 m^3 is followed by a pumping station adjacent to the WWTP. About 50 ha are equipped for irrigation with reclaimed wastewater, of which only 36.5 ha are used. About 95% of the treated wastewater is used to irrigate fruit trees and only 5% for fodders. Fruit trees are mainly peach and apricot. The total land area is 4,963 ha of which 4,356 ha are cultivated (2,971 ha of olives, 1,615 ha of fruit trees, and 30 ha of forestry). Due to water shortage in the area, out of 4,356 ha only 350 ha are irrigated and the rest is rain-fed. Moreover, due to the small scale of the WWTP, wastewater is mainly supplied between 7 am and 7 pm, which is not practical and insufficient for irrigation.

A unique farmers' committee was formed at the early stage of project construction in 1996 for facilitating its implementation (discussed in Chapter 6). There are water meters but these are rarely used due to the continuous malfunctioning. Therefore, water application is estimated based on the land area, type and age of crops, and irrigation scheduling.

3.2.4.5 Water and sanitation tariffs

A block tariff structure is adopted for pricing of water supply and sanitation in order to recover the O&M cost and part of the capital cost. SONEDE clients receive a quarterly invoice with the exception of major industrial and touristic consumers who are invoiced monthly. The invoice is divided in two parts: the first, pertaining to water, comprises a fixed part corresponding to the fixed dues according to the diameter of the connecting meter and a variable part containing the amount of water consumed (Table 3.22). The second part is related to wastewater use, and again comprises fixed and variable dues according to the metered water consumption (Table 3.23). The wastewater dues are collected by a SONEDE invoice and remitted to ONAS.

Cross subsidies or inter-block subsidies characterize the Tunisian tariff policy. The block tariff structure is an advantage for small consumers at the expense of large consumers. The first three blocks receive indirect subsidies from the higher blocks that are invoiced at tariffs above the average (Table 3.24).

Table 3.22: Structure of the water supply tariffs in Tunisia (Aniba, 2002; Limam, 2002).

Tariff	*Water consumption category (domestic)*							
	0-20	0-40	0-70		0-150		>150	
	0-20	0-40	0-40	41-70	0-70	71-150	0-150	>150
Fixed (US$/bill)	2.36	14.69	38.19		59.15		157.62	
Plus US$/m³	0.1	0.15	0.15	0.31	0.31	0.46	0.46	0.56
Stand pipes: 0.096 US$/m³ (all water)								
Tourism: 0.50 US$/m3 (all water)								

Table 3.23: Structure of the sanitation tariffs in Tunisia (Aniba, 2002; Limam, 2002).

Tariff	*Water consumption category*									
	0-20	*21-40*		*41-70*		*71-150*		*>150*		
	0-20	*0-20*	*21-40*	*0-40*	*41-70*	*0-70*	*71-150*	*0-70*	*71-150*	*>150*
Fixed (US$/bill)	0.90	0.97	0.97	2.66	2.66	5.24	5.24	5.39	5.39	5.39
Plus US$/m³	0.01	0.01	0.11	0.15	0.15	0.15	0.29	0.15	0.29	0.32
Industry: 5.63 US$ (fixed) + 0.35 US$/m³ low pollution (COD <25 mg/l, BOD <30 mg/l, TSS 0 mg/l) 0.47 US$/m³ medium pollution (COD <400 mg/l, BOD <400 mg/l, TSS <1,000 mg/l) 0.54 US$/m³ high pollution (COD >400 mg/l, BOD >400 mg/l, TSS >1,000 mg/l)										
Tourism: 5.63 US$ (fixed) + 0.66 US$/m³										

Table 3.24: Inter-block cross subsidies of water supply in Tunisia (Limam, 2002).

Use	*Block (m³/quarter)*	*% Volume consumed*	*Average tariffs US$*	*Average tariffs %*	*Subsidies (%)*
Household	0-20	10	95	31.8	26
+	21-40	20	151	50.7	38
Collective	41-70	22	175	59.0	34
+	7-150	14	326	110.0	-6
Industry	> 151	27	518	174.5	-76
Stand pipes		*1*	*95*	*31.8*	*3*
Tourism (hotels)		*6*	*553*	*186.3*	*-19*

In Tunisia, water pricing is governed by State policy that aims at promotion of agricultural expansion and water saving. Prior to 1997, the price of reclaimed wastewater for irrigation varied from one scheme to another at TD0.031-0.068/m³ (US$0.027-0.061). This price was estimated at about 35%-95% of the selling price of freshwater water. In 1997, it was decided to significantly decrease the price to a uniform TD0.020/m^3 (US$0.014). This price is greatly subsidized with the aim of promoting the reuse of treated wastewater (Al-Atiri *et al*., 2002).

3.2.4.6 Institutions in charge of wastewater reuse

Several ministries and agencies are responsible for water and wastewater planning, management, monitoring, and pollution control. The main ministries/agencies include:

- *Ministry of Environment and Land Use Planning* or Ministère de l'Environnement et de l'Aménagement du Territoire (MEAT). Its responsibilities include formulation of strategies, coordination and control of activities for the protection of nature and the environment, abatement of pollution and nuisances, and improvement of the quality of life. The ministry has two major directorates-general: one is in charge of identification of adequate measures for rational land management in order to ensure the sustainability of the natural resources and to protect fragile ecosystems, and the other is in charge of evaluating the general situation of the environment, proposing guidelines to the national strategy for the protection of environment, developing action plans for conservation of natural resources, and reducing or eliminating sources of pollution.

  Three autonomous organizations operate under the supervision of MEAT to ensure monitoring, enforcement, reduction of pollution, and protection of natural resources:

  i) *National Sewerage and Sanitation Office* or Office National de l'Assainissement (ONAS). It was instituted by a law in 1974, following the creation of MEAT as a central institution for wastewater management and protection of the water resources. ONAS is a public institution of industrial and commercial nature endowed with legal status and financial autonomy. It intervenes only in urban areas for which responsibility is ensured by decree. It is in charge of management, operation and maintenance, and supply of wastewater collection, treatment, and disposal in urban, industrial, and touristic areas.
  ii) *National Agency for Protection of the Environment* or Agence Nationale de Protection de L'Environnement (ANPE). It is in charge of executing the mandates of MEAT with respect to prevention, monitoring, enforcement and public awareness. ANPE manages the environmental impact assessment system and monitors industrial discharges and their treatment units. ANPE's mandate has been broadened to include the reparation of ecological damages and the execution of a national solid waste management program.
  iii) *Tunis International Center of Environment Technologies* or Le Centre International des Technologies de l'Environnement de Tunis (CITET). It is in charge of capacity building, as well as research, development and adaptation of technologies and new techniques. At present CITET has broadened its activities to include: training, technical assistance, information and documentation, and provision of laboratory testing for governmental organizations and the private sector.
  iv) *Ministry of Agriculture* (MoA) is in charge of all water management responsibilities, except for wastewater collection and treatment. These responsibilities cover planning, monitoring, and implementing the allocation of resources in the country. The Regional Commissioners for Agricultural Development or Cornmissariat régional de développement agricole (CRDA), linked to the MoA, are the institutions responsible

for the development of public irrigation schemes at regional level. In each of the existing 24 Governorates, one CRDA groups the main services of the MoA.

- *Ministry of Public Health* (MoH) is in charge of evaluation, control/monitoring, technical assistance, education, public awareness, and research. Among other responsibilities, the MoH is in charge of supervising the hygienic conditions of public places (restaurants, hospitals, etc.) and controlling the discharges of wastewater from treatment plants.
- *Ministry of Industry* (MoI) is in charge of participating in the elaboration of the government strategy for the abatement of pollution and the protection of the environment.
- *Ministry of Interior* (MoInt) is in charge of the follow up of (1) the national program for the protection of the environment and (2) the legal and regulatory framework for environment and sanitation. In addition to the ministries responsible for water and wastewater management, there are a number of consultative institutions, among which: (i) the commission for public hydraulic domain, (ii) the national commission for water, (iii) the national commission for environment, (iv) the national commission for sustainable development, and (v) the national commission for conservation of water and soil.
- *National Institute for Research in Rural Engineering, Water and Forests* (INGREF) contributes to the promotion of reuse by researching the impacts on plants and the soil as well as the ways to improve the quality of treated wastewater.

3.3 References

Abuirmeileh, N. (1987). Agricultural development and food security in Jordan. In Bichara Khader and Adnan Badran (eds.), The Economic Development of Jordan, pp. 93-117. Croom Helm, London

Al-Atiri, R., Rezgui, F., and Aniba, B. (2002). Wastewater reuse: the case of Tunisia. Water Demand Management Forum, Beirut, Lebanon.

Al-Jayyousi, O. R. (1995). Agricultural adjustment systems in the Jordan Rift Valley. Technical Report, University of Applied Sciences, Amman, Jordan.

Al-Weshah, R. A. (2000). Optimal use of irrigation water in the Jordan Valley: a case study. Water Resources Management, **14**: 327-338.

Aniba, B. (2002). Valuation of wastewater: the case of Tunisia. Water Demand Management Forum, Water Valuation, Beirut, Lebanon.

Bahri, A. (1998). Water resources development and management in Tunisia. Technical Paper, National Research Institute for Agricultural Engineering, Waters, and Forestry. Tunisia.

Bahri, A. and Brissaud, F. (1996). Wastewater reuse in Tunisia: assessing a national policy. Wat. Sci. Tech., **33**(10-11): 87-94.

Bataineh, F., Najjar, M., and Malkawi, S. (2002). Wastewater reuse in the Hashemite Kingdom of Jordan. Water Demand Management Forum, Beirut, Lebanon.

CITET, Tunis International Center of Environment Technologies. (2003). Website: http://www.citet.nat.tn/english/water/mobilisation.html.

Department of Statistics. (2001). Statistical year book. Amman.

EMWIS, Euro-Mediterranean Information System on the know-how in the Water Sector. (2001). Water in Jordan. Website: http://www.semide-jo.org/Intro_wtr_Resources.htm.

FAO. (1997). The AQUASTAT country profiles. Website: http://www.fao.org/ag/agl/aglw/aquastat/countries/index.stm.

Hadidi, K. (2002). Valuation of irrigation water: the case of Jordan. Water Demand Management Forum, Water Valuation, Beirut, Lebanon.

Jaber, J. and Mohsen, M. (2001). Evaluation of non-conventional water resources supply in Jordan. Desalination **136**: 83-92.

JWA, Jordan Water Authority. (1999). The annual operation and maintenance report. Ministry of Water and Irrigation, Amman, Jordan.

Limam, M. (2002). Valuation of drinking water: the case of Tunisia. Water Demand Management Forum, Water Valuation, Beirut, Lebanon.

METAP, Mediterranean Environmental Technical Assistance Program. (2001). Tunisia water quality management. Country Report on Water Quality and Potential METAP Interventions, November 2001, Tunisia.

MoA, Ministry of Agriculture. (1998). Eau 21 – Stratégie du secteur de l'eau en Tunisie à long terme 2030. Report prepared by Khanfir, R., Louati, M.H., Frigui, H.L., El Echi, M.L., Marzouk, A., and Alouini, A. Tunisia.

MWI, Jordanian Ministry of Water and Irrigation. (1999). Annual report. Amman, Jordan.

MWI, Jordanian Ministry of Water and Irrigation. (2000). Annual report. Amman, Jordan.

MWI, Jordanian Ministry of Water and Irrigation. (2001). Annual report. Amman, Jordan.

MWI, Jordanian Ministry of Water and Irrigation. (2003). Website: http://www.mwi.gov.jo/ministry_of_water_and_irrigationout.htm

MWI, Ministry of Water and Irrigation. (1998). Irrigation water policy. Policy Paper No. 2, February, 1998. Amman, Jordan.

NIS, Jordanian National Information System. (2003). Jordan. Website: http://www.nis.gov.jo, Jordan

ONAS, Tunisian National Sewerage and Sanitation Office. (1999). Annual Report. Tunisia.

ONAS, Tunisian National Sewerage and Sanitation Office. (2000). Annual Report. Tunisia.

Shatanawi, M. and Salman, A. (2002). Impact of full cost recovery on irrigation water in the farming economics in the Jordan Valley. University of Jordan, Amman.

Taha, S. and Bataineh, F. (2002). Valuation of water for domestic use: the case of Jordan. Water Demand Management Forum, Water Valuation, Beirut, Lebanon.

Chapter 4 Performance and Cost of Wastewater Treatment in Jordan and Tunisia

4.1 Introduction

The MENA countries have a considerable rate of sewage collection, yet the rate of wastewater treatment is still low and subsequently is responsible for the overall low utilization of wastewater as a basic water resource, and thus for a low *Wastewater Reuse Index* (*WRI*) (Chapters 2 and 3). This Chapter assesses the experience of Jordan and Tunisia in treating the municipal wastewater that already is collected in urban and peri-urban communities. The opportunity for then re-using this treated wastewater in irrigated agriculture will be discussed in Chapters 5, 6, 7, and 8.

Lagoons (L), activated sludge systems (AS), and trickling filters (TF) are the most frequently used systems for municipal wastewater treatment in the region (Bahri, 1998; Jamrah, 1999; Faruqui, 2000) (see also Chapter 2). These systems have, in theory, good performance to produce treated effluents suitable for restricted irrigation (Tchobanoglous and Burton, 1991). However, in practice, each treatment system performs differently depending upon technology-related aspects (which are called by Alaerts *et al*. (1991) the *hardware*), and the enabling environment for the proper functioning of this system (which is called by Alaerts *et al*. (1991) the *software*). The factors that determine the performance of a wastewater treatment system are (i) appropriateness of design and implementation, (ii) wastewater characteristics, (iii) climatic conditions, (iv) O&M skills, (v) availability of funds, (vi) availability of replacement equipment and materials, (vii) quality of management and institutions, and (viii) stringency and enforcement of standards and regulations for effluent discharge or reuse (Figure 4.1). The overall performance of the treatment technologies, or its cost-effectiveness, can be assessed based on the achieved effluent quality and the treatment costs.

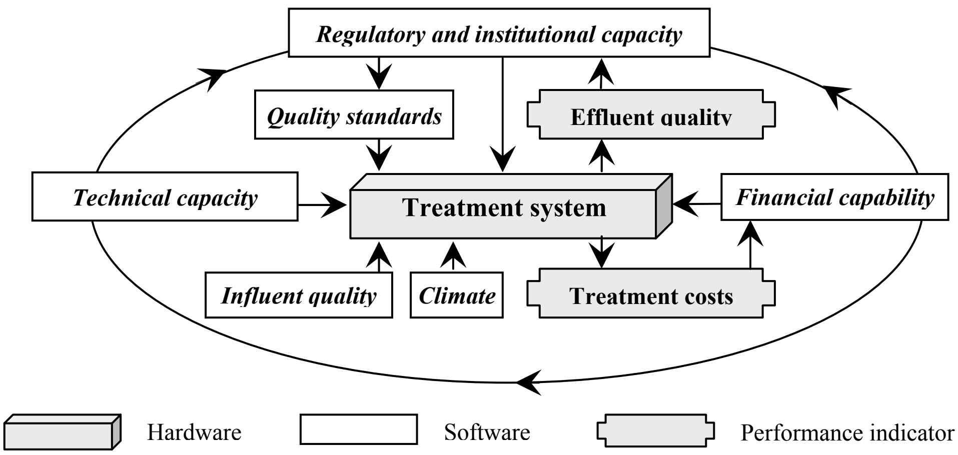


Figure 4.1: Major factors affecting the performance of wastewater treatment systems.

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The following considerations and criteria are proposed in literature to assess the appropriateness of the wastewater treatment technologies:

- Technologies have to provide the most socially and environmentally acceptable level of service at the least economic cost (Kalbermatten *et al*., 1982).
- Technologies must have a low land requirement if land is not abundant at reasonable cost (Salameh and Bannayan, 1993; Ghazzawi, 1996, Tsagarakis *et al*., 2003).
- Technologies should have a low capital investment need and require low energy input and mechanization, in order to reduce the risk of malfunction (CEHA, 1995; Frijns and Jansen, 1996; Boller, 1997).
- Technology selection should account for the availability and regular supply of skilled labor, local manufacturing, and O&M potential for the equipment (Veenstra and Alaerts, 1996).
- Technologies should be capable to produce treated effluents suitable for discharge/reuse. For reuse in agricultural irrigation, the overriding criterion must be the capability to achieve acceptable levels of pathogen reduction and to ensure certain level of nutrients in the treated effluent (Yu *et al*., 1997).
- The selection of any treatment technology must be accompanied in advance by a detailed examination of the country's self-sufficiency and technological capacity (Rose, 1999).
- Technologies should be capable of being incrementally upgraded as user demand or quality standards and treatment guidelines increase (Boller, 1997).
- Sophisticated and expensive technologies have no chance of working for long in developing countries, where usually there are insufficient trained staff, facilities for maintenance, and funds (Kalbermatten, 1999).

Lagoons have been traditionally considered the technology of choice for domestic wastewater treatment in arid and semi-arid countries when land is abundant at moderate cost. However, the population growth and expansion of the residential areas have rapidly increased the value of land. Lagoons now are less popular in the MENA region because they are recognized as land consuming, groundwater polluting, and as a nuisance to the public due to odor problems, insect infestation, landscape distortion, and depreciation of the land value in the neighborhoods (Salameh and Bannayan, 1993; Jamrah, 1999). Moreover, the evaporation rate is very high, and this acts against water saving policies. Since the 1980s, this has negatively influenced the perception concerning the appropriateness of lagoons, and it has promoted mechanical treatment systems even though they are known as sophisticated and expensive, such as activated sludge systems and trickling filters (Ghazzawi, 1996). The Economic and Social Development Plan (1998-2002) of the Ministry of Water and Irrigation (MWI) proposed in 1997 plans and budget estimates to gradually convert all lagoon systems in Jordan into mechanical systems. Likewise, in Tunisia, almost all newly constructed wastewater treatment plants (WWTPs) employ mechanical systems. Therefore, the performance of these sophisticated treatment technologies such as activated sludge systems and trickling filters remains questionable given that the enabling environment for the proper functioning of these technologies arguably is still weak.

4.2 Objective

The objective of this chapter is to assess and better understand the performance of wastewater treatment in the MENA region based on the past 20-30 years experiences in Jordan and

Tunisia. This assessment comprises (i) the technical performance of WWTPs and the costs required to achieve this performance, (ii) to address the question "do the MENA countries manage to make the treatment systems work?", and "is there room for improvement?", and (iii) the relevance of conventional wastewater treatment technologies in a policy context that aims increasingly at reuse in agriculture.

In the countries of the study (Jordan and Tunisia) central government agencies typically collect data on the wastewater treatment plants from an environmental protection objective, whereas the offices at the individual plants collect data pertaining to process control. However, these data are not always compatible. Moreover, no agency tends to collect and analyze data and other information from the perspective of overall *sector* management performance, or at sector policy level. Hence, to fill this gap, a subsidiary objective of this study is to collect reliable data that address this concern from existing data-bases, and to generate additional data for this purpose from the field sites.

4.3 Technical performance of the treatment systems

4.3.1 Data collection and analysis

Thirty-one WWTPs were selected and surveyed in the two countries based on the following criteria:

- 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. In both countries, the capacity of most existing WWTPs is less than 15,000 m^3/day (Annex C). However, three larger plants[8] 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.
- 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 without knowing whether they are cases of success or failure.

Table 4.1: 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%)*

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

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

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 4.1 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 (Annex C). The MWI and ONAS receive weekly, monthly, and annual reports from their local laboratories available at each treatment plant as well as from their central laboratories. 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. The collected data covered the summer (dry) and winter (wet) seasons. The summer months were chosen to cover the months of May through October of each year, while the winter months cover November through April. The collected data were analyzed for each country on a year-average basis. However, averaging out unequal sets of grab sample values was a limitation (Tables 4.3 and 4.4).

Table 4.2: Standards for wastewater treatment effluent in selected MENA countries.

Parameter	*Jordan*	*Tunisia*	*Israel*	*Kuwait*	*Saudi Arabia*
BOD_5 (mg/l)	150	30	35	10	10
COD (mg/l)	500	90	-	40	-
TSS (mg/l)	200	30	30	10	10
Coliforms (MPN/100 ml)	1,000	-	250	1,000	2.2

Source: USEPA, 1992; Al-Lafi, 1996; WERSC, 1998.

In the MENA region in general, wastewater treatment facilities are often planned and designed with little concern for reuse, since the common approach adopted so far is based on producing effluents that comply with the discharge requirements set for "traditional" pollution control objectives (Section 4.5.2). Tunisia is mainly concerned about coastal protection. Jordan is mainly concerned about protection of groundwater and surface water resources that are used for potable water purposes. Thus, the performance of WWTPs in the region is normally judged based on the removal efficiencies of BOD, COD, and TSS, with less concern for pathogen removal and nutrients content. Table 4.2 shows that the implicit objectives for wastewater treatment vary from one country to another, which can be attributed to their respective technical and economic capabilities. In Israel and the oil-rich Gulf States, stricter requirements and standards are adopted than in other countries like Jordan and Tunisia. Thus, the Jordanian WWTPs are judged based on their capability to produce effluent quality consistent with the following guidelines (USEPA, 1992; Al-Lafi, 1996; WERSC, 1998): BOD <150 mg/l, COD <500 mg/l, TSS <200 mg/l, TDS 2,000 mg/l, NH_4-N 25-50 mg/l, NO_3-N 0.5-50 mg/l, PO_4-P <15 mg/l, and faecal coliform <1,000 MPN/100ml. The Tunisian WWTPs are judged based on their capability to produce effluent quality consistent with the following guidelines: BOD <30 mg/l, COD <90 mg/l), TSS <30 mg/l, and faecal coliforms <1,000 MPN/100 ml. These objectives reflect the standards and guidelines adopted in the two countries for using the reclaimed wastewater in restricted irrigation (Chapter 5). The actual and design organic loads (kg BOD/day) are compared for each of the surveyed WWTPs in order to check for overloading.

The local laboratories available at most of the WWTPs in the two countries check the treatment performance by collecting daily grab samples from the influent and effluent of each unit in the treatment train. The central laboratories monitor the overall treatment system with less concern for performance of the units within the process. They collect grab samples from the influent and effluent of the treatment plants as well as from different locations along the conveyance system to the reuse/discharge sites. There was no other choice but accepting year-averages of the collected data despite the limitation of (i) averaging out grab sample values, and (ii) averaging out unequal sets of values. Both countries follow the *Standard Methods for the Examination of Water and Wastewater by the American Public Health Association* (APHA, 1995). The BOD_5 is measured without settleable solids (filtered sample). The COD is measured by the $K_2Cr_2O_7$-digestion method. Lack of complete information on TDS, NH_4-N, NO_3-N, and PO_4-P in Tunisia, and of other indicators such as heavy metals and SAR in the two countries, prevented using them in the overall assessment.

The analysis of the microbiological processes that occur within the various stages of treatment is beyond the scope of this research. In addition to effluent quality, the technical performance of the surveyed WWTPs also included land area and energy requirements. The requirements for personnel and spare parts and supplies, which are also of a technical nature, are discussed in the operational cost section.

Table 4.3: Effluent characteristics of the surveyed WWTPs in Jordan (year-averages).

WWTP	*Type*	*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	33	123	68	1,168	185	2	38	1,000
Abu Nuseir	AS	17	79	29	823	37	11	23	222
Fuheis	AS	11	72	21	669	1	94	14	850
Ramtha	L	239	540	361	1,546	159	4	43	2,000
Aqaba	L	111	407	384	879	63	250	20	24,330
Mafraq	L	198	525	249	1,432	135	3	68	28,840
Madaba	L	282	784	239	1,439	109	3	37	25,201
Karak	TF	46	225	82	896	72	10	56	1,500
Kufranja	TF	65	209	34	935	80	23	35	3,198
Tafila	TF	35	138	47	798	14	35	33	1,272
Baq'a	TF	80	348	115	1,093	88	3	43	38,330

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

Table 4.4: Effluent characteristics of the surveyed WWTPs in Tunisia (year-averages).

WWTP	*Type*	*BOD (mg/l)*	*COD (mg/l)*	*TSS (mg/l)*	*Faecal coliform (MPN/100 ml)*
SE1 Hammamet	AS	17	70	15	41,000
SE3 Nabeul	AS	19	92	23	290,000
Wardanin	AS	15	77	20	na
Grombalia	AS	14	76	13	920,000
Sahline	AS	9	52	8	410,000
Mejdez El Bab	AS	27	75	21	28,000
Beja	AS	43	267	42	43,000
Hammamet Sud	AS	24	90	24	23,000
Menzel Borguiba	AS	11	61	11	15,000
Rades	L	96	381	184	3,000
Lella Meriam	L	97	197	56	170,000
Houmt Essouk	L	68	193	51	3,000
Kalaat El Andalos	L	87	330	130	3,500
Sidi Bou Ali	L	49	302	58	na
Monastir El Ghadir	TF	16	77	17	na

Table 4.5: Actual vs. design capacity of the surveyed WWTPs.

	WWTPs	*Type*	*Year*	*Actual plant capacity (m^3/day)*	*Design plant capacity (m^3/day)*	*Actual/design capacity ratio*	*Actual BOD load (kg/day)*	*Design BOD load (kg/day)*	*Actual/design load ratio*	*Specific BOD load (kg BOD/PE.day)*
Jordanian WWTPs (1999)	*Abu Nuseir*	OD+RBC*	1986	1,411	4,000	0.35	895	4,400	*0.20*	0.06
	Fuheis	AS	1997	1,019	2,400	0.42	690	2,388	*0.29*	0.05
	Jerash	EA	1983	1,603	3,500	0.46	1,794	4,045	*0.44*	0.06
	Baq'a	TF	1988	10,284	6,000	**1.71**	14,747	5,400	***2.73***	0.07
	Karak	TF	1988	1,146	786	**1.46**	835	848	***0.99***	0.06
	Kufranjah	TF	1989	1,734	1,900	0.91	2,308	1,615	***1.43***	0.07
	Tafila	TF	1987	851	800	0.53	802	1,680	*0.48*	0.11
	Aqaba	L	1987	8,774	9,000	0.97	3,097	8,100	*0.38*	0.06
	Madaba	L	1989	3,609	2,000	**1.80**	4,988	1,700	***2.93***	0.07
	Mafraq	L	1988	1,933	1,800	**1.07**	1,094	1,485	*0.74*	0.06
	Ramtha	L	1987	2,174	1,920	**1.13**	2,596	1,574	***1.65***	0.08
Tunisian WWTPs (2000)	*Hammamet SE1*	AS	1980	3,646	4,208	0.87	963	1,321	*0.73*	0.04
	Hammamet Sud	EA	1995	5,433	11,386	0.48	2260	2,722	*0.83*	0.08
	Nabeul SE3	OD	1981	2,326	3,500	0.66	435	720	*0.60*	0.04
	Grombalia	OD	1993	2,165	2,445	0.89	916	1,900	*0.48*	0.05
	Beja	EA	1994	7,302	14,000	0.52	9,916	7,800	***1.27***	0.10
	Mejdez El Bab	EA	1994	933	4,500	0.21	558	2,000	*0.28*	0.03
	Menzel Borguiba	EA	1997	4,024	11,065	0.36	1,360	4,700	*0.29*	0.02
	Wardanin	OD	1993	1,060	1,500	0.71	525	600	*0.87*	0.04
	Sahline	OD	1993	3,001	2,560	**1.17**	957	750	***1.28***	0.15
	Kalaat El Andalos	L	1994	379	1,500	0.25	228	680	*0.33*	0.02
	Rades	L	1976	1,282	700	**1.83**	454	265	***1.71***	0.04
	Sidi Bou Ali	L	1996	385	644	0.60	132	446	*0.30*	0.04
	Houmt Essouk	L	1991	1,733	3,500	0.50	704	1,500	*0.47*	0.03
	Lella Meriam	L	1982	797	1,726	0.46	309	540	*0.57*	0.09
	Monastir El Ghadir	TF	1962	2,633	2,600	**1.01**	908	1,200	*0.76*	0.02

AS: activated sludge; OD: oxidation ditch; EA: extended aeration; L: lagoon; TF: trickling filter.

* RBC: rotating biological contactor (out of service).

4.3.2 Effluent quality

4.3.2.1 Biochemical and chemical oxygen demands

The 5-day biochemical/biological oxygen demand (BOD_5 or BOD) is the most widely used parameter of organic pollution. It measures the dissolved oxygen used by microorganisms in the biochemical/biological oxidation of organic matter. Despite its widespread use, the BOD test has a number of limitations, namely (i) it only measures the biodegradable organics, and (ii) it requires an arbitrary long time to give results (Metcalf and Eddy, 1991). However, it is frequently used to (1) determine the approximate quantity of oxygen required for biological stabilization of organic matter present, (2) determine the size of the wastewater treatment plant, (3) measure the efficiency of treatment processes, and (4) determine compliance with prescribed requirements for reuse or discharge. The chemical oxygen demand (COD) measures the biologically and chemically degradable content of organic matter in both wastewater and natural waters, thus, it is more inclusive than BOD. In general, the COD is higher than the BOD because more compounds can be chemically oxidized than can be biologically oxidized.

In most municipal wastewater where organics are readily degradable, the COD/BOD ratios are typically 1.25-2.5 (Metcalf and Eddy, 1991). When the wastewater also contains nonbiodegradable organics, the effluent COD may exceed influent COD. Some nonbiodegradable organics will accumulate during biooxidation due to oxidation byproducts of organic matter in the wastewater and byproducts of the endogenous microbiological metabolism (Jamrah, 1999). It is important to develop correlations between BOD and COD concentrations, which must be defined for each individual wastewater (Viessman and Hammer, 1985). There is generally no correlation between BOD and COD when organic suspended solids that are present in the wastewater are only slowly biodegradable. Ideally, for a wastewater that is composed of biodegradable organic substances, the COD concentration approximates the ultimate carbonaceous BOD. Yet, this simple relationship is rarely substantiated when testing municipal wastewaters. Many organic compounds can be oxidized chemically that are only partly biodegradable. There is generally also no correlation between BOD and COD in complex effluents containing refractory substances (Eckenfelder, 1989). For this reason, treated effluents may exert virtually no BOD and yet exhibit a high COD. Since the COD will report virtually all organic compounds, many of which are either partially degradable or nonbiodegradable, it is proportional to the BOD only for readily assimilable substances such as sugars. The gradual oxidation of reduced nitrogen in the wastewater such as ammonical nitrogen and proteins, also contributes to oxygen consumption during the treatment process. However, in the BOD measurement this oxidation is precluded, while the COD may to some extent incorporate oxygen demand due to these reactions.

Table 4.6: Influent COD/BOD ratios according to country and treatment system (year-average)

Country	*AS*				*TF*				*L*			
	Min.	*Max.*	*Avg.*	*STD.*	*Min.*	*Max.*	*Avg.*	*STD.*	*Min.*	*Max.*	*Avg.*	*STD.*
Jordan (n=3, 4, 4)	1.9	2.3	2.2	0.2	1.2	2.7	2.1	0.7	1.9	3.7	2.6	0.8
Tunisia (n= 9, 1, 5)	1.9	3.0	2.4	0.4	3.1	3.1	3.1	-	1.7	3.2	2.2	0.6
Both countries (n=12, 5, 9)	1.9	3.0	2.3	0.3	1.2	3.1	2.3	0.8	1.7	3.7	2.4	0.7

Table 4.7: Effluent COD/BOD ratios 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)	3.7	6.5	*5.0*	1.4	3.2	4.9	*4.1*	0.7	2.3	3.7	*2.8*	0.6
Tunisia (n= 9, 1, 5)	2.8	6.2	*4.8*	1.1	4.8	4.8	*4.8*	-	2.0	6.2	*3.8*	1.6
Both countries (n=12, 5, 9)	*2.8*	*6.5*	*4.9*	*1.1*	*3.2*	*4.9*	*4.2*	*0.7*	*2.0*	*6.2*	*3.4*	*1.3*

Table 4.8: Influent BOD (mg/l) 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)	634	1,119	*810*	268	729	1,434	*1,109*	330	353	1,382	*874*	492
Tunisia (n= 9, 1, 5)	187	1,358	*489*	348	345	345	*345*	-	343	601	*418*	105

Table 4.9: Effluent BOD (mg/l) 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)	11	33	*20*	11	35	80	*57*	20	111	282	*208*	73
Tunisia (n= 9, 1, 5)	9	43	*20*	10	16	16	*16*	-	49	97	*79*	21

Table 4.10: Removal of BOD (%) 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)	97.1	98.4	*97.6*	0.7	93.7	96.3	*94.9*	1.1	65.0	80.0	*73.3*	7.6
Tunisia (n= 9, 1, 5)	89.8	97.2	*95.3*	2.4	95.4	95.4	*95.4*	-	72.9	85.7	*80.5*	6.1

Table 4.11: Influent COD (mg/l) 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)	1,233	2,523	*1,769*	672	1,538	3,922	*2,255*	1,122	903	5,107	*2,413*	1,886
Tunisia (n= 9, 1, 5)	452	2,628	*1,100*	651	1,074	1,074	*1,074*	-	659	1,213	*888*	244

Table 4.12: Effluent COD (mg/l) 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)	72	123	*91*	28	138	348	*230*	87	407	784	*564*	158
Tunisia (n= 9, 1, 5)	52	267	*96*	66	77	77	*77*	-	193	381	*281*	83

Table 4.13: Removal of COD (%) 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)	93.6	95.4	*94.7*	1.0	87.3	91.1	*89.4*	1.9	54.9	84.6	*69.3*	13.6
Tunisia (n= 9, 1, 5)	79.6	94.8	*90.5*	4.6	92.8	92.8	*92.8*	-	47.1	74.8	*67.4*	11.5

Results of this study show that the average influent COD/BOD ratios for the activated sludge (AS), trickling filter (TF), and lagoon (L) systems are about 1.9-3.0(average 2.3), 1.2-3.1(2.3), and 1.7-3.7(2.4), respectively (Table 4.6, Annex C). These results show that raw sewage in Jordan and Tunisia contains a high percentage of nonbiodegradable organic matter, compared with sewage in industrialized or more temperate regions (Metcalf and Eddy, 1991). This is probably mainly due to the presence of fractions of industrial wastewater (about 5-8%) and to the combined sewer systems used. The COD/BOD ratios become even higher for treated effluent, with 2.8-6.5(4.9), 3.2-4.9(4.2), and 2.0-6.2(3.2) for the AS, TF, and L systems, respectively (Table 4.7). This indicates that the proportion of the nonbiodegradable content in treated effluent is relatively higher than that in raw wastewater and that the efficiency of BOD removal is higher than that of COD removal. The results also show that the COD/BOD ratios for the treated effluents are highest in the case of the AS systems; indicating a more favorable performance based on BOD removal, compared to that of the TF and L systems (Tables 4.3-13). The somewhat disappointing performance of lagoons can be partly attributed to the common problem that these systems where the first to be built in the region, but tend to be grossly overloaded by now. In addition, the technology has erroneously acquired the reputation that it is "simple" in operation, and this may have lead to directing more resources and process knowledge to the mechanical treatment plants. Finally, it must be borne in mind that the lagoon effluents often carry over algal biomass which is reflected in the effluent BOD and COD values, but by itself does not represent "pollution"—or what is more relevant in the reuse context, presence of pathogens.

Figures 4.2 and 4.3 present the relationships between the BOD and COD of the influent and effluent for the individual WWTPs in Jordan and Tunisia, respectively. The coefficients of determination (R^2) represent the proportion of the variance of the COD that can be explained by the BOD; the closer this coefficient is to unity the more the variation in the COD can be explained by the variation in the BOD. A positively correlated relationship exists between BOD and COD both for the influent and effluents of the AS plants in the two countries. The results for the TF plants are less conclusive because (i) the sample is small, (ii) the high strength of influent, and (iii) the fact that many of these plants are overloaded. The results for the L plants are also inconclusive, which is mainly attributed to (i) the high strength of influent, (ii) the fact that many of these plants are overloaded, and (iii) lower removal efficiency on BOD, COD, and TSS, partly because of the high algal content of the effluent.

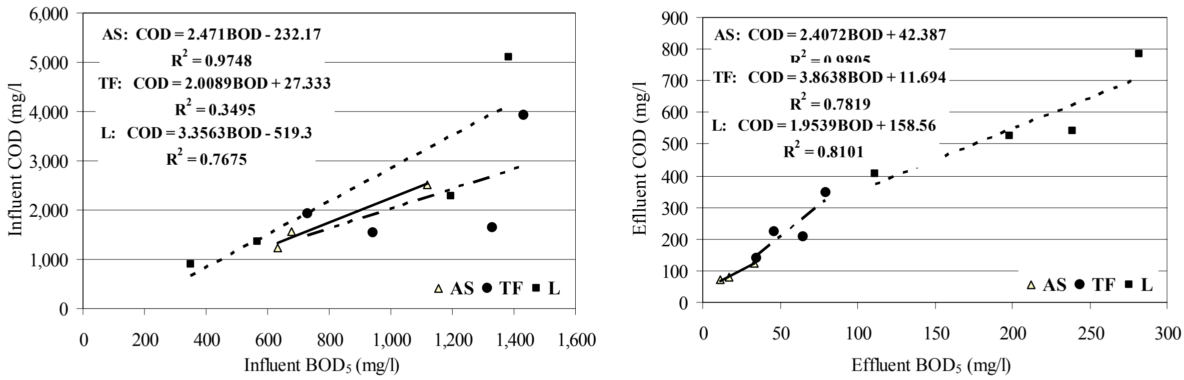


Figure 4.2: BOD_5 vs. COD for the surveyed WWTPs in Jordan.

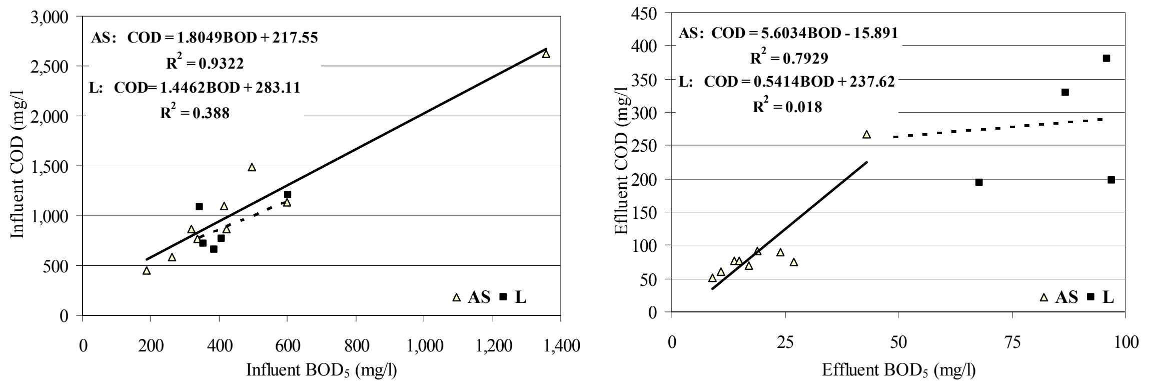


Figure 4.3: BOD_5 vs. COD for the surveyed WWTPs in Tunisia.

The three surveyed AS plants in Jordan meet the prescribed objective for removal of BOD (<150 mg/l) and COD (<500 mg/l). Eight of the nine surveyed AS plants in Tunisia meet the requirement for BOD removal (<30 mg/l), while seven plants meet the requirement for COD removal (90 mg/l). The five surveyed TF plants in Jordan and Tunisia meet the requirement for BOD and COD removals. None of the surveyed L plants in both countries meets the requirement for BOD removal. Only one L plant in Jordan and none of the five surveyed L plants in Tunisia meet the prescribed requirement for COD removal.

In the case of the AS and TF plants, the scale of treatment does not influence the removal efficiencies of BOD (95%) and COD (90%), while in the case of L plants when the plant capacity increases from 1,000 to 9,000 m^3/day, the removal efficiencies of BOD and COD decrease by about 15% and 20%, respectively (Figure 4.4), which mainly due to overloading of lagoons.

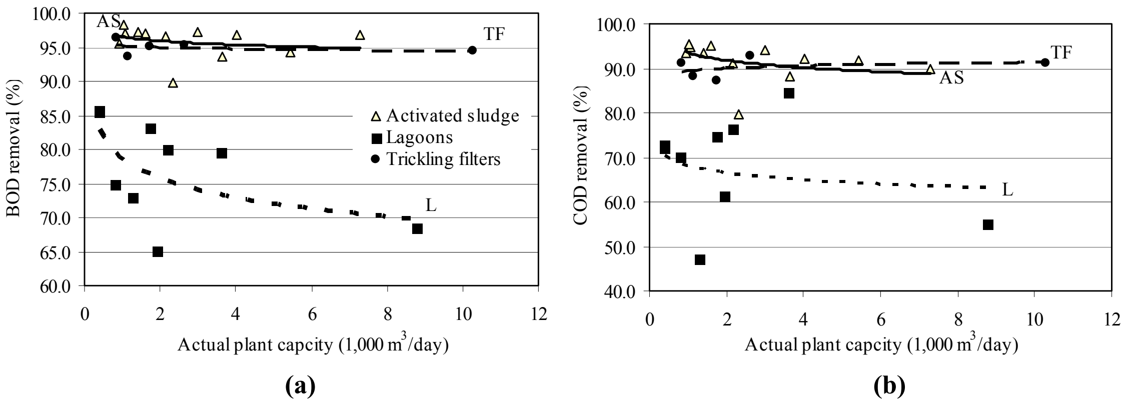


Figure 4.4: Effect of plant scale on (**a**) BOD and (**b**) COD removal.

4.3.2.2 Suspended and dissolved solids

Total suspended solids (TSS) can lead to the development of sludge deposits and anaerobic conditions when poorly treated wastewater is discharged in the aquatic environment, and, in a reuse context, it has negative impact on maintenance of irrigation system, especially sprinkler and drip systems (Pettygrove and Asano, 1985). Thus, the effluent TSS concentration is an important performance indicator of WWTPs. In Jordan and Tunisia, WWTPs are often designed with the objective to reduce the concentration of TSS to less than 200 mg/l and 30 mg/l, respectively, although these values are geared more to the environmental protection objective than to the reuse objective. This study shows that all the surveyed AS and TF plants in the two countries meet the respective TSS requirement. Out of nine L plants surveyed in both countries, only two Tunisian plants meet the TSS requirement, which is mainly due to lagoons overloading.

In the case of AS and TF plants, the scale of the plant does not influence the TSS removal efficiency (95%), while in the case of lagoons, plant capacity increase from 1,000 to 9,000 m^3/day is correlated with decreasing TSS removal efficiency by about 25% (Figure 4.5).

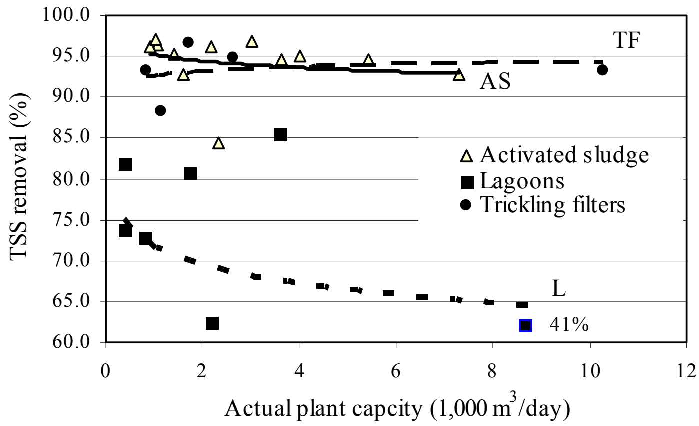


Figure 4.5: Effect of plant scale on TSS removal.

Table 4.14: Influent TSS (mg/l) according to treatment system in Jordan.

Country	*AS*				*TF*				*L*			
	Min.	*Max.*	*Avg.*	*STD.*	*Min.*	*Max.*	*Avg.*	*STD.*	*Min.*	*Max.*	*Avg.*	*STD.*
Jordan (n=3, 4, 4)	601	943	755	174	697	1720	1035	482	266	1657	828	628
Tunisia (n= 9, 1, 5)	148	574	371	158	333	333	333	-	196	495	297	122

Table 4.15: Effluent TSS (mg/l) according to treatment system in Jordan.

Country	*AS*				*TF*				*L*			
	Min.	*Max.*	*Avg.*	*STD.*	*Min.*	*Max.*	*Avg.*	*STD.*	*Min.*	*Max.*	*Avg.*	*STD.*
Jordan (n=3, 4, 4)	21.0	68.0	*39.3*	25.1	34.0	115.0	*69.5*	36.5	239.0	384.0	*308.3*	74.9
Tunisia (n= 9, 1, 5)	8.0	42.0	*19.7*	10.0	17.0	17.0	*17.0*	-	51.0	184.0	*95.8*	59.1

Table 4.16: Removal of TSS (%) 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)	92.8	97.1	*95.0*	2.2	88.2	96.7	*92.9*	3.5	41.3	85.6	*63.1*	22.2
Tunisia (n= 9, 1, 5)	84.5	96.9	*94.1*	3.8	94.9	94.9	*94.9*	-	72.8	82.0	*77.3*	4.7

Total salt concentration (for all practical purposes, the total dissolved salts or TDS) is one of the most important agricultural water quality parameters, because the salinity of the soil water is related to, and often determined by, the salinity of the irrigation water. Plant growth, crop yield, and produce quality are affected by TDS in the irrigation water. Likewise, the rate of accumulation of salts in the soil, or soil salinization, is also directly affected by the salinity of the irrigation water. Results of this study show that all the surveyed WWTP effluents in Jordan meet the TDS requirement (<2,000 mg/l) for agricultural irrigation with reclaimed wastewater. The Tunisian standards for irrigation with reclaimed wastewater do not include TDS. The results from the surveyed WWTPs in Jordan show that the AS and TF plants are more effective that the L plants in meeting the TDS requirement for agricultural irrigation (Table 4.17). This can be attributed to some extent to algal growth and poor desludging of the overloaded L plants, but also to the fact that their influents tend to be more saline.

Table 4.17: Effluent TDS (mg/l) according to treatment system in Jordan.

AS (n=3)				*TF (n=4)*				*L (n=4)*			
Min.	*Max.*	*Avg.*	*STD.*	*Min.*	*Max.*	*Avg.*	*STD.*	*Min.*	*Max.*	*Avg.*	*STD.*
669.0	1168.0	*886.7*	255.5	798.0	1093.0	*930.5*	122.7	1432.0	1546.0	*1472.3*	63.9

4.3.2.3 Nutrients (NH_4-N, NO_3-N, and PO_4-P)

Nitrogen and phosphorus are two key nutrients to plants—both in the natural environment and in agriculture. When in open water bodies exposed to sun light, phosphorus and nitrogen stimulate algal growth that pollutes surface water by upsetting the oxygen balance in the water, and thus threatens the aquatic system (eutrophication). Reclaimed wastewater usually contains enough of these nutrients to supply a large portion of a crop needs (USEPA, 1992). However, nitrogen at the same time stimulates vegetative growth in most crops and may delay maturity and reduce crop quality and quantity. The nitrogen and phosphorus content in irrigation water, however, is not constant and would require continuous monitoring and adjustment. Similarly, it is difficult to control the timing and quantity of nutrient availability in the water supplies and achieve a reasonably consistent fertilizer application. The farmer may also doubt the very presence of these nutrients in his irrigation supply, and if for any reason there are losses in yields, the irrigation water will be the focus of dispute. Nitrogen and phosphorus can also cause maintenance costs due to weed growth and clogging of the conveyance system. Thus, the relative benefit of nitrogen (NH_4^+ and NO_3^-) and phosphorus (PO_4^{3-}) have to be carefully considered. Finally, it must be noted that a variable part of the organically bound nitrogen, e.g. that associated with proteins, is not measured by NH_4-N, but needs to be quantified by a Kjeldahl-N test. However, practice in the MENA region has not yet progressed to the point that these data are routinely available. The ammonical nitrogen, however, typically covers a quarter to all of the reduced nitrogen in sewage.

The Jordanian guidelines for agricultural irrigation with treated wastewater limit the concentrations of NO_3-N and NH_4-N to 50 mg/l (100 mg total-N/l). This study shows that the surveyed WWTPs in Jordan that meet the NH_4-N requirement (<50 mg/l) comprise two AS plants, one TF plant, and none of the four L plants. The effluent of two AS plants, the four TF plants, and three L plants meet the NO_3-N requirement (<50 mg/l) (Table 4.3 and 4.18). This means that the adopted treatment systems can potentially produce effluents suitable for use in irrigated agriculture. The wide variation of nitrogen content in reclaimed wastewater implies continuous monitoring prior to any reduction in use of artificial fertilizers by farmers.

Table 4.18: Effluent nutrients (mg/l) according to treatment system in Jordan.

Parameter	*AS (n=3)*				*TF (n=4)*				*L (n=4)*			
	Min.	*Max.*	*Avg.*	*STD.*	*Min.*	*Max.*	*Avg.*	*STD.*	*Min.*	*Max.*	*Avg.*	*STD.*
NH_4-N	0.5	185.0	*74.2*	97.7	14.0	88.0	*63.5*	33.6	109.0	159.0	*134.3*	25.0
NO_3-N	2.0	94.0	*35.7*	50.7	3.0	35.0	*17.8*	14.2	2.5	4.0	*3.3*	0.8
PO_4-P	*14.0*	*38.0*	*25.0*	*12.1*	*33.0*	*56.0*	*41.8*	*10.4*	*37.0*	*68.0*	*49.3*	*16.4*

For effluent discharge and artificial recharge, the Jordanian guidelines limit the concentration of NO_3-N to 25 mg/l, and that of NH_4-N and PO_4-P to15 mg/l. Only one AS plant, one TF plant, and none of the L plants meet the NH4-N requirement. Two AS plants, three TF plants, and three L plants meet the NO_3-N requirement, while only one AS plant and none of the TF or L plants meet the PO_4-P requirement (<15 mg/l). These figures show that strict environmental policies can be an incentive for using the reclaimed wastewater for irrigation.

In Tunisia, the concentration limit of NO_3-N, NH_4-N, and PO_4-P are not included in the guidelines for agricultural irrigation with treated wastewater, which suggests that the government does not believe these parameters as critical; this is an incentive to use reclaimed wastewater of low quality in irrigation. These parameters are included in the guidelines for discharge in the sea (NO_3-N, NH_4-N, and PO_4-P to 90, 30, and 0.1 mg/l, respectively) as well as in reservoirs and rivers (NO_3-N, NH_4-N, and PO_4-P to and 50, 1, and 0.05 mg/l, respectively). The concentrations of NO_3-N, NH_4-N, and PO_4-P in the effluents of 15 Tunisian WWTPs studied by Bahri (1998) range between 2.1-23.2 mg/l, 14.4-48.4 mg/l, and 1.23-4.34 mg/l, respectively.

It can be concluded that the activated sludge systems and trickling filters in the two countries are more efficient than the lagoons in reducing the concentrations of NH_4-N. The three systems are comparable in reducing the concentrations of NO_3-N and PO_4-P (Table 4.3). The suitability of the treated effluent for irrigation, discharge, or artificial recharge varies from one plant to another and from one system to another. Thus, the three systems are technologically capable to produce suitable effluents, in terms of nutrients, for agricultural reuse and safe discharge but all depends on the enabling environment to achieve such performance. Most WWTPs are fairly functioning (i.e., close to their theoretical performance), which suggests that the technical management and O&M of the collection and treatment systems function reasonably well. Those plants that are less performing such as lagoons are typically overloaded, which suggests that there is lack of investment and expansion; the performance is measured against standards. In general, the standards still seem more geared to environmental protection objectives than reuse objectives, which suggests some institutional weakness at the level of sector policy.

4.3.2.4 Faecal coliform

Even when the BOD_5 is reduced to low levels (<20 mg/l), the treated effluents may still contain large amounts of pathogenic bacteria, viruses, protozoa, and helminth ova. From the perspective of effluent reuse, these water characteristics are at least as, if not more important as the conventional BOD and COD values. The concentrations of faecal coliforms in treated effluents are still high compared to the quality guidelines adopted for effluent discharge and reuse (Chapter 5). The detention time in mechanical treatment systems is low, generally less than one day, which explains largely the poor effluent quality in terms of faecal coliforms, as borne out with the values observed in all Tunisian plants. The removal performance in the case of the Jordanian lagoons appears to be also low, probably because of their chronic overloading, and the poor desludging. The study (Table 4.19) shows that the effluents of the three surveyed AS plants in Jordan, none of those in Tunisia, and none of the TF or L plants in both countries, meet the requirements in terms of faecal coliforms that are typical for environmental protection objectives (<1,000/100 ml). Nevertheless, these effluents comply with the WHO guidelines for restricted irrigation but not with those for unrestricted irrigation. Therefore, tertiary or advanced treatment will have to be considered in time to improve the pathogens removal especially in those areas where the effluent is to be used for unrestricted irrigation.

Table 4.19: Faecal coliforms (1,000*MPN/100 ml) 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	1.00	*0.69*	0.41	1.27	38.33	*11.07*	18.19	2.00	28.84	*18.68*	14.56
Tunisia (n= 9, 1, 5)	15.00	920.00	*221.25*	318.94	na	na	-	-	3.00	170.00	*58.83*	96.27

4.3.3 Land requirement

The land requirement becomes a crucial factor in the selection of treatment technologies when land is not available at low price (Ghazzawi, 1996). The figures collected in the study (Table 4.20) refer to the entire area of the installation including any access paths or roads and ancillary units such as offices, store rooms, labs, etc. As would be expected, mechanical systems need less space than natural ones, at the expense, however, of higher costs for equipment, construction, and O&M. The results from 26 WWTPs show that the L plants require large land area (1.4-4.5(2.6) m^2/PE) compared with the AS plants (0.2-1.3(0.5) m^2/PE) and the TF plants (0.3-0.8(0.5) m^2/PE). The wide range of results for each type of treatment is attributed to the variation in sludge treatment processes; some plants are fully mechanized, others use drying beds. These values are consistent with other research findings; in Veenstra and Alaerts (1996), the land requirement for AS and TF systems is cited as 0.5-1 m^2/PE and for natural treatment systems 5-10 m^2/PE.

Table 4.20: Specific land requirement (m^2/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)	0.4	0.5	*0.4*	0.1	0.3	0.8	*0.6*	0.2	1.4	3.4	*2.3*	0.8
Tunisia (n= 9, 1, 5)	0.2	1.3	*0.6*	0.3	0.4	0.4	*0.4*	-	1.7	4.5	*2.8*	1.1
Both countries (n=12, 5, 9)	*0.2*	*1.3*	*0.5*	*0.3*	*0.3*	*0.8*	*0.5*	*0.2*	*1.4*	*4.5*	*2.6*	*0.9*

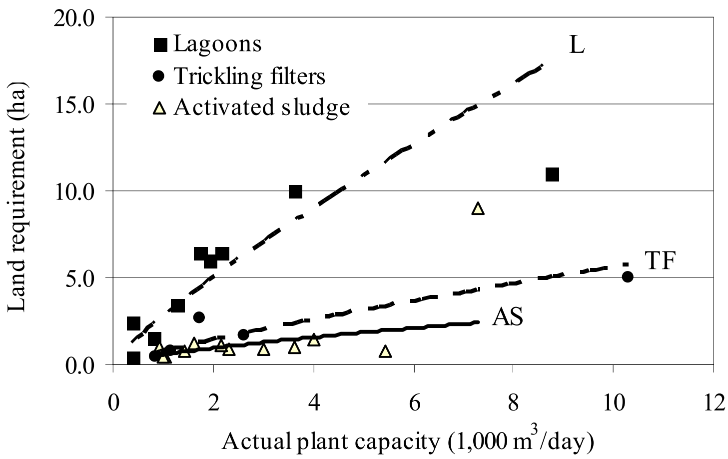


Figure 4.6: Effect of plant scale on land requirement (ha).

Increasing the treatment capacity drastically increases land requirement, especially for lagoons; for a doubling of capacity, the area increases by 50% for lagoons, and by 100% for the AS and TF plants (Figure 4.6). In general, it appears that lagoons for large communities require excessive land area.

It was reported by plant managers and land owners that the construction of WWTPs affects the value of neighboring land. They argue that people tend to avoid buying land in the vicinity of WWTPs because of odor, insects, and landscape distortions. The effect is highest in the close vicinity of treatment plants (within 100-500 meters of the plant perimeter) and the effect decreases with distance from the plant location. Although this phenomenon occurs near all surveyed treatment plants, it is more pronounced for the L plants than for the AS and

TF plants, possibly because of the large area of land that is occupied by a lagoon system (Ghazzawi, 1996). However, it was difficult to get estimates for the extent of this depreciation because the value of land strongly depends on the local demand. This depreciation influences the economic analysis of the treatment options, though it does not enter the financial analysis.

No evidence was found that property values near irrigated land are influenced by the type of irrigation water.

Land availability and value are site and country specific, however, it can be concluded that lagoon systems are probably less appropriate for MENA countries that witness a rapid population growth and an appreciation of land value, especially in and near urban areas. The site selection of a proposed treatment plant is to be based on a trade-off between land cost, plant cost, cost of the trunk sewer to carry wastewater outside the city, and the cost of conveyance of the treated effluent to the discharge and/or reuse site (Chapter 5).

4.4 Financial performance of the treatment plants

4.4.1 Analysis

The financial performance of the surveyed 26 WWTPs is assessed based on the (i) annuatized capital expenditure/cost (CAPEX), (ii) annuatized operational expenditure (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 4.1 (Metcalf and Eddy, 1991; Peters and Timmerhaus, 1991):

$$\textit{Equivalent cost at year } \boldsymbol{A} = \textit{Cost at year } \boldsymbol{B} \,.\, \frac{\textit{Cost index at year } \boldsymbol{A}}{\textit{Cost index at year } \boldsymbol{B}} \tag{4.1}$$

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.

4.4.2 Capital costs of 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 4.21: 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*

Table 4.22: 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 4.23: 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 4.24: 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 4.25: 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 4.26: 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$/PE/y) for the L plants is within the same range of that for the TF, and AS plants, which is 0.32-9.17(2.29), 0.51-8.4(3.08), and 0.43-8.45(4.07), respectively (Table 4.22). The per capita cost of equipment (US$/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 4.21). 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 4.23), and the construction cost as percentage of CAPEX averages 55.5%, 64.8%, and 83.3%, respectively (Table 4.24). 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 4.25 and 4.26). 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.

4.4.3 Operation and maintenance costs of treatment (OPEX)

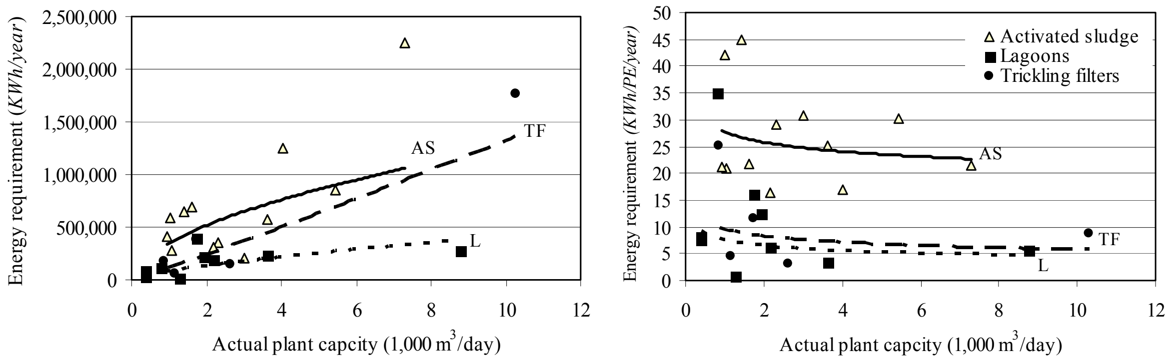
The operational expenditures (OPEX) can be divided into three major categories: energy, personnel, and spare parts and supplies (chemicals and maintenance). The operational costs of sludge treatment and disposal are included within these. Each of these categories is discussed below.

4.4.3.1 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 4.7.

In Jordan the annual per capita energy requirement (KWh/PE/y) for the AS plants is very 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 4.27). 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). 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 4.28). 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 4.29). 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 4.7: Energy requirement: (**a**) KWh/year, (**b**) KWh/PE/year).

Table 4.27: 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 4.28: 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 4.29: 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*

4.4.3.2 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 4.30). 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 4.31). 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 4.8a. 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 4.8b). 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 4.32). 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 4.9). 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 4.30: 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 4.31: 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 4.32: 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

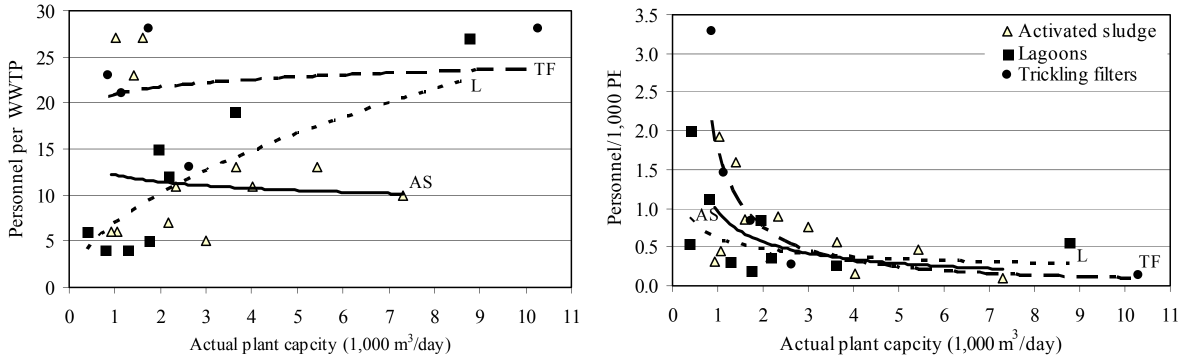


Figure 4.8: Effect of plant scale on total number of personnel: (**a**) per WWTP, (**b**) per 1,000 PE.

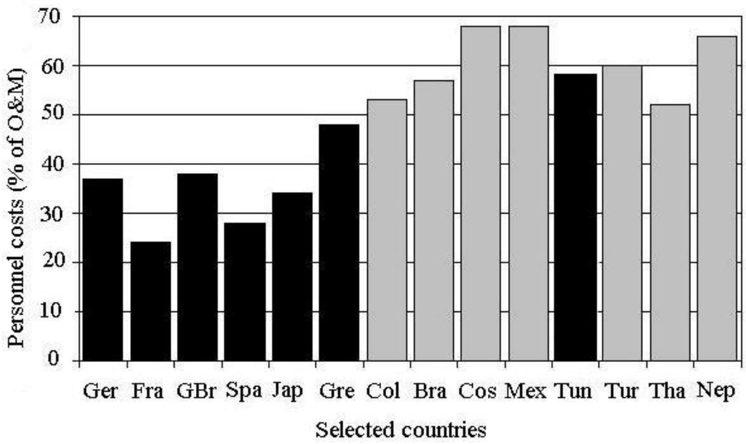


Figure 4.9: Personnel cost as percentage of OPEX in selected countries (Kemper *et al.*, 1994).

4.4.3.3 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 4.34). 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 4.33). Figure 4.10 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

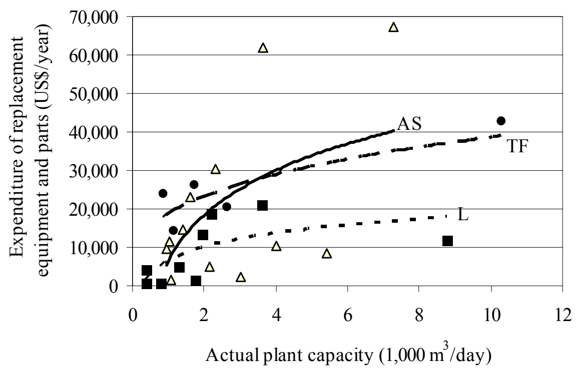
parts are not necessarily decisive in differentiating treatment technologies on their overall financial performance.

Table 4.33: Cost of equipment replacement and parts (US$/PE/y) according to country and treatment system.

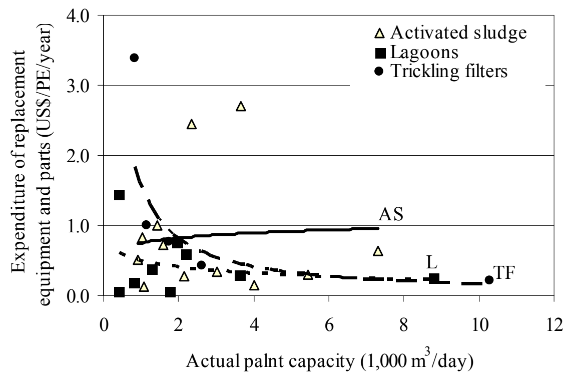
Country	*AS*				*TF*				*L*			
	Min.	*Max.*	*Avg.*	*STD.*	*Min.*	*Max.*	*Avg.*	*STD.*	*Min.*	*Max.*	*Avg.*	*STD.*
Jordan (n=3, 4, 4)	0.7	1.0	*0.9*	0.1	0.2	3.4	*1.3*	1.4	0.2	0.8	*0.5*	0.2
Tunisia (n= 9, 1, 5)	0.1	2.7	*0.8*	1.0	0.4	0.4	*0.4*	-	0.1	1.5	*0.4*	0.6

Table 4.34: 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 4.10: Effect of plant scale on expenditure on equipment replacement and parts: (**a**) US$/year, (**b**) US$/PE/year.

4.4.3.4 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 4.35). 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 4.37). 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 4.36). 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 4.35: 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 4.36: 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 4.37: 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

4.4.4 Total costs of treatment (TOTEX) and economies of scale

WWTPs with large capacity enjoy economies of scale (Figures 4.11-4.13). 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 4.38). 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 4.39). 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 4.38: 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 4.39: 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*

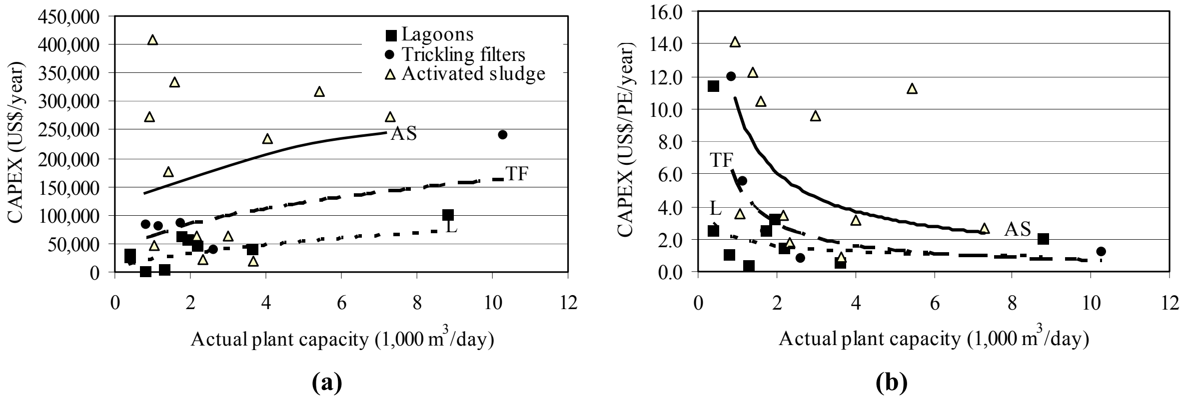


Figure 4.11: Effect of plant scale on CAPEX: (**a**) US$/year, (**b**) US$/PE/y.

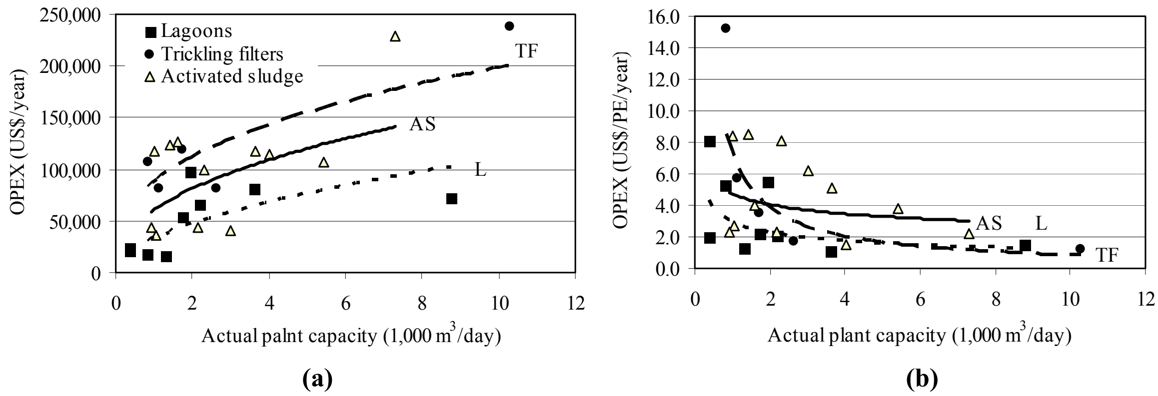


Figure 4.12: Effect of plant scale on OPEX: (**a**) US$/year, (**b**) US$/PE/y.

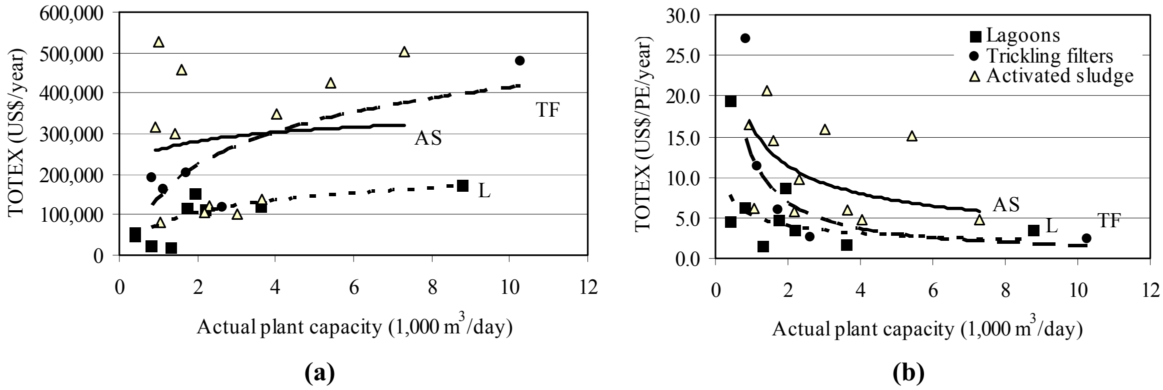


Figure 4.13: Effect of plant scale on TOTEX: (**a**) US$/year, (**b**) US$/PE/y.

4.5 The enabling environment for wastewater treatment

4.5.1 Approach

A total of 72 selected resource persons (58 administrators and 14 plant managers) were interviewed in Jordan and Tunisia (Chapter 3) using a descriptive questionnaire (Chapter 1 and Annex D.1). Respondents were asked to identify the major factors (obstacles) influencing performance of the wastewater treatment activities in their respective country. These responses were then weighted and ranked based on the times each factor was reported important. The results are displayed for country because responses varied markedly between the two countries. The respondents in both countries believe that good performance in wastewater treatment is constrained by a large number of factors; those that exert the highest effect (>70%) are bolded in Table 4.40. Although all factors are interrelated they are categorized into four major clusters: (i) performance of the treatment technologies, (ii) regulatory and institutional framework, (iii) financing, and (iv) technical capacity to manage wastewater facilities. These clusters are discussed below.

Table 4.40: Reported major obstacles affecting wastewater treatment performance in Jordan and Tunisia.

Factors	*Times a factor was reported as important*	
	Jordan, n =38 (%)	*Tunisia, n =34 (%)*
Performance of the treatment technologies:		
High cost of treatment	**74**	62
Inappropriateness of the selected treatment system	25	18
Regulatory and Institutional framework:		
Stringency of reuse standards and low demand for the treated effluent	**85**	65
Institutional deficiencies (such as overstaffing and inadequate cooperation)	**78**	52
Poor involvement of the private sector	41	**86**
Financing::		
Low local funding and over-reliance on grants and loans	**82**	**93**
Poor cost recovery	66	35
Technical capacity to manage wastewater facilities:		
Lack of local skills for design and construction of WWTPs	63	**79**
Over-reliance on foreign expertise	58	**72**
Lack of local skills for O&M of WWTPs	22	13

4.5.2 Regulatory and institutional framework

4.5.2.1 National strategies and regulations

The International Decade for Drinking Water Supply and Sanitation (1980-1990) witnessed major efforts and improvements in the sanitation service in all MENA countries (CEHA, 1995). Protection of public health and the environment was the primary incentive for these efforts, including the construction of WWTPs (Bazza, 2002). During the last thirty years, many WWTPs were built in each country to protect public health, the environment, and the water resources. Most of these plants were constructed close to the discharge points, mainly wadis, rivers, and seas. The treated effluent from the WWTPs was not recognized as a valuable product, which is still typical for the attitudes in developing countries (Gijzen, 2001). Israel, Jordan, and Tunisia were the first countries to recognize the importance of treated effluent since the 1960s. Nowadays, due to water shortage and the growing demand for increased water supply, the national strategies of all MENA countries recognize treated wastewater as a non-conventional resource of water and nutrients. These countries apply different quality standards for reuse of the reclaimed wastewater in irrigation, artificial recharge, and industries (Chapter 5). Increasingly now, efforts are made to make better use of the treated effluents from WWTPs that originally were designed for other purposes than reuse. In other words, the MENA countries have been applying a supply-driven policy and the consequences are often expensive and impractical, especially if the treated effluents have to be redirected and transported to faraway reuse sites. A more demand-driven approach (from a reuse perspective) has been introduced in many new-generation WWTPs. However, these attempts are still limited to civil-engineering considerations regarding the location of the WWTPs in the vicinity of agricultural lands, with unsatisfactory concern for the perceptions of the potential users of the reclaimed water (Chapters 5, 6, 7, and 8). Yet, large proportions of the reclaimed wastewater are still not reused but transported and discharged faraway. In order to succeed, attempts for the demand-driven approach must (i) include an in-depth pre-assessment of the local conditions for each scheme and of the perceptions of the farmers as well as the public, (ii) integrate environmental protection with water resources management and agricultural policies, and (iii) experiment with a much larger degree of participation and authority of the end-users/farmers in the original system design, as well as in management decisions of the treatment facility.

Deficiencies in the regulatory and legislative system soon results in poor policies, poorly specified authorities and responsibilities, administrative bottlenecks, lack of commitment and long-term vision of the administration, and lack of political support and administrative will to sanction breaches of the regulations and take emergency action. This is particularly evident where it concerns illegal connections to water supply or collection wastewater networks—which can affect quantity or quality objectives, respectively—especially by industries. Other critical deficiencies in the regulatory framework include: (i) persistent low tariffs, for political purposes, and thus poor cost recovery, (ii) insufficient involvement of the private sector, (iii) extensive delays in the reallocation of water to uses with higher economic returns, and (iv) inadequate water quality standards for reuse/discharge. These deficiencies are discussed where appropriate in the Sections below and in the forthcoming Chapters.

4.5.2.2 Institutional capacity of public authorities and utilities

Although the treatment performance, at a sectoral level as well as at the level of the individual WWTP, can be considered reasonable compared to what is achieved in industrialized countries on one hand, and the poorer developing nations on the other, the sectoral objectives and the sector's institutional capabilities are not particularly sophisticated or advanced. One of the major challenges for wastewater management in the MENA region is the institutional framework (see also Bazza, 2002). Wastewater management sectoral responsibilities, which include planning, design, construction, and O&M of collection systems, WWTPs, and reuse schemes, are usually fragmented among different governmental departments with no or little coordination. The various institutions that are directly involved in wastewater management in Jordan and Tunisia have been mentioned in Chapter 3. In addition to lack of cooperation between these bodies, the important tasks of monitoring and enforcement for the purpose of performance assessment and for corrective measures, are not clearly identified among them (Bazza, 2002) (see also Chapter 6). The other tasks in wastewater management are often regarded the sole responsibility of the households or the owners of the systems. Although national legislation often defines the requirements for safe wastewater disposal by individual households and industries, the responsibility for monitoring and ensuring compliance is not well defined (Bakir, 2000). Even more critically, the responsibility for monitoring and ensuring compliance for the purpose of stimulating reuse is not clarified either.

According to Saghir *et al*. (2000), substantial efforts have been undertaken in the past to improve the performance of public utilities through financial support for infrastructure investment, technical assistance, and covenants stipulating higher, more realistic tariffs. However, in the absence of a serious change in the institutional framework and in the overall incentive system, these efforts have met with modest success. The still disappointing performance of most public water and sanitation utilities can be attributed, to a large extent, to the administrative and political environment in which these utilities have to operate. Some of the important factors affecting the performance of public utilities are beyond their own control. For example, tariff increases are usually decided at higher, political level and often avoided due to political reasons. Arrears by public entities, which sometimes have insufficient budgetary allocations, lead them to not pay their bills, shifting the budget problem to the utilities. More important, public utilities are often expected to contribute to the alleviation of unemployment by hiring and keeping on their payroll a large number of low-qualified staff, some of which are not essential to maintaining operations. At the same time, utilities are subject to civil service salary rules, severely restricting their ability to attract, motivate, and maintain qualified personnel that is essential to successfully perform key technical and managerial functions. Thus, these institutions become overstaffed (see above in this chapter) and experience frequent changes in leadership and management. In order to minimize the impacts of change, the performance of permanent staff and the institutionalization of sectoral policies need to be strengthened.

4.5.2.3 Private sector involvement

The nature of certain duties and responsibilities within the water and sanitation sector are becoming increasingly unfit for execution by the governmental departments. Certain functions are better suited for execution by the private sector, capitalizing on their flexibility and quick response, especially in the field of maintenance. Partnerships with the private sector are meant to reduce budgetary pressures on public budgets, bring in operating efficiencies of specialized companies, and provide access to new technology, capital and skills. Yet this partnership is generally limited to the O&M in the water and sanitation sectors. Service contracting, which is the simplest form of private sector involvement, is very common in O&M of the Tunisia WWTPs. Private contactors are assigned specific tasks such as construction and equipment maintenance. As a result, the number of permanent personnel in most of the WWTPs is maintained low compared with that in Jordan (see earlier).

The external aid agencies, especially the World Bank, have put considerable efforts in promoting privatization as a partial solution for the financial deficiencies in the region. In spite of the strategies and the institutional arrangements that were put in place, public-private partnerships are still in their infancy. The main constraints to the program in Jordan include the limited absorptive capacity of the financial markets, public strategic preferences on foreign ownership, and public perceptions of the impact of privatization on labor and consumer prices (MWI, 1998). Recently, a number of public-private partnerships succeeded in infrastructure areas such as power generation, telecommunications, as well as in the water and sanitation sector. LEMA, which is a consortium formed by Lyonnaise des Eaux (75%) and MW Arabtech, was contracted in 1999 in the Greater Amman Water Management area for the O&M of the water supply and sewerage systems via a service-management support contract. In the first six months of the contract, the quality of service has significantly improved by (i) reducing the number of water leaks from 350 to 130, (ii) US$1.7 million unexpected revenue from sewage invoiced, and US$1 million collected, (iii) manpower reduced by returning 200 out of 1,350 staff that had been first transferred to LEMA , (iv) about 5,000 new water connections installed, (v) response time to complaints for sewerage problems reduced to less than 12 hours, (vi) a computerized accounting system purchased, customized, and implemented (vii) planned maintenance of pumps did reduce breakdowns by 80%, and (viii) 68% of the leaks repaired in less than 24 hours. At the same time, the water tariffs were kept unchanged. As a result, the Water Authority of Jordan (WAJ) has extended the contract until the end of 2004. Because private involvement is giving good results in Jordan, the government decided to widen the involvement of the private sector to the wastewater treatment sector. The Al-Samra WWTP, which is one of the largest lagoon systems in the world, is being upgraded via a BOT contract at a cost of US$125-150 million.

Involving the private sector in the late stages of the project causes more difficulties than if it is done in earlier stages. The major objective for the private investors is the financial profit; accordingly they launch improvements in the existing system by increasing the O&M efficiency on one hand, which is a virtue and should be a sectoral (public good) objective. On the other hand, upgrading the existing system increases cost and tariffs. The opportunity to recover costs, which is a fundamental incentive for attracting the private sector, is hindered by the current regulations that make tariff decisions highly, if not overly political.

In order to successfully attract the private sector and to improve the level and the efficiency of services, the role of the public authorities and utilities has to be redefined. It is essential that governments demonstrate a stronger political commitment, create an enabling legal and institutional framework, promote a high degree of technical skill among the civil servants regulating the operator, and ensure a fair and transparent bidding process. An appropriate regulatory framework is essential in order to provide strong incentives for the private sector to focus on the alleviation of poverty. The private operators could be requested to cover poor neighborhoods, identify the most appropriate levels of service in those areas in close collaboration with local communities, and design tariffs that do not discriminate against the poor (Saghir *et al*., 2000).

4.5.3 Financial capability

The shortages of finance for investment and the inability to recover costs from users still characterize the financial management of the water and sanitation sector in the two countries as well as in the other countries of the region. About 82% and 93% of the surveyed administrators in Jordan and Tunisia, respectively, believe that lack of financial resources on the national level increased over-reliance on external financial aids, especially for financing the investment (Table 4.40). This over-reliance adversely influences the infrastructural development, not because donor funding is not needed, but because searching for external funding has become the only option. Each country has a list of water and sanitation projects and searches for external grants and loans. Tables 4.41 and 4.42 show the financial flow of the WAJ where the deficit between the financial resources and revenues is about US$46 millions in year 1998. These figures do not include the interest on international loans as well as the installments for paying back of these loans (which are typically repaid from the national budget). The limited financial resources for the MWI do not allow improving the wastewater treatment sector without reliance on external resources. To overcome this problem, other financing options deserve better attention. This includes revising the water and sanitation tariffs as well as involving the private sector.

Full recovery of the actual cost of water and sanitation services, including the depreciation, is not yet a priority for any MENA country. However, the reliance on external aid for financing capital requirements encourages the current low tariffs since the only major concern is to recover the recurring costs that should be locally financed. The level of wastewater tariffs is usually very low, and in most countries of the region not even the O&M costs of sanitation services are recovered (Table 4.43). Governments at central levels tend to monopolize planning and decision-making, while community involvement which might increase the opportunities for local fund raising, is not sufficiently encouraged. The connection fees paid by subscribers to the sewerage network are considered to be contributions to the investment costs. The sanitation tariffs, which are based on the water consumption, are considered to be contributions to the recurring costs. In order to better address this issue, performance efficiency must be raised and water tariffs need to be restructured in line with the consumer's affordability and willingness to pay (Chapters 7 and 8).

Table 4.41: Financial resources of the WAJ for year 1998 (MWI, 1999).

Source of finance	*JD million*	*US$ million*
Water revenues	40.2	56.28
Sanitation revenues	14.8	20.72
Share from the Ministry of Finance	*20.9*	*29.26*
Share from the Government (German Debt Swap)	*4.1*	*5.74*
Share from the international loans	*16.5*	*23.1*
Share from the local loans	30.0	42
Share from grants and donations	*10.7*	*14.98*
Total income	*137.3*	*192.22*

Table: 4.42: Expenses of the water supply and sanitation in Jordan for year 1998 (MWI, 1999).

Item	*JD million*	*US$ million*
Operational and managerial expenses	51.6	72.24
Interest on local loans	19.7	27.58
OPEX	*71.3*	*99.82*
Installments for local loans	37.7	52.78
Development projects	61.1	85.54
CAPEX	*98.8*	*138.32*
TOTEX	*170.1*	*238.14*

Table 4.43: Wastewater operational cost and price in some MENA countries (Khouri, 1992).

Country	*Cost (US$/m^3)*	*Price (US$/m^3)*
Jordan	0.37	0.08
Kuwait	0.40	0.03
Syria	0.19	0.08
Tunisia	0.12	0.03
Turkey	0.26	0.23

4.5.4 Technical capacity to manage wastewater treatment

More than two thirds of the surveyed administrators in each of the two countries (Table 4.40) report that local capabilities in the realm of engineering, consultancy, and contracting are weak and have resulted in the over-reliance on foreign expertise (MWI, 1998). Despite the wide range of treatment technologies practiced worldwide, engineers and decision-makers in the region stick to only few technologies that they are familiar with; they don't have exposure to a broader variety of technological options. This restriction is attributed to cost considerations and lack of finance, lack of skills, time limitations, and more importantly, reliance on external funding and expertise, which often is associated with pre-determined choices. Even when local funds and expertise are involved, the role of foreign engineers and consultancy offices is still obvious. In the field survey, the foreign touches are clearly reflected in process design, layout, architecture and even landscape architecture for each surveyed WWTP.

On the other hand, only about 22% and 13% of the interviewed administrators in Jordan and Tunisia, respectively, consider the lack of O&M skills an obstacle for proper wastewater treatment in their respective countries. The O&M skills are comparatively abundant because Jordan and Tunisia have their own training programs and refresher courses for their O&M staff. In Tunisia, new staff members, regardless of their academic background, have to go through special training courses before they can start their assignment. The Tunisian efforts have been successful at the O&M level of WWTPs. This resulted in a reduced numbers of personnel while performance of WWTPs has improved. The case of Jordan is similar. However, effective performance of the O&M personnel is constrained by the higher-level institutional weaknesses such as poor regulatory enforcement, weak management and lack of incentives. As mentioned before, each WWTP has a few key senior staff whose role is decisive in the plant performance. It is common, however, that the highly qualified workers at the WWTPs prefer to move to better administrative positions in the same institution or somewhere else, where salaries are higher and community esteem is better. It has been noted, during the field visits, that Secondary and Diploma education levels are generally deemed satisfactory for staff assigned to the technical aspects of O&M of the plants. Thus, in conclusion, local availability of skilled personnel does not appear to be an obstacle for O&M of WWTPs.

The availability of construction materials and equipment does not seem to be a limiting factor for construction or O&M of wastewater treatment facilities in Jordan and Tunisia. Because both countries have good foreign trade systems, most of the essential equipments and materials are available in the local market, although they are often imported.

Despite the advancements in information technology and knowledge transfer, the openness to the industrialized world, and the existing regional networks, the dissemination of results and sharing of experiences that shorten the learning curve are often limited to the efforts of the external aid agencies. Only Tunisia has reasonable experience in cooperation with other MENA and African countries, where non-Tunisians are trained to manage wastewater treatment and reuse, based on the Tunisian experience. This cooperation deserves to be extended to cover all MENA countries.

4.6 Conclusions and recommendations

The main finding in this Chapter 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.

The weaknesses in the enabling environment work out at different levels of the institutional framework:

- The sectoral policies and objectives regarding wastewater treatment are not well elaborated and limited to "conventional" considerations that are still geared rather to environmental and public health protection. These environmental objectives tend to be too much derived from the experiences in industrialized countries with generally more temperate climates and less water scarcity.
- At more operational level, these policies that are less attuned to the local situation, have led to the selection of discharge regulations, WWTP effluent indicators, and WWTP treatment processes, that suggest a preoccupation with reducing oxygen consumption in receiving water bodies. The regulations and process selection are found to be much less geared to the objective of maximizing the amount of wastewater reuse, notably in agriculture.
- The public sector and, thus, the wastewater agencies, tend to be less performing, due to fragmentation, absence of strong incentives for excelling staff performance in this specific sector, and overstaffing in the administration.

However, both on the count of regulations and discharge standards, and on the count of process selection and treatment performance, the Tunisian sector was shown to perform better than that in Jordan. This may be explained partly by Tunisia's earlier start with wastewater management, as Jordan was mired in a regional conflict in the 60s and 70s. Jordan's lower progress, however, is in remarkable contrast with the fact that it experiences a much higher level of water resource shortage than Tunisia.

Almost all the surveyed activated sludge and trickling filter systems in Jordan and Tunisia are reasonably efficient in reducing the concentrations of the conventional organic pollution indicators BOD, COD, and TSS, and in achieving the guidelines for restricted irrigation in the two countries. In contrast, none of the surveyed lagoons complies with these guidelines. This is largely attributable to these lagoons being older and thus overloaded, as well as to the fact that some of the organic effluent standards (such as on TSS) may be less relevant for reuse purposes. However, all the surveyed plants, except for the three activated sludge plants in Jordan, fail to reduce the concentration of faecal coliforms to permissible levels (<1000/100 ml). Therefore, tertiary or advanced treatment (possibly including polishing lagoons) has to be considered to improve the removal of pathogens with the specific purpose for the effluent to be used for unrestricted irrigation. However, the existing WHO guidelines still allow such treated effluents with high faecal coliforms for restricted irrigation.

The activated sludge systems and trickling filters overall seem superior to lagoons in terms of effluent quality, land requirement, and popularity, but at the expense of costs. The lower performance on effluent quality can be retraced to their overloading. 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, the mechanical modifications to some natural lagoon systems 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 "enabling environment" in Jordan and Tunisia comprises the following:

i) Supply-driven approach. The adopted approaches for wastewater treatment process selection and designs in the two countries still have disposal into a river or other surface water body as the principal objective. Most of the existing WWTPs were designed for environmental protection, while reuse has rarely been recognized as a determining objective in the early decades of the planning and implementation of these plants. Even when reuse was considered, the assessment of the actual demand of the prospective reclaimed-wastewater-users is often very limited. This fragmented approach leads to a decidedly less well performing reuse policy. Moreover, the nutrients content in the reclaimed wastewater rarely has been considered an asset in the design criteria for WWTPs as well as in setting the quality standards and regulations for wastewater reuse. Therefore, wastewater that was once conceived as only a "waste to be disposed of" has increasingly become recognized as a highly valuable, sustainable source of water for an increasing number of applications, and as a viable part of the water cycle as well as a source of nutrients.

ii) Institutional framework. Planning, design, implementation, operation, and maintenance of wastewater facilities are usually distributed among many governmental departments, where coordination and cooperation between these bodies is lacking. Moreover, these public utilities are often overstaffed and experience frequent changes in sector leadership and management. They are expected to contribute to the alleviation of unemployment by hiring and keeping a large number of lower-qualified staff, several of which are not needed. At the same time, utilities are subject to civil service salary rules, severely restricting their ability to attract, motivate, and maintain qualified personnel that is essential to successfully perform key technical and managerial functions. Therefore, the tasks and responsibilities need to be more clearly defined among the respective institutions, and the performance of permanent staff needs to be improved. Involving the private sector in the wastewater treatment business is an option that deserves more consideration since it might help overcome to some extent the aforementioned weaknesses, beside the financing deficiencies.

iii) Financial resources. 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.

iv) Technical capacity. Despite the wide range of treatment technologies applied worldwide, engineers and decision-makers in the two countries stick to a limited range of technologies and don't have exposure to much variety. This selectivity is attributed to cost considerations and lack of finances, lack of skills, time limitations, and, more importantly, reliance on external funding and expertise. Even when local funds and expertise are involved, the role of foreign engineers and consultancy offices is still obvious. In contrast, the O&M skills are abundant because Jordan and Tunisia have their own training programs and refresher courses for their O&M personnel. However, effective performance of the O&M personnel is constrained by higher-level institutional weaknesses represented by poor leadership, and lack of incentives.

The availability of construction materials and equipment does not seem to be a limiting factor for construction or O&M of wastewater treatment facilities in Jordan and Tunisia. Because both countries have fairly open foreign trade systems, most of the essential equipments and materials are available in the local market, although they are often imported from other countries.

Finally, despite the advancements in information technology and knowledge transfer, the openness to the developed countries, and the existing regional communication networks, the dissemination of results and the sharing of experiences that shorten the learning curve are still conspicuously limited to the efforts put in by the external aid agencies.

4.7 References

Alaerts, G., Blair T., and Hartvelt, F. (1991). A Strategy for water sector capacity building. IHE report series 24, Delft.

Al-Hamdi, M. (2000). Competition for scarce groundwater in Sana'a plain, Yemen: a study on the incentives system for urban and agricultural water use. PhD thesis, IHE-Delft, The Netherlands.

Bahri, A. (1998). Fertilizing value and pollution load of reclaimed water in Tunisia. *Wat.Res.*, **32**(11): 3484-3489.

Bakir, H. (2000). Guiding principles and options for accelerated extension of wastewater management services to small communities in EMR countries. Technical expert consultation on innovative wastewater management for small communities in EMR countries. Amman - Jordan, 6-9 November 2000. WHO, Regional Office for the Eastern Mediterranean, Regional Centre for Environmental Health Activities (CEHA). Amman.

Bazza, M. (2002). Wastewater recycling and reuse in the Near East region: experience and issues. In proceedings of the IWA Regional Symposium on Water Recycling in Mediterranean Region, Iraklio, Greece, 26-29 September 2002: 43-59.

Bode, H. and Grüebaum, T. (2000). The cost of municipal sewage treatment- structure, origin, minimization- methods of fair cost comparison and allocation. *Wat. Sci. Tech.*, **41**(9): 289-298.

Boller, M. (1997). Small wastewater treatment plants - A challenge to wastewater engineers. *Wat. Sci. Tech.*, **35**(6): 1-12.

CEHA. (1995). Appropriate technologies for water supply and sanitation in Jordan. CEHA special studies, No. 3. World Health Organization, Eastern Mediterranean Office, Regional Centre for Environmental Health Activities, Amman.

Eckenfelder, W. (1989). Industrial water pollution control. New York, McGraw-Hill Company.

Faruqui, N. (2000). Wastewater treatment and reuse for food and water security. IDRC. Ottawa, Canada. www.idrc.ca/waterdemand/SpecialPapers_e.html

Frijns, J. and Jansen, M. (1996). Institutional requirements for appropriate wastewater treatment systems. In A. Balkema, H. Aalbers and E. Heijndermans (Eds.), Workshop on sustainable municipal waste water treatment systems, pp: 54-66. Leusdan, the Netherlands. ETC in co-operation with WASTE. 12-14 November, 1996.

Ghazzawi, Z. (1996). Appropriateness of waste stabilization ponds to arid and semi-arid areas of the Middle East. First Latin America Conference on Waste Stabilization Ponds and Reuse. Cali, Colombia.

Gijzen, H. (2001). Low cost wastewater treatment and potentials for reuse: a cleaner production approach to wastewater management. Paper presented at Cairo workshop 2001.

Haruvy, N. (1997) Agricultural reuse of wastewater: nation-wide cost-benefit analysis. *Agriculture, Ecosystems and Environment*, **66**, 113-119.

Jamrah, A. (1999). Assessment of characteristics and biological treatment technologies of Jordanian wastewater. *Bioprocess Engineering*, **21**: 331-340.

Kalbermatten Associates Inc. (1999). Study to identify gaps, issues and constraints in urban environmental sanitation. Report No. 1: Preliminary identification of gaps. A study funded by the Department for International Development, United Kingdom, and executed by the UNDP/World Bank Water and Sanitation Program Washington, D.C., U.S.A.

Kalbermatten, J., Julius D. and Gunnerson C. (1982). Appropriate sanitation alternatives; A technical and economic appraisal. International Bank for Reconstruction and Development, Washington, USA.

Kalbermatten, J., Julius, D., Gunnerson C. and Mara, D. (1982). Appropriate sanitation alternatives; A planning and design manual. International Bank for Reconstruction and Development, London, UK.

Kemper, K., Yepes, G., and Garn, M. (1994). Personnel costs as an indicator for water and sanitation utility performance in developing countries. The World Bank, Transportation, Water and Urban Development Department, Infrastructure Note WS-12, Washington DC, pp. 5.

Khouri, N. (1992). Wastewater reuse implementation in selected countries of the Middle East and North Africa. Canadian Journal of Development Studies, Special Issue.

Metcalf and Eddy Inc. (1991). Wastewater engineering: Treatment, disposal, and reuse. McGraw-Hill International. Third Edition.

MWI. (1998). The economic and social development plan (1998-2002). The Ministry of Water and Irrigation, Amman.

MWI. (1999). The annual report of the Ministry of Water and Irrigation. Amman.

Nowak, O. (2000). Expenditure on the operation on municipal wastewater treatment plants for nutrient removal. *Wat. Sci. Tech*., **41**(9): 281-289.

Peters, M. and Timmerhaus, K. (1991). Plant design and economics for chemical engineers. McGrawHill Chemical Engineering Series. Fourth Edition.

Pettygrove, S. and Asano, T., eds. (1985). Irrigation with reclaimed municipal wastewater: a guidance manual. Chelsae, Mich., Lewis Publishers.

Saghir, J., Schiffler, M., and Woldu, M. (2000). Urban water and sanitation in the Middle East and North Africa Region: The way forward. The World Bank, Middle East and North Africa Region, Infrastructure Development Group.

Salameh, E. and Bannayan, H. (1993). Water resources of Jordan: present status and future potentials. Friedrich Ebert Stiftung, Amman.

Sperling, M. (1996). Comparison among the most frequently used systems for wastewater treatment in developing countries. *Wat. Sci. Tech*., **33**(3): 59-72.

Tchobanoglous, G. and Burton, F. (1991). Wastewater Engineering: Treatment, Disposal, and Reuse. Metcalf and Eddy, Inc. McGraw-Hill, Inc.

Tsagarakis, K. P., Mara, D. D., and Angelakis, A. N. (2003). Application of cost criteria for selection of municipal wastewater treatment systems. *Water, Air, and Soil Pollution*, **142**: 187-210.

USEPA. (1992) Manual guidelines for water reuse. U.S. Environmental Protection Agency, Washington D.C.

Veenstra, S. and Alaerts, G. (1996). Technology selection for pollution control. In Balkema, A., Aalbers, H., and Heijndermans, E. (Eds.), Workshop on sustainable municipal waste water treatment systems: pp: 17-40. Leusdan, the Netherlands. ETC in co-operation with WASTE. 12-14 November, 1996.

Viessman, W. and Hammer, M. (1985). Water supply and pollution control. New York, Harper Collins.

Yu, H., Tay J. and Wilson, F. (1997). A sustainable municipal wastewater treatment process for tropical and subtropical regions in developing countries. *Wat. Sci. Tech*., **35**(9): 191-198.

Chapter 5: The Incentive Systems for Use of Reclaimed Wastewater in Irrigated Agriculture

5.1 Introduction

The previous Chapters emphasized that the low use of treated effluents is one of the prominent limitations for maximizing the quantity and improving the quality of treated wastewater. In Jordan and Tunisia as well as in the other MENA countries, substantial proportions of treated effluents that are suitable for restricted irrigation are not used but discharged into the receiving water bodies. In other words, the supply side of the reclaimed-wastewater market is growing against stagnancy in the demand side of the market. Understanding this phenomenon entails analyzing and assessing many technical, financial, regulatory, institutional, and socio-cultural (dis)incentives. In general, incentives work because they shape the reasons why individuals (stakeholders) behave the way they do. Behavior is driven by a perception that the benefits obtained from an action exceed its costs or that the risk of suffering from the behavior is negligible compared to the benefits, so the risk is worth taking. Incentives can also involve the promise of rewards or the threat of penalties (Wright, 1997).

The technical and regulatory factors mainly include (i) the adopted guidelines and standards for wastewater treatment and reuse (WHO, 1989; USEPA, 1992; FAO, 1985; Abu Rizaiza, 1999; Angelakis *et al*., 1999), (ii) vulnerability of public health, aquifers, soil, crops, and irrigation equipment (WHO, 1989; Al-Salem, 1996; Haruvy, 1997; Shatanawi and Fayyad, 1996), (iii) reliability of storage, conveyance, and distribution of the reclaimed wastewater (Bahri and Brissaud, 1996; Friedler, 2001), (iv) effectiveness of the policy for pricing of freshwater and reclaimed wastewater and for agricultural-urban water transfer (MWI, 1999; Faruqui, 2000; Saghir *et al*., 2000; ONAS, 2001).

Mere financial costs of reclaimed-wastewater use make it an expensive water resource; the financial costs mainly include the investment and operational costs related to collection and treatment of influent, and conveyance and distribution of treated effluents. However, in practice, there are economic impacts involved that make reclaimed-wastewater irrigation reasonably competitive to other water sources. This fact stems from added value to water resources and agriculture and the avoided costs related to reclaimed-wastewater utilization (Johnson, 2002); the avoided-costs are those of developing new water resources, prevention of health risks and of environmental degradation (Johnson, 2002).

The institutional factors mainly include the distribution of skills, tasks, and responsibilities among a large number stakeholders that have own interests to protect even while intending to be cooperative (Alaerts *et al*., 1991; UNDP *et al*., 1992; Khouri *et al*., 1994; Mills and Asano,

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1996). Stakeholders involve the public, the health, environment, agriculture, and water resources officials and decision-makers, the wastewater infrastructure managers, the farmers, and many others.

The socio-cultural factors mainly include the beliefs and values of a culture that vary widely from one part of the world to another. Wastewater reuse projects are too often planned and implemented based upon only technical and financial feasibility studies. Moreover, there are few in-depth studies of the socio-cultural aspects of reuse projects in the developing countries (Mara and Cairncross, 1989; Thanh and Visvanathan, 1991; Khouri *et al.*, 1994; Rowe and Abdel-Magid, 1995; Al-Hamdi, 2000).

5.2 Objective and approach

The main objective is to identify, analyze, and assess the potential factors (incentives and disincentives) that promote or discourage the use of reclaimed wastewater in irrigated agriculture based on the intensive field-surveys of stakeholders in Jordan and Tunisia. In other words, analysis and assessment of the technical, financial, regulatory, institutional, and socio-cultural influences affecting the demand side of the reclaimed-wastewater market. This analysis will help understand the underlying fundamental driving forces for wastewater reuse, as derived from existing field experiences in countries that are representative for the MENA region.

In order to achieve the study objective, a number of selected irrigation schemes were surveyed and methodological interviews with stakeholders were conducted as part of the fieldwork in Jordan and Tunisia. The selected stakeholders represented government administrators, operational staff, farmers, and common public (households) in each of the two countries (the fieldwork is described in Chapters 1 and 3, while the employed questionnaires are presented in Annex D).

The approach applied entails identifying the factors that influence decisions, weighing them, and analyzing each of them independently irrespective of its weight. Assumptions behind this approach are that: (1) in general, factors with a high weight tend to be more important driving forces, (2) factors with low weight, however, are not necessarily ineffectual, as incentives and disincentives typically do function as isolated factors but mutually reinforce or otherwise affect each other, and (3) it is difficult to make generalized conclusions regarding these factors since each of their weight can differ according to the specific conditions of the scheme and the country. The major strength of this analysis stems from involvement of the actual stakeholders, rather than from presumed merits of the wastewater reuse technology. Also, it allows identification and weighing of a larger set of factors that need to be considered in the planning and implementation of reuse projects. This approach complements the conventional "cost-benefit analysis" (CBA) that is often performed to assess the value of project proposals; no project should be financed unless benefits outweigh costs (Cost-Benefit Handbook, 1998). CBA is in principle very inclusive since it can consider attributing monetary values to health, environmental, socio-cultural, and other impacts (Section 5.3.4.2). Therefore, comprehensive CBA was not applied in this study, and the study limited itself to the analysis of the data that underpin the valuations.

The analyses in the following Sections are based on the data collected through questionnaires, reports, studies, personal discussions, and other case studies. However, some repetition is inevitable since many factors are closely related. The employed methodology for analysis of each factor is explained where appropriate.

5.3 Results and discussion

5.3.1 Identifying the factors that influence utilization of reclaimed wastewater

The descriptive analysis of the responses of administrators and farmers identified factors that are deemed to influence decision-making and perceptions in Jordan and Tunisia (Table 5.1 and Figures 5.1, 5.2). The results show that the rank of the various factors varies between the stakeholder groups as well as the two countries. This is mainly attributed to the different interests and priorities of each stakeholder and to the limited administrators' knowledge of farmers' interests and priorities and vice versa. Therefore, each factor has to be analyzed independently and irrespective of its ranking.

However, there are prominent factors that have been equally ranked by both administrators and farmers in these two countries. These factors are:

- Finding reliable users for reclaimed wastewater is often ignored in the planning of WWTPs.
- Awareness is needed to change the attitudes of farmers.
- Inadequate infrastructure for storage, conveyance, and distribution.
- Farmers' accessibility to freshwater makes reuse unattractive.
- The stringent quality standards and regulations hamper reuse.
- Farmers' involvement is important but it is often ignored.
- Conflicting interests and poor coordination between the various institutions hamper reuse.
- The wastewater treatment approach with the discharge objective hampers reuse.
- Pricing of freshwater and reclaimed wastewater influence reuse.

The results also show that there are some factors that mainly administrators and partly farmers in both countries recognize as influential. These factors are: (i) reuse poses health risks to farmers and crop consumers, (ii) water scarcity at national level makes reuse attractive, (iii) reuse increases crop yield due to fertilizers in reclaimed wastewater, and (iv) reuse poses impacts on quality of soil, crops, and water resources.

The results also show that there are some factors that mainly farmers and partly administrators in these two countries recognize as influential. These factors are: (i) cropping restriction lowers agricultural profitability, (ii) concern for criticism by reference/peer groups and public hampers reuse, and (iii) unavoidable use of freshwater hampers reuse.

Both administrators and farmers in these two countries agree on the factors of less concern. These factors are: (i) reuse poses impacts on irrigation equipment, (ii) land fragmentation in the traditional inheritance system hampers reuse, (iii) people have psychological aversion to wastewater irrigation and crops, (iv) religion prohibits irrigation with reclaimed wastewater, and (v) consumers will reject crops irrigated with reclaimed wastewater.

Table 5.1: Administrators' and farmers' ranking of the factors that potentially influence the use of reclaimed wastewater in irrigated agriculture in Jordan and Tunisia.

Factors considered:	*Administrators*		*Farmers*	
	Jordan (n=38)	*Tunisia (n=34)*	*Jordan (n=46)*	*Tunisia (n=50)*
	%	%	%	%
Finding reliable users for reclaimed wastewater is often ignored in the planning of WWTPs	**100**	**100**	**100**	**100**
Awareness is needed to change the attitudes of farmers	**100**	**100**	**100**	**100**
Inadequate infrastructure for storage, conveyance, and distribution	**100**	**88**	**100**	**100**
Reuse poses health risks to farmers and crop consumers	**100**	**97**	61	20
Farmers' accessibility to freshwater makes reuse unattractive	**95**	**88**	**96**	**100**
Water scarcity at national level makes reuse attractive	**95**	**79**	28	32
Reuse increases crop yield due to fertilizers in reclaimed wastewater	**82**	**97**	13	36
The institutional conflicting interests hamper reuse	**79**	**97**	54	**72**
The stringent quality standards and regulations hamper reuse	**76**	**97**	**89**	**100**
Farmers' involvement is important and often ignored	**71**	**88**	**78**	**96**
The discharge approach of wastewater treatment hampers reuse	**71**	**94**	59	**86**
Reuse poses impacts on quality of soil, crops, and water resources	66	**88**	57	16
Cropping restriction lowers agricultural profitability	58	35	**100**	**82**
Pricing of freshwater and reclaimed wastewater influence reuse	47	**85**	**100**	**86**
Reuse poses impacts on irrigation equipment	21	9	43	10
Concern for criticism by reference/peer groups and public hampers reuse	13	6	**87**	48
Land fragmentation in the traditional inheritance system hampers reuse	3	18	15	24
People have psychological aversion to wastewater irrigation and crops	3	9	13	8
Religion prohibits irrigation with reclaimed wastewater	3	0	13	4
Unavoidable use of freshwater hampers reuse	0	3	24	**85**
Consumers will reject crops irrigated with reclaimed wastewater	0	6	48	14

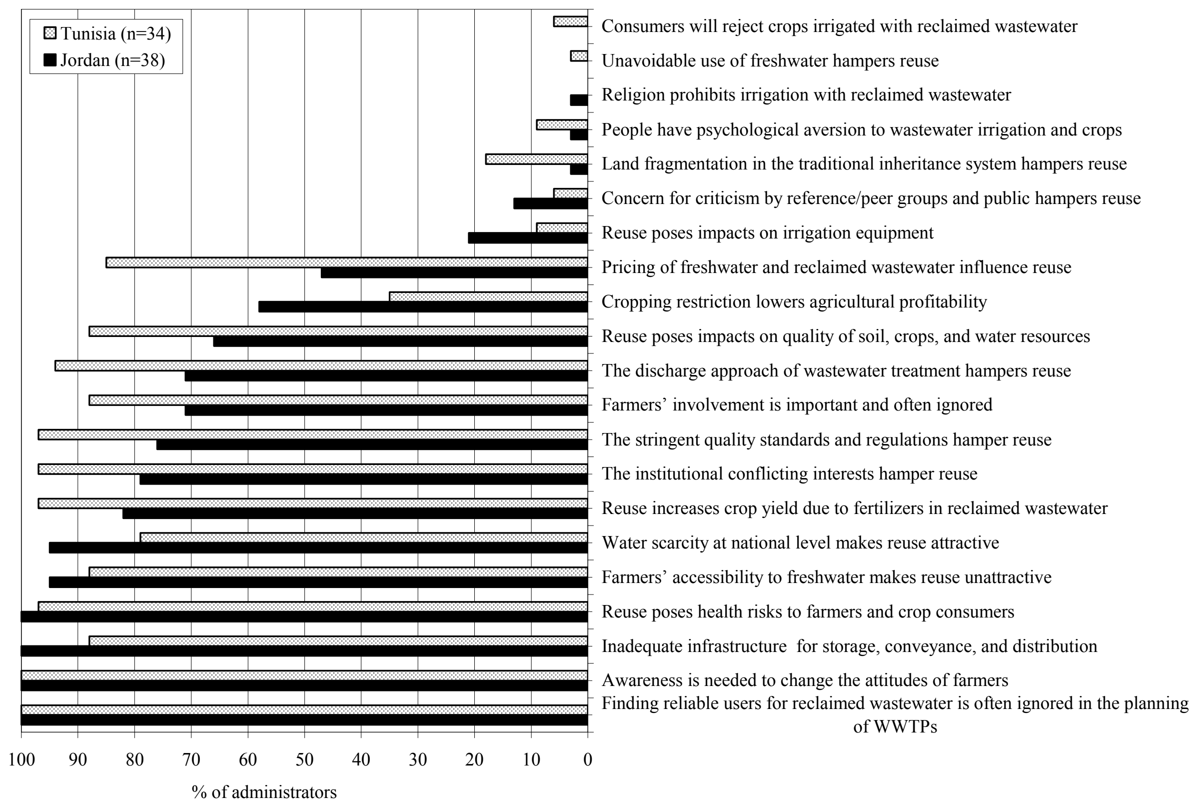

Figure 5.1: Administrators' ranking of the factors that potentially influence the use of reclaimed wastewater in irrigated agriculture in Jordan and Tunisia.

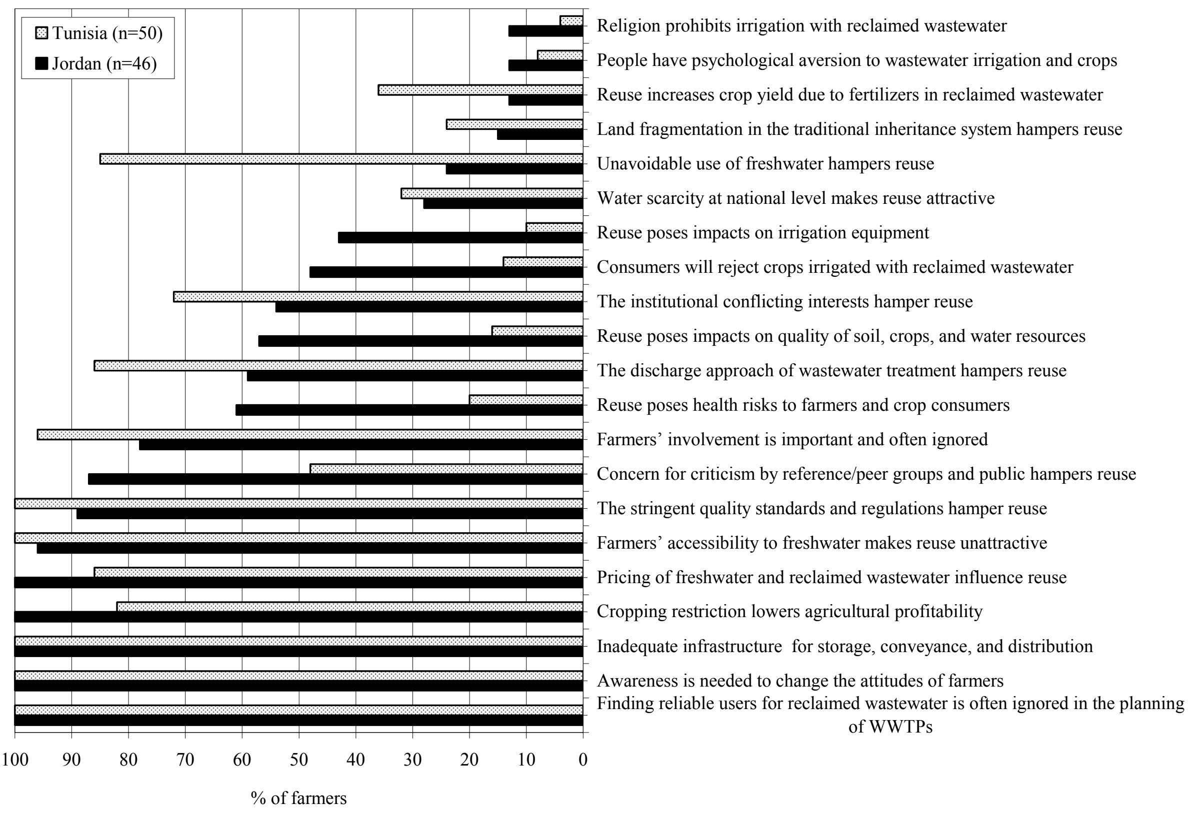

Figure 5.2: Farmers' ranking of the factors that potentially influence the use of reclaimed wastewater in irrigated agriculture in Jordan and Tunisia.

5.3.2 Quantity of available reclaimed wastewater

5.3.2.1 National water availability/scarcity

Even if all produced wastewater were collected and reclaimed, it could only modestly contribute to the augmentation of national water resources. The maximal production of wastewater is still very low compared with the total water demand, especially for agriculture (Chapter 2). However, each unit of reused wastewater avoids using a similar volume of freshwater and avoids pollution of water resources, in addition to the fact that it brings its rich nutrients content to the field. Because of this triple positive effect, the contribution of wastewater to alleviating water scarcity makes more sense. Thus, most water and environmental policies of the region recognize wastewater as a non-conventional resource. In other words, in arid and semi-arid regions, water scarcity functions as an "incentive" for wastewater reuse, though several obstacles may hamper implementation of such policies. This incentive was recognized by most of the surveyed administrators and only about third of the farmers in each country, thus it functions better at national government level.

5.3.2.2 Water availability/accessibility at irrigation scheme level

All the surveyed farmers and administrators perceive the availability/scarcity of freshwater, next to the reclaimable wastewater, as a major factor that can influence the decision to opt for wastewater irrigation. Because water availability varies from one place to another, within the same country, four possible scenarios have to be recognized: (i) where water is abundant enough to meet the entire agricultural demand and/or where sufficient rainfall makes irrigation itself unattractive, (ii) where freshwater is naturally very scarce, (iii) where freshwater is available but cannot meet the agricultural water demand, and (iv) where there is an enforced restriction on use of freshwater. These scenarios can be explained as follows:

i) Where freshwater is abundant enough to cover the entire agricultural demand and/or where sufficient rainfall makes irrigation itself unattractive.

Where the availability of freshwater is sufficient to meet the full irrigation water needs, wastewater irrigation becomes more controversial and unattractive. From one viewpoint, availability of freshwater makes reclaimed wastewater redundant. From another, reclaimed wastewater may compete with freshwater due to the nutrient contents and the extra low price. For example, in Jordan the irrigation scheme of Baq'a, where expensive groundwater from deep wells is the main source of irrigation water. Farmers that are able to cover their entire water need from their own groundwater wells would in principle not welcome the idea of using reclaimed wastewater, if it were available. In contrast, farmers that have to buy the groundwater from their neighbors at high price would prefer to have access to reclaimed wastewater, provided it is suitable for their crops and available at a lower price than that for the groundwater. As the reclaimed wastewater is not yet available, the farmers continue to use the expensive water. Likewise, sufficient rainfall makes wastewater irrigation less financially attractive, because the marginal increase in productivity would have to offset the entire (high) cost of the irrigation system (Khouri *et al*., 1994). In addition, any low price that a farmer will have to pay for reclamation of wastewater can never compete with rainwater that is of good quality and free of charge. Moreover, introducing reclaimed wastewater for such cases will not generate a benefit in terms of saving freshwater resources. In conclusion, the availability of freshwater is a disincentive for wastewater irrigation, but other considerations such as water price, and supply reliability can overturn this disincentive.

ii) Where freshwater is naturally very scarce.

In those cases where freshwater is scarce, there is a high potential for introducing reclaimed wastewater, depending upon availability of land and farmers who are willing to use and pay for such water. For instance, in the Soukra scheme of Tunisia, reclaimed wastewater irrigates about 600 hectares of citrus orchards and fodder because no other water is available: the groundwater is saline, surface water does not exist, and rainfall is insufficient. Nonetheless, the area equipped for wastewater irrigation is not fully utilized (about 50% only is irrigated). This means that water shortage alone is not a sufficient incentive and other considerations play a role.

iii) Where freshwater is available but cannot meet the agricultural water demand.

In such cases, irrigation with reclaimed wastewater becomes controversial. On one hand, the need for supplementary water supplies increases the opportunities for use of reclaimed wastewater. On the other hand, health risks and cropping restriction curtail these opportunities, and render such water disproportionately unattractive. Fore example, in the Jordan Valley, freshwater from the King Abdullah Canal is used at low price for unrestricted irrigation. But since the demand for water exceeds the available supplies, especially in summer (dry season), the Jordanian government makes indirect use of the reclaimed wastewater by using it to augment freshwater supply. Direct irrigation with this water was not applied because (i) farmers have access to freshwater at too low price, (ii) certain profitable crops would have been banned from such irrigation, and (iii) wastewater treatment/reclamation plants exist at faraway distance only. However, the government utilizes the existing King Talal Dam to augment the freshwater supply by mixing it with secondary treated effluents that flow by gravity from a number of plants. The blended water flows also by gravity to reach downstream framers who use this water for unrestricted cropping. Therefore, wastewater has indirectly increased the availability of water in a place that fully relies on agriculture for living, without influencing its agricultural traditions or changing the water price.

iv) Where there is an enforced restriction on the use of freshwater.

Once again, the rapid population increase in the region and the scarcity of the water resource fuel the debate about reallocation of freshwater supplies from the agricultural to the domestic and industrial uses. This means that another form of water shortage may occur as a result of enforced restriction on the use of freshwater for irrigation. In such cases, reclaimed wastewater could be the substitute if the major disincentives are mitigated. First, the supplies of reclaimed wastewater must be sufficient and reliable, to offset the quantities of freshwater that are taken out. Second, the lower quality of the reclaimed wastewater may force farmers to change their cropping choices by shifting from high value crops to lower value crops. Obviously, this reduction in income would have to be factored in. Thus, improving the quality of the treated effluents by adding tertiary treatment facilities may be required to permit unrestricted cropping and control at least the potential health impacts. For example, the Tunisian regulations do not allow freshwater irrigation within the reclaimed-wastewater irrigation schemes. Nonetheless, some farmers do supplement with water from their own shallow groundwater wells to irrigate orchards, despite its high salinity. Freshwater from the Madjerda Canal, however, was banned for irrigation in the Cebala scheme, after the wastewater reuse project was implemented there. More than half of the land equipped for this irrigation is not utilized because farmers are prohibited from using wastewater for irrigation of vegetables and cash crops which are of course preferred. There, the reuse option in effect became limited to those farmers who used to irrigate fodder and cereal crops, while some other farmers had to quit agricultural activity because of the narrower margins. A second example, also from Tunisia, is the scheme of Ouzarah and Al-Resalah, where the farmers cultivating a plot of 36 ha have requested the authorities to re-allow use of freshwater for irrigation for growing vegetables, since in principle the reclaimed wastewater would only permit restricted irrigation.

In conclusion, the availability of freshwater next to reclaimed wastewater is a major disincentive for reuse, unless other factors make reclaimed wastewater more attractive and competitive to freshwater; these factors comprise, notably, water quality and water price (Chapters 6 and 7). The Tunisian example shows that the prohibition of using reclaimed wastewater for unrestricted irrigation, in the same scheme where freshwater is used, irrevocably lowers the value of the crop output to the point that reuse loses its incentives.

5.3.2.3 Storage and reliability of supplies

The requirements for the management of the supply of reclaimed wastewater differ from those of freshwater. Traditional water supply systems that draw water from ground or surface water often can employ the resource as source and storage facility at the same time. If the full yield of the source is not needed, the water is kept for later use. In the case of reclaimed-wastewater reuse, supplies are continuous and what cannot be used instantly must be stored as it otherwise will be disposed and lost in some way or another. Thus, the supply may be available when the demand is low and vice versa. Storage of the reclaimed wastewater must allow coping with hourly, daily, and seasonal fluctuations of water supply and demand (Friedler, 2001). As an additional effect, storing a secondary effluent in maturation ponds helps upgrade the water quality to meet the WHO guidelines for unrestricted irrigation (USEPA, 1992; Pearson and Mara, 1993; Bahri and Brissaud, 1996; Bahri, 1999).

Depending on the volume and pattern of the effluent supply and the projected reuse demand, storage requirements may become a significant design consideration and have a substantial impact on the capital and operational costs of the system. Therefore, where the primary objective is resource management rather than pollution control, the reclaimed-wastewater supply and demand have to be calculated and the most cost-effective means of allocating that resource determined.

Almost all administrators and farmers in Jordan and Tunisia reported that the absence or insufficiency of storage, and the ensuing unreliability of supply, are major limiting factors for the growth of wastewater reuse. Besides, 38 out of the 51 interviewed reclaimed-wastewater farmers emphasized that they are severely affected by this problem. Currently, both countries are experimenting with storage of reclaimed wastewater in existing dams or newly built reservoirs (not destined for potable water supply) as well as with artificial recharge of groundwater aquifers.

Storage reservoirs were constructed at many reuse schemes in Tunisia in order to cope with the daily demand fluctuations, but the storage volumes are relatively small and cannot cope with the seasonal fluctuations (e.g., Wardanine (500 m^3), Soukra (3,800 and 5,800 m^3), Cebala and Al-Taweel (4,000 m^3)). Storage capacity for reclaimed wastewater in some other countries is shown in Table 5.2.

Table 5.2: Storage of reclaimed wastewater in selected MENA countries (Banks, 1991).

	Abu Dhabi (UAE)	*Dubai (UAE)*	*Taif (Saudi Arabia)*	*Doha (Qatar)*
Storage capacity (m^3)	83,000	Elevated 4,000 Ground 40,000	Elevated 20,000 Ground 100,000	Elevated 9,000 Ground 10,000

Blending reclaimed water with freshwater is widely practiced in Jordan and Tunisia. In Jordan, most of the treated wastewater is blended with freshwater from the King Talal Dam and used downstream in the Jordan Valley. The blending ratio has allowed unrestricted irrigation and increased the reliability of water supply, which stimulated reuse (Shatanawi and Fayyad, 1996; Faruqui, 2000). The consequences of water blending on the water quality before and after the blending are discussed in Section 5.3.3.6.

Groundwater recharge with reclaimed wastewater is still restricted for different reasons, such as the shallowness of the groundwater level, the use of groundwater for potable water supply, the poor quality of the reclaimed wastewater in terms of salinity, and the potential impacts on the aquifer quality (Bahri, 1999). However, if soil-aquifer-treatment (SAT) is properly applied, improved operation of this facility can lead to groundwater quality that meets unrestricted irrigation requirements (Bouwer, 1991). Artificial recharge is successfully practiced in the Dan Region Project of Israel where more than 100 million cubic meters of treated wastewater are annually leached and recharged in sandy areas to the aquifer. The resulting high quality reclaimed water is then pumped up by production wells to the main conveyance system and to the distribution network to be used for unrestricted irrigation (Shelef and Azov, 1996; Idelovitch, 2001). In Tunisia, the shallow sandy aquifer of Nabeul has been seasonally recharged since 1985. Activated sludge effluents that are not used for irrigation during winter season are infiltrated and stored into the aquifer, thus increasing the volume that farmers can pump up during peak demand season to irrigate citrus orchards.

5.3.3 Quality of the reclaimed wastewater

5.3.3.1 Wastewater treatment approach

About 94% and 71% of the interviewed administrators as well as about 86% and 59% of the farmers in Tunisia and Jordan, respectively, were critical of the current approach adopted for wastewater treatment. The approaches towards design of wastewater treatment still have effluent disposal as the principal objective, which however is not necessarily compatible with the objective of making the effluent most suitable for reuse. Thus, these approaches are a major disincentive for reuse. Wastewater needs to be recognized as a sustainable alternative source of water for an increasing number of applications and as a viable part of the water cycle (Eden, 1996; Friedler, 2001) (see also Chapter 4).

5.3.3.2 Quality standards and regulations

The potential market for reclaimed wastewater depends on the quantity as well as the quality of the treated effluents that can be supplied. One of the most critical objectives in any reuse program is to assure that health protection is not compromised. Other objectives, such as preventing environmental degradation, avoiding public nuisance, and meeting user requirements, must also be satisfied in implementing a successful reuse program, but they are subjugated to the safe delivery and use of properly-treated reclaimed wastewater (USEPA, 1992). Therefore, the constituents of concern in reclaimed wastewater (see Chapter 2) need to be eliminated or reduced in concentration, and, where necessary, the direct or indirect contact with reclaimed wastewater needs to be prevented or limited. With the increasing level of sophistication level in wastewater treatment, it is possible to reduce the undesirable constituents to acceptable levels or even virtually eliminate them from water (Asano and Levine, 1996). However, some of the constituents, notably the nutrients are valuable, especially when the intended use is agricultural irrigation.

The large number of constituents in reclaimed wastewater necessitates monitoring and regulating its application for the intended use. However, the concern for public health dominated most of the development of quality standards and guidelines in the twentieth century (Angelakis *et al*., 1999). The first regulations of the twentieth century were developed by the California State Department of Public Health as early as 1918 and further refined (Ongerth and Jopling, 1977). The concern for public health led to high quality standards that call for total elimination of pathogens in reclaimed wastewater (Al-Hamdi, 2000). In 1973, the World Health Organization (WHO) proposed similar stringent guidelines; for irrigation of crops that might be consumed raw, the quality of the treated effluents had to be high and close to potable water quality. These guidelines were based on the concept of "zero risk", which however implies far-going treatment at high cost, which would be out of reach in most developing countries. Many countries around the world copied the California and WHO standards, but few countries could in practice meet these standards because of the high technological and managerial demands, and the excessive expense.

Subsequently, the WHO initiated a new, more rational approach that is based on the evaluation of the health risks using epidemiological evidence and taking into account the technical and economic capabilities of the developing countries. This resulted in less restrictive standards and guidelines in 1989 that are more easily achievable using conventional treatment (Mara and Cairncross, 1989). These guidelines take into account the treatment processes, the irrigation systems, the potentially exposed groups (consumers and farmers), and the crops to be irrigated (Table 5.3). The justification for these new standards was the fact that in most countries of the world there are no limitations on the use of *surface* water from moderately polluted rivers and lakes for unrestricted irrigation, as no negative health effects have been reported from such practices. One of the WHO world surveys showed that more than 50% of the world's rivers and lakes have a mean faecal coliforms count of 1,000-10,000 per 100 ml. Also, the new USEPA guidelines for the use of river water for unrestricted crop irrigation permit 1,000 fecal coliforms per 100 ml. Thus, these recent WHO guidelines are more lenient with respect to maximum allowable concentration of fecal coliforms in reclaimed wastewater for unrestricted irrigation, but they are stricter concerning helminthes concentration (Shuval, 1991). However, some environmentalists have criticized the new WHO guidelines arguing that they provide insufficient safeguard to public health. This criticism is based mainly on the consideration that the origin and composition of indicator organisms in natural rivers differs from those in municipal wastewater (Shelef, 1991; Al-Salem, 1996; Shelef and Azov, 1996). As a result, many countries persist in adopting the more restrictive standards (Table 5.4).

In practice, however, the inability to comply with the stricter standards, with endemic water shortage, and ineffective enforcement of regulations, generally encourage the illegal use of raw or poorly treated wastewater, even for irrigation of vegetables and crops that are consumed raw. According to Gunnerson *et al*. (1985), in about 80% of the cities of the third world, unregulated irrigation of vegetables with raw wastewater is practiced. According to Shuval (1991), "*insisting to achieve only the very best prevents achieving the good*"; authorities often reject simple or intermediary wastewater treatment that would markedly improve the situation, since they do not comply with the unrealistic, stringent health standard that they had set themselves.

Many quality standards and guidelines in the MENA countries were based on existing regulations, including: the California Standards, the WHO guidelines, the USEPA guidelines, the FAO guidelines, and others (Abu Rizaiza, 1999). The FAO guidelines that determine the suitability of a given effluent for irrigation are often used as a basis for the criteria in most MENA countries, including, pH, salinity, SAR, nitrogen, toxic ions, trace elements, and heavy metals (Ayers and Westcot, 1985) (Table 5.5). Tables 5.4 and 5.5 compare the quality standards for irrigation with reclaimed wastewater in selected MENA countries with international standards. These standards are developed based on standards taken from countries with very different climatological and economic conditions and expectations. These standards are comparatively demanding and unintentionally impose unnecessary limitations on disposal and reuse of wastewater, and they are hard to reach with the available technological capacity and financial resources. Despite the high removal efficiencies of these technologies, their effluent quality is still relatively poor due to specific circumstances of its "strong" sewage (Chapter 4). Improving the effluent quality requires post treatment, substantially raising the capital and operational costs under conditions of scarce financial resources. At least some authors, in addition to most of the interviewed administrators and farmers in Jordan and Tunisia, believe that the unrealistically high quality requirements of treated effluents frustrate the development of wastewater treatment and reuse (Abu-Rizaiza, 1999).

In conclusion, in practice, more conservative and stricter standards are often adopted without proper studying the site- and locally specific conditions. Therefore, in each country of the region, there is great need for quality standards and regulations with the least quality restrictions that can in effect improve reuse and at the same time are compatible with the local conditions without jeopardizing public health.

Table 5.3: Recommended reclaimed-wastewater quality guidelines for use in agriculture (WHO, 1989).

Category	*Reuse conditions*	*Exposed group*	*Intestinal nematode [b] (arithmetic mean no. of eggs per liter [c])*	*Faecal coliforms (geometric mean no. per 100 ml [c])*	*Wastewater treatment expected to achieve the required microbiological quality*
A	Irrigation of crops likely to be eaten uncooked, sports fields, public parks [d]	Workers, consumers, public	≤ 1	≤1000 [d]	A series of stabilization ponds designed to achieve the microbiological quality indicated, or equivalent treatment
B	Irrigation of cereal crops, industrial crops, fodder crops, pasture and trees [e]	Workers	≤ 1	No standard recommended	Retention in stabilization ponds for 8-10 days or equivalent helminth and faecal coliform removal
C	Localized irrigation of crops in category B if exposure of workers and the public does not occur	None	Not applicable	Not applicable	Pre-treatment as required by the irrigation technology, but not less than primary sedimentation

[a] In specific cases, local epidemiological, socio-cultural and environmental factors should be taken into account and the guidelines modified accordingly; [b] Ascaris Trichuris species and hookworms; [c] During the irrigation period; [d] A more stringent guideline (≤ 200 faecal coliforms per 100 ml) is appropriate for public lawns, such as hotel lawns, with which the public may come into direct contact; [a] In the cases of fruit trees, irrigation should cease two weeks before fruit is picked, and no fruit should be picked off the ground. Sprinkler irrigation should not be used.

Table 5.4: Different microbiological quality standards for irrigation with reclaimed wastewater.

Country	*Restricted irrigation*	*Unrestricted irrigation*
Oman	Maximum 23 TC/100 ml; average 2.2 TC/100 ml Greenbelt irrigation: <10,000 TC/100 ml	Crop irrigation not permitted
Kuwait	< 10,000 TC/100 ml	<100 TC/100 ml, but not for salad crops or strawberries
Saudi Arabia	100-200 FC/100 ml ≤ 1 intestinal nematode/l	< 2.2 TC/100 ml; <50 FC/100 ml ≤ 1 intestinal nematode/l
WHO	- ≤ 1 intestinal nematode/l	200-1,000 FC/100 ml ≤ 1 intestinal nematode/l
Arizona (USA)	Reuse for non-food crops: 100 FC/100 ml (median) 4,000 FC/100 ml (single sample)	Reuse for food crops: 2.2 FC/100 ml (median) 25 FC/100 ml (single sample) Reuse for processed food: 1,000 FC/100 ml (median) 2,500 FC/100 ml (single sample)
California (USA)	Fodder, fiber, and seed: primary treatment Pasture for milking animals: 23 TC/100 ml (median)	2.2 TC/100 ml (median) 23 FC/100 ml (single sample)

TC: total coliform; FC: faecal coliform

Source: WHO, 1989; USEPA, 1992; Abu-Rizaiza, 1999; Al-Hamdi, 2000.

Table 5.5: Effluent from 15 Tunisian WWTPs compared against the Tunisian, Jordanian, FAO, and USEPA standards for irrigation with reclaimed wastewater (mg/l unless otherwise indicated).

Parameter	*Effluent from 15 WWTPs*				*Standards and guidelines*				
	Min.	*Max.*	*Mean*	*STD.*	*Tunisia*	*Jordan*	*Saudi Arabia*	*FAO*	*USEPA*
pH	7.5	7.9	7.6	0.1	6.5-8.5	6-9	6.0-8.4	6.5-8.5	6-9
COD	61.4	639.5	173.6	152.7	90	200-700	-	-	-
BOD_5	17.8	69.8	35.3	18.4	30	50-250	10	-	< 30
TSS	14.7	190.9	42.5	47.9	30	200	10-20	-	< 30
TDS (g/l)	1.52	5.61	2.61	1.08	-	2	-	2	0.5-2
EC (dS/m)	2.39	8.94	4.10	1.68	7	-	-	0.7-3	-
Nk	16.9	53.1	30.0	11	-	50-100	-	30	-
NH_4-N	14.4	48.3	26.2	10.6	-	25-50	-	-	-
NO_3-N	2.1	23.2	9.5	6	-	0.5-50	10	-	-
PO_4-P	1.23	4.34	2.34	1.08	-	15	-	-	-
Ca	121	238	168	31	-	400	-	400	-
Mg	54	188	85	36	-	60	-	60	-
K	18	120	52	27	-	-	-	-	-
B	-	-	-	-	-	0.01-1	0.5	0.7-3	-
Na	293	1,438	537	293	-	230	-	900	-
HCO_3	333	1,046	524	189	-	520	-	600	-
SO_4	304	922	532	147	-	1,000	-	1,000	-
Cl	338	2,490	791	526	2,000	350	-	1,100	-
SAR	5.1	17.6	8.5	3.8	-	9-12	-	3-15	-
Cd	0.004	0.008	0.005	0.001	0.01	0.01-0.015	0.01	0.01	0.01-0.05
Co	0.012	0.031	0.019	0.006	0.1	0.05	0.05	0.05	0.05-5
Cr	0.009	0.023	0.016	0.004	0.1	0.05-0.10	0.1	0.1	0.1-1
Cu	0.011	0.025	0.017	0.004	0.5	0.2	0.4	0.1	0.2-5
Fe	0.108	0.511	0.226	0.115	5	1-5	5	5	5-20
Mn	0.022	0.112	0.054	0.025	0.5	0.2-1	0.2	0.2	2-10
Ni	0.021	0.049	0.034	0.009	0.2	0.2-0.4	0.02	5	0.2-2
Pb	0.035	0.066	0.044	0.008	1	0.1-5	0.1	2	5-10
Zn	0.023	0.063	0.036	0.011	5	2-15	4		2-10

Source: FAO, 1985; USEPA, 1992; Al-Lafi, 1996; Bahri, 1998; WERSC, 1998.

5.3.3.3 Health impacts

Despite numerous epidemiological studies on raw wastewater reuse in both developed and developing countries, direct correlations between incidence of infectious diseases and the reuse are hard to find. Nonetheless, evidence suggests that agricultural farmers who are exposed to untreated or insufficiently treated wastewater risk enteric infections, particularly from *Ascaris lumbricoides* and *Trichuris trichiur*a. The risk of cholera and typhoid in consumers of uncooked vegetables irrigated with wastewater is based on circumstantial evidence, however (Shuval *et al*., 1986). Studies from Mexico City's reuse scheme show strong evidence that a higher level of risk exists of transmission of various diseases associated with helminth eggs (nematodes or worms), among farm workers exposed to wastewater, especially children (Blumenthal, 2000).

Most MENA countries took preventive public health measures by prohibiting reclaimed-wastewater irrigation of crops that can be eaten raw or uncooked. Nonetheless, reclaimed wastewater in Tunisia, which is permitted only for restricted irrigation, is frequently used to irrigate green belts, public yards, and golf courses, where in theory chances exist that people can come into contact with the irrigated lawn. Also, during the farm-surveys in Jordan and Tunisia many workers were observed to have direct contact with such water. In the Jordan Valley, where blended water from the King Talal Dam (KTD) is used, some farmers confirm that they use this water even for *Wodoo'* (ritual cleansing prior to Muslim prayers) although they are aware of the presence of the traces of wastewater. Finally, irrigation of fruit trees in Tunisia does not cease two weeks before fruit is picked, and fruits are picked up from the ground, which violates the WHO health guidelines. In all instances, no health impacts were claimed, which may be attributed to continuing improvement of the water quality after irrigation, and rapid dye-off of pathogens in the storage reservoirs in these hot climates. The retention times in practice exceeds the survival times (Feachem *et al*., 1983); impoundment time or the time effluent in blended conditions spends traveling in the canal, then being sprayed on the crop exposed to sunlight. However, survival time is not necessarily a good indicator but the way how farmers "manipulate" the water increase or lower the risk to ingest the active contaminant or expose skin or open wounds to it. Also, adult farmers may develop more immunity to some bacteria and viruses than children. These partly explain why in Mexico children suffer more from infections than adults.

In both countries, farmers that have experienced reclaimed-wastewater irrigation seem to be more realistic than administrators and freshwater farmers. The survey results show that 100% and 97% of the interviewed administrators in Jordan and Tunisia, respectively, believe that wastewater reuse poses health risks to farmers and crop consumers. The conservative opinions of the administrators do not necessarily reflect a high level of knowledge about the actual health impacts associated with wastewater irrigation. Interestingly, farmers have significantly less conservative opinions; 61% and 20% of the surveyed farmers in Jordan and Tunisia, respectively. The freshwater farmers that have not experienced irrigation with reclaimed wastewater also have conservative opinions; the aforementioned 61% and 20% of farmers in Jordan and Tunisia are mostly freshwater farmers. Apparently, the administrators in both countries are cautious about public health, therefore they adopt more conservative opinions than farmers. This, in effect, imposes a financial penalty on the country because (i) the overly restrictive standards require expensive wastewater treatment, and (ii) farmers are forced to use more expensive freshwater. However, the knowledge of administrators and farmers is often narrow since they mostly recognize the short-term impacts related to some types of infectious diseases, while few recognize the possible long-term impacts associated with the various constituents in reclaimed wastewater. For instance, the health impacts also have important economic consequences. The heavy parasitic burden caused by helminthes can cause digestive and nutritional disturbances, abdominal pain, vomiting, diarrhea, and loss of weight eventually leading to anemia. The anemic condition further prevents victims from developing, both physically and intellectually. This raises costs associated with medical treatment and the loss of the ability to generate revenue as an adult (Shuval *et al*., 1986).

The household-surveys in Section 5.3.6.3 show that, respectively, 89% and 100% of the Jordanian and Tunisian public that reject raw-sewage crops (97.1% and 99.3% of the total, respectively) attribute their decision to potential health impacts. On the other hand, respectively, 44% and 60% of the Jordanian and Tunisian public that reject treated-sewage crops (18.3% and 28.5% of the total, respectively) attribute their decisions to potential health impacts.

In conclusion, the concern for health impacts associated with the reclaimed wastewater is a disincentive for reuse. In order to overturn this disincentive, more research is needed on the actual impacts to farmers and crop consumers, and awareness is needed for administrators as well as for farmers and crop consumers.

5.3.3.4 Cropping restriction

Cropping restrictions as a result of the stringent standards and regulations discouraged wastewater reuse in the region (Abu Rizaiza, 1999; Bahri, 1999). About 100% and 82% of the interviewed farmers and 58% and 35% of the interviewed administrators in Jordan and Tunisia, respectively, conceive cropping restriction as a crucial disincentive for irrigation with reclaimed wastewater. They claim that crop choice is restricted which leads to a narrow range of permitted crops (e.g. fodders, cereals, and trees) that are of low value and generate low income. The majority of farmers in the region can be considered poor, manage small farms (<0.5 ha), and rely on agriculture as the main source of income. Obviously, farmers prefer freedom in crop choice to have maximum flexibility to adjust their cropping pattern to the market demands.

Some of the permitted crops can be more profitable than vegetables and cash crops, and thus, cropping restriction does not necessarily imply less profit. Indeed, the field survey shows that the profit from restricted irrigation can be similar to, and sometimes better than, unrestricted irrigation. The high frequency and yield of harvests, the low price of the reclaimed wastewater, and the lower fertilizer demand, make fodder very profitable (for details, see also Annex E and Chapter 6). Cropping restriction/freedom clearly influences the willingness of farmers to use and pay for reclaimed wastewater; subsequently, the degree of freedom in cropping is an important incentive to make the market more receptive for reclaimed wastewater (elaborated in more detail in Chapter 7).

In conclusion, the field evidence from Jordan and Tunisia contrasts with the common assumption that cropping restrictions necessarily are a disincentive for irrigation with reclaimed wastewater.

5.3.3.5 Reclaimed wastewater as fertilizer

Considerable research has been undertaken into the value of nutrients in reclaimed wastewater and their effect on crop yield. In Mexico, the productivity of alfalfa, corn, wheat, oats, and tomato increased by 70-140% when irrigation was switched from freshwater to reclaimed wastewater (Jiménez, 1995). In Jordan, the effect of reclaimed-wastewater irrigation was studied on the crop yield of sweet corn, cotton, soybean, watermelon, and tomato (Fardous and Jamjoum, 1996; WERSC, 1989, 1998). Reclaimed-wastewater irrigation produced higher crop yield than freshwater irrigation (Table 5.6). However, only 13% and 36% of the surveyed farmers and 82% and 97% of the surveyed administrators in Jordan and Tunisia, respectively, did recognize the commercial value of the nutrients in the wastewater.

Table 5.6: Effect of nutrients contained in reclaimed wastewater irrigation on crop yield of sweet corn, soybean, cotton, watermelon, and tomato (WERSC, 1989, 1998).

Crops	*Yield (ton/Donum)*					
	Drip irrigation		*Sprinkler irrigation*		*Furrow irrigation*	
	Reclaimed wastewater	*Freshwater*	Reclaimed wastewater	*Freshwater*	Reclaimed wastewater	*Freshwater*
Sweet corn:						
Total dry matter	0.983	0.862	1.169	1.027	0.583	0.482
Stover	0.339	0.473	0.382	0.324	0.259	0.204
Ear	0.644	0.389	0.787	0.703	0.324	0.278
Soybean	0.250	0.251	0.191	0.185	-	-
Cotton	0.219	0.206	-	-	-	-
Watermelon	5.201	3.400	-	-	-	-
Tomato	1.794	1.375	-	-	-	-

Table 5.7: Comparison of farmers' expenditure on fertilizer.

Crops	*Fertilizer (US$/Donum/Season)*			
	Min.	*Max.*	*Avg.*	*STD.*
Fodders and cereals irrigated with reclaimed wastewater	0	89	*13*	23
Fruit trees irrigated with reclaimed wastewater	18	179	*86*	37
Fruit trees irrigated with groundwater	71	229	*133*	54
Vegetables irrigated with groundwater	220	714	*370*	150
Vegetables irrigated with surface water	36	476	*223*	114
Vegetables irrigated with blended wastewater + freshwater	119	429	*227*	90

Our study (Table 5.7 and Figure 5.3) shows that there is about 65% saving in actual fertilizer expenditure when irrigating fruit trees with reclaimed wastewater compared to irrigating with fresh groundwater. Also, interestingly, many farmers irrigating with blended water behave like those irrigating with freshwater and still spend almost equal sums on artificial fertilizer despite the high nutrient content in the reclaimed wastewater. These farmers seem to not have confidence in the quality of reclaimed wastewater, or they unconsciously attribute their high crop yield and agricultural profit to the application of the artificial fertilizer; this is consistent with the observation that they tend to use less fertilizer for low-value fodder crops than for fruit trees and vegetables.

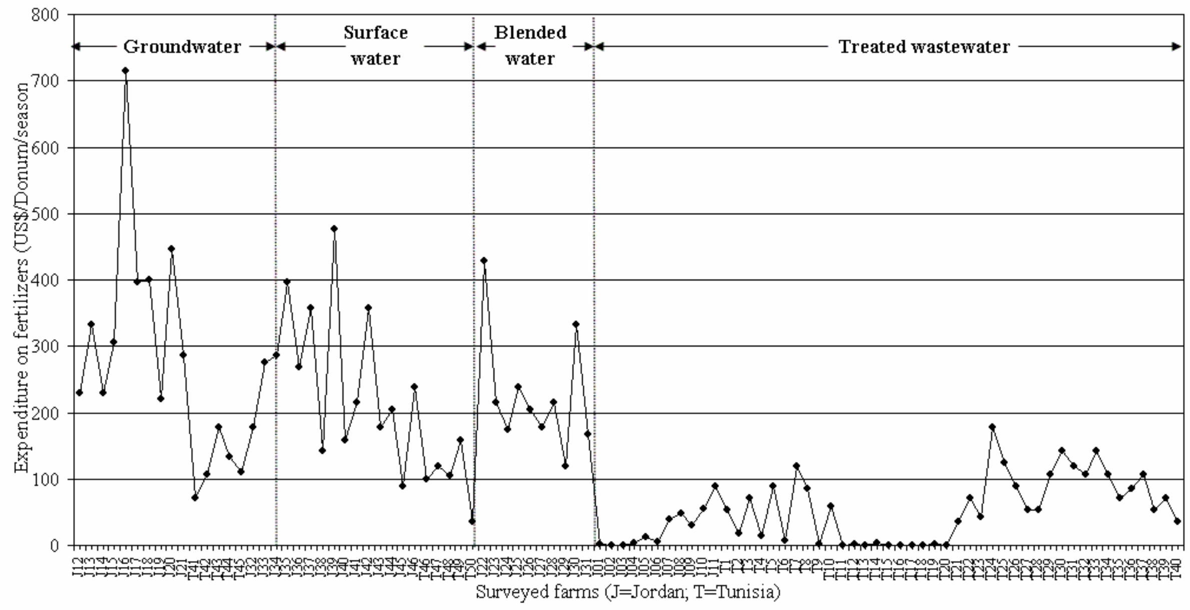

Figure 5.3: Expenditure on fertilizer application per unit area as function of origin of irrigation water.

5.3.3.6 Impact on soil, crops, water resources, and irrigation equipment

Irrigating with reclaimed wastewater can have a significant impact over time on the quality of soils, crops, and groundwater if the application load of certain constituents in the wastewater is very high (USEPA, 1992; Fardous and Jamjoum, 1996; Siebe, 1995; Haruvy, 1997; Bahri, 1998; Hussain and Al-Sati, 1999). However, studies that focus on the MENA region are very few. Table 5.5 shows that the EC and SAR, and the nutrients, and heavy metals concentrations in the effluents of 15 Tunisian WWTPs do not exceed the permissible limits above which such effects occur.

- *Impact on soil*

The quality of irrigation water is of particular importance in arid areas where high temperature and low relative humidity result in high rates of evaporation, with consequent deposition of salt which tends to accumulate in the soil profile. The physical and mechanical properties of the soil, such as dispersion of particles, stability of aggregates, soil structure and permeability, are very sensitive to the type of exchangeable ions present in irrigation water. Thus, when wastewater reuse is being planned, several factors related to soil properties must be taken into consideration (FAO, 1985). Sodium is an unique cation that has effects on soil. Excessive sodium in irrigation water leads to structural breakdown of soils and blockage of pore spaces, which in turn leads to root diseases and plant injury. High concentrations of sodium are toxic to woody plants, such as citrus, vines and others, and result in declining productivity. The most reliable index of the sodium hazard of irrigation water is the Sodium Adsorption Ratio (SAR), which is used as a measure to predict the infiltration problems in soils. Equation 4.1 is usually used to calculate SAR. The SAR values of the effluents from 15

Tunisian WWTPs (Table 5.5) and that of blended water in KAC in Jordan (Table 5.8) do not exceed those recommended by the FAO (Bahri, 1998).

$$SAR = \frac{Na}{\sqrt{\frac{Ca + Mg}{2}}}$$; where the ionic concentrations are expressed in meq/l. (5.1)

In Jordan, Fardous and Jamjoum (1996) conducted an experiment in Khirbet Al-Samra WWTP for irrigation of corn plants in loamy clay soil through a drip irrigation system. They mainly concluded that (i) soil pH at two different depths (0-10 and 10-20 cm) was not affected by irrigation with reclaimed wastewater, (ii) increased levels of nutrient concentrations and EC were observed, especially at 0-10 cm soil depth, and (iii) no general trend of increase or decrease was observed in heavy metal concentration in the soil, although higher concentrations occurred near the soil surface.

Similarly, according to Bahri (1987), application of treated wastewater at the Soukra scheme in Tunisia where the soils are alluvial and sandy-clayey to sandy, has not adversely affected the physical or bacterial quality of the soils. However, the chemical quality of the soil varied considerably, with an increase in electrical conductivity and transformation of the geo-chemical characteristics of soil. Trace elements concentrated in the surface layer of soil, particularly zinc (Zn), lead (Pb), and copper (Cu), but did not increase to toxic levels. Results from the large-scale reuse schemes in Israel, Mexico, and Saudi Arabia have shown that heavy metal contamination and salinity have not exceeded tolerance levels after many years (Siebe, 1995; Haruvy, 1997; Hussain and Al-Sati, 1999).

- *Impact on crop quality*

The study of Fardous and Jamjoum (1996) showed that wastewater reuse does not lead to significant change in N and P concentrations in the seeds and leaves of corn plants as compared to freshwater use, but that the highest concentrations observed were higher in corn seeds. No large differences were found in the concentration of trace elements in the corn leaves and seeds except for Fe in the corn leaves, which reached up to 227-506 ppm. There was no increase or decrease found in the heavy metal concentration in the corn leaves and seeds.

In our study, in the Jordan Valley, where treated effluents are blended with surface water, few farmers reported low quality in their squash, tomatoes, and cucumber crops. Those who did report lower crop quality claimed that reclaimed wastewater causes distortions in the crop shape. In Tunisia, where treated effluents at the Soukra scheme are used for citrus irrigation, farmers claim that high salinity levels negatively influence the quality of their crops. This is an important issue since crop quality is directly linked with crop marketing.

- *Impact on water quality*

Irrigation with reclaimed wastewater may impact the quality of ground and surface waters in terms of salinity, and levels of nitrate and other nutrients, of heavy metals, and pathogens. This impact varies from one site to another depending on the treatment process and local conditions. In Israel, the extensive reuse of wastewater has led to high concentrations of nitrates in ground aquifers (Haruvy, 1997). With respect to heavy metals, fluoride, and boron, unless these elements were already present in large concentrations in the drinking water or added to the sewage in significant amounts by industrial discharges, their concentrations in reclaimed wastewater are usually well below the maximum limits for irrigation water (FAO, 1985).

Table 5.8: Chemical analysis for water quality in KAC before and after mixing with KTD water; periodical samples collected through 1993 and 1994 (WERSC, 1996; Shatanawi and Fayyad, 1996).

*Parameter**	*Outflow water from KTD*				*KAC water before mixing with KTD water*				*KAC-north water after mixing with KTD water*			
	Min.	*Max.*	*Avg.*	*STD.*	*Min.*	*Max.*	*Avg.*	*STD.*	*Min.*	*Max.*	*Avg.*	*STD.*
EC (μS/cm)	1.91	2.38	*2.05*	0.14	0.72	0.98	*0.89*	0.06	0.91	2.49	*1.86*	0.45
pH	7.22	7.97	*7.63*	0.16	7.73	8.45	*8.13*	0.21	7.33	8.55	*7.78*	0.30
HCO_3	6.14	11.11	*7.93*	1.23	3.83	5.96	*4.70*	0.63	4.38	8.93	*6.33*	1.20
CO_3	0.00	0.50	*0.06*	0.12	0.00	0.93	*0.30*	0.23	0.00	0.71	*0.18*	0.22
Ca	4.30	6.90	*5.67*	0.50	2.50	4.20	*3.13*	0.39	2.40	7.62	*6.13*	1.32
Mg	3.40	5.36	*4.52*	0.52	1.38	3.74	*2.76*	0.60	1.50	6.30	*3.95*	1.13
Cl	7.50	12.34	*9.61*	1.04	2.30	3.71	*3.10*	0.31	3.40	12.10	*8.85*	2.47
NO_3	0.01	1.55	*0.42*	0.40	0.09	0.65	*0.20*	0.12	0.10	1.72	*0.70*	0.37
Na	8.33	11.57	*9.57*	0.87	2.12	4.20	*3.59*	0.43	3.87	12.02	*8.57*	2.25
K	0.51	0.83	*0.65*	0.09	0.10	0.83	*0.19*	0.17	0.15	0.84	*0.51*	0.20
SO_4	1.44	4.08	*2.60*	0.59	0.84	3.77	*1.90*	1.20	0.97	17.85	*3.70*	3.61
SAR	3.69	4.93	*4.24*	0.34	1.23	2.50	*2.10*	0.24	2.20	5.63	*3.79*	0.76
*T coliform ***												
Winter	4.5×10^3				4.3×10^3				5.8×10^3			
Summer	7.15×10^1				5.4×10^3				5.0×10^4			
*F coliform ***												
Winter	4.1×10^2				4.0×10^2				3.6×10^3			
Summer	4.1×10^1				3.8×10^2				4.8×10^4			

* meq/l unless otherwise mentioned.
** Geometrical means (MPN/100 ml).

Where freshwater is mixed with treated effluents, water quality becomes a major concern to the traditional water users. The effect of reclaimed wastewater from the King Talal Dam (KTD) on the freshwater quality in the King Abdullah Canal-north (KAC) is shown in Table 5.8. These water bodies are described in Chapter 3. The quality of treated effluents from Al-Samra WWTP at the inflow of KTD is not shown since it does not significantly differ from the quality of the outflow. However, some quality improvement to the water from KTD occurs since this water crosses 23 km in Wadi before it reaches the KAC. The effects of water mixing (in a ratio of 3 fresh: 1 effluent) on the quality of KAC water are significant, especially with respect to salinity, SAR, and coliform, nitrate, and sulphate concentration. These results suggest that the blended water is neither suitable for irrigation of sensitive crops nor for crops eaten raw. Nonetheless, unrestricted irrigation is applied. The Royal Scientific Society (RSS, 1997) studied the effects of irrigation with the effluent from Al-Samra waste stabilization ponds on the contamination of nearby groundwater wells that are used for potable and irrigation purposes. The RSS monitored 12 wells along the Wadi Dhleil that reaches the KTD. The RSS results revealed that EC, concentrations of TDS, NO_3^-, Cl^-, Na^+, SO_4^{2-}, FC, and TC in most wells exceeded the limits of the Jordanian standards for drinking water quality. This was mainly attributed to the poor effluent quality from Al-Samra plant and to the agricultural activity within the study area.

In conclusion, the impacts of irrigation with reclaimed wastewater on the quality of surface and groundwater could be substantial, especially when the freshwater is intended to be used as a source for drinking water. However, the impact varies from one scheme to another depending upon a number of factors such as geological and geographical characteristics of surface and groundwater resources, structure of the irrigated soil, effluent quality, standards and regulations. Thus, the negative impact of reclaimed-wastewater irrigation on quality of water resources is a disincentive that functions more at national policy level than at farmers' level.

- *Impact on irrigation equipment*

According to the health criteria of the WHO (1989), selection of the appropriate irrigation system is very important. Flooding involves the least investment, but probably exposes field workers to the greatest risk. Sprinkler irrigation should not be used on vegetables and fruits unless the effluent meets the guidelines for unrestricted irrigation, and flood irrigation should not be used for vegetables. Subsurface or localized irrigation, particularly when the soil surface is covered with plastic sheeting, can give the greatest degree of health protection, besides using water more efficiently and often producing higher yields. Drip irrigation equipment requires high degree of removal of suspended solids that may cause clogging of the drip openings. According to the Tunisian standards, in areas where sprinkler irrigation is to be adopted, buffer zones surrounding the irrigated area must be created. These standards also prohibit direct grazing of animals on land irrigated with reclaimed wastewater.

In Jordan and Tunisia, furrow and flooding systems are frequently used for irrigation of fodders and cereal crops, and in rare cases sprinkler irrigation was observed. Sprinkler systems are often applied for irrigation of golf courses in Tunisia. Drip and sprinkler systems are in practice frequently used for unrestricted irrigation with blended water. Furrow and flooding systems were observed in a few farms. However, most surveyed farmers comply with the regulations and guidelines that impose certain irrigation systems.

About 38% of the reclaimed-wastewater farmers reported clogging of drip-irrigation systems. Some of the farmers who use furrow irrigation system reported clogging of soil surface, which increases evaporation and prevents effective irrigation. Clogging of drip emitters may be attributed to the high concentrations of iron, calcium, and magnesium as well as algal growth in storage reservoirs (Shatanawi and Fayyad, 1996).

However, compared with the other considerations that are being discussed, the effect of such problems that was reported as a disincentive by about 21% and 43% of the surveyed administrators in Jordan and Tunisia, respectively, and by about 10% of the farmers in each country, to be small.

5.3.3.7 Unavoidable use of freshwater

The fact that reclaimed-wastewater farmers may still have to buy expensive freshwater for supplementary irrigation and/or preparing pesticide and insecticide solutions has been emphasized by about 24% and 85% of the surveyed farmers in Jordan and Tunisia, respectively; mostly reclaimed-wastewater farmers. Surveyed farmers that irrigate fruit trees, especially apples and peaches, reported that they avoid using the reclaimed wastewater for irrigating the recently planted trees since they believe such water is fatal for such plants. Therefore, farmers start applying wastewater gradually after the first or second year, after which they depend more on reclaimed wastewater. Because of this problem, surveyed farmers of the recently-planted fruit trees, especially apples and peaches, in the Murnag scheme (Tunisia) reported that each farmer buys about 15 m^3 freshwater/ha every two weeks from private vendors at a high price (TD2.7/m^3 or US$1.9/$m^3$). In Yemen, farmers avoid irrigating cash crops, especially grapes and *Qat*, with undiluted effluent since it "burns" the leaves on the *Qat* tree and changes the taste of grapes (Al-Hamdi, 2000). This means that some framers will have to invest in an additional supply system for freshwater to supplement reclaimed-wastewater supplies, otherwise they rely on expensive water from private vendors.

Recently, the Tunisian regulations force farmers using reclaimed wastewater to connect to the potable water supply system so as to avoid domestic use of wastewater under emergency conditions. As an incentive, the government subsidizes the construction of these connections, whilst farmers pay for the metered water consumption. However, the fact that farmers are charged the bulk tariff for the potable water supply makes supplementary irrigation with this water unfeasible. It can be concluded that in all cases, partial use of freshwater is inevitable, which is a disincentive for wastewater irrigation. Once again, the influence of this factor seems to be minimal compared to the other (dis)incentives being studied, especially in Jordan. Interestingly, none of the surveyed administrators in Jordan and only about 3% of that in Tunisia agree with this conclusion.

5.3.4 Financial and economic impact

5.3.4.1 Financial costs of wastewater reclamation

The financial and economic costs of using wastewater for agricultural irrigation are often high because they include the investment and operational costs related to collection and treatment of influent, and conveyance and distribution of treated effluent. These costs vary greatly from one scheme to another. Beside the high investment cost of sewerage, the conveyance and distribution of the reclaimed wastewater are the most costly components in reuse projects (Johnson, 2002). On the other hand, in most countries the existing standards and regulations for irrigation with reclaimed wastewater are often milder than those for discharge of wastewater into the environment. This implies that agricultural reuse can reduce the treatment costs, which is an important benefit. However, if treatment does not lower the pathogen concentration in the reclaimed wastewater to a level that meets public health criteria, regulations often prohibit irrigation of certain high-value crops such as vegetables. The value of these crops may be high enough to justify higher treatment levels (Khouri *et al*., 1994).

No single factor is likely to influence the cost of wastewater reclamation project more than the conveyance and distribution of the reclaimed wastewater from its source to its point of use. This is mainly because the system includes pipelines, pump stations, and storage facilities. The conveyance and distribution costs in Jordan and Tunisia represent, respectively, about 18-67% and 21-76% of the total costs (including investment) (Table 5.9). In the Irvine Ranch Water District of California (USA), the costs of the post-treatment and the distribution network are respectively 24% and 43% of the total investment cost (Bartone, 1994). In Dubai (UAE), the costs of treatment (incl. tertiary treatment), and the costs of conveyance and distribution, are 27% and 50% of the total investment, respectively (Al-Hamdi, 2000).

Table 5.9: Costs of wastewater treatment and conveyance and distribution against tariff of wastewater sale, in Jordan and Tunisia.

Tariff/cost	*Jordan*		*Tunisia*	
	*JD/m³ **	*US$/m³*	*TD/m³*	*US$/m³*
*Tariff **	0.0–0.049	0.0–0.08	0.02–0.10	0.014–0.08
*Conveyance and distribution costs ***				
Operational costs	0.028–0.084	0.04–0.12	0.125–0.21	0.09–0.15
Total costs incl. depreciation	0.070–0.147	0.10–0.21	0.175–0.35	0.13–0.25
*Treatment costs ****				
Operational costs	0.014–0.238	0.02–0.34	0.042–0.24	0.03–0.17
Total costs incl. depreciation	0.035–0.665	0.05–0.95	0.056–1.30	0.04–0.93
Total costs of treatment and conveyance incl. depreciation	0.105–0.812	0.15–1.16	0.231–1.65	0.17–1.18
Conveyance and distribution costs as percentage of the total costs incl. depreciation	18.1–66.7%		21.2–75.8%	

* One US$ = 0.70 JD = 1.4 TD (exchange rates of 2001).

** Prices and costs are based on the data provided by the Tunisian Ministry of Agriculture and the Jordanian Ministry of Water and Irrigation. These tariffs and costs pertain to direct irrigation with reclaimed wastewater and blended water.

*** The treatment costs are based on the findings of this study (Chapter 4).

Although most WWTPs in Tunisia are located quite a distance away from the agricultural land, the government constructed conveyance and distribution systems at all irrigation schemes. In most cases, this was done with support of external aid agencies. As an incentive to promote reuse, augment water availability, control pollution, and encourage agricultural production, the capital and operational costs are subsidized. Nonetheless, the utilization rates of reclaimed wastewater are still low. In Jordan, on the other hand, the infrastructural requirements for conveyance of treated wastewater for direct irrigation are more limited since most WWTPs are located close to the agricultural land. Nonetheless, direct reuse is limited to one to a few farms within the surroundings of some WWTPs, and large schemes do not exist (see Chapter 3). The agricultural land irrigated with blended water lies at a distance from WWTPs, but the use of gravity conveyance systems (wadis and canals) drastically reduces the supply costs. Here, the rates of wastewater utilization are high.

These results show that the conveyance and distribution costs can be a major disincentive for irrigation with reclaimed wastewater in cases where the infrastructure requirements are high and the financial resources to build them are limited. However, this is not a reclaimed-wastewater-specific disincentive since it is also valid, to certain extent, for freshwater irrigation. Thus, as far as possible, using the reclaimed wastewater in the vicinity of the WWTPs overturns this disincentive and even makes wastewater irrigation more attractive.

5.3.4.2 Economic impact of wastewater reclamation

Cost-benefit analysis (CBA), which is often performed to assess the economic impact of project proposals, can also be extended to evaluate compare the costs and benefits of the with-project (action) and the without-project (inaction) alternatives (UNEP, 1993). The economic assessment should rest on proper understanding of related aspects such as water scarcity, sanitation, public health, environmental protection, agricultural development, tourism, employment opportunities, social values, and others. The economic assessment of wastewater reuse projects must consider, in addition to financial costs, the costs associated with health risks, environmental degradation, and any other negative impact. On the other hand, the assessment must consider the benefits associated with wastewater reuse. These benefits, in addition to any other positive impact, notably include (i) the agricultural-added value due to fertilizer content and increased production (ii) the avoided costs of developing new potable water sources and construction of water treatment plants, (iii) the avoided costs associated with the prevention of health risks, and (iv) the avoided costs associated with the protection of environmental degradation, and the net "value" of environmental improvement. These potentially numerous relationships make CBA very complex, as CBA requires explicit data (Johnson, 2002). In particular, the quantification of the health and environmental impact costs and benefits is complex, and is usually based on a number of tenuous assumptions and estimations, as well as on data analyses of case studies that may be only very rough approximations. Therefore, the CBA results, just like any other procedure to assess the value of a project proposal, often are controversial (CBA-Handbook, 1998). The CBA studies are obviously very sensitive to the quality of the underlying data, particularly those concerning the most important benefits, such as health and environment. CBA results vary from one country to another and from one scheme to another, depending on local conditions; thus making it difficult to draw generic conclusions that are valid at national or regional levels (UNEP, 1993).

- *Agricultural-added value*

Other economic benefits accrue from lower costs of fertilizer application, and increased crop productivity (Section 5.3.3.5 and Chapter 6). Depending on current irrigation and fertilization practices, the use of wastewater irrigation can lead to a significant improvement in productivity because of the availability of additional water and the nutrient content in the wastewater.

- *Health-related economic impact*

The health costs are notably those related to infectious diseases to field workers and crop consumers. Because a treatment system that removes all potential contaminants prior to effluent reuse may be unaffordable, especially in developing countries, the final design of the system must attempt to minimize the health effects and risks of downstream exposure to the effluent. Transmission of the pathogens to humans can occur through consumption of irrigated produce, or meat from cattle that have grazed on irrigated land, by working in the irrigated fields, or by residing close to irrigated lands that employ spraying techniques (Shuval *et al.*, 1986). Medical expenses for the treatment of illness and disease can be substantial. However, the externalities associated with the health impacts may have an even more significant impact on economic productivity. Farmers who are affected by infectious diseases lose productivity, decreasing their revenue generation capability. Similarly, sick children may experience physical development problems, and suffer from lack of schooling.

Health benefits arise from avoided costs because of improved sanitation as compared to a without-reclamation situation, and from reduced pollution loads in surface water. Johnson (2002), on the other hand, suggests that implementation of a wastewater reuse can be very beneficial to public health. Other than the directly affected population, primarily food consumers and field workers, the public health status is improved by the sanitation function of removing the wastewater from the urban area and the environment at large. If such a collection system were not installed, a much larger population would likely suffer from exposure to waste. Additionally, when a sewerage system without treatment exists and discharges to surface water, usually a much larger downstream population would be subject to negative impacts.

- *Environmental-related economic impact*

The impact of wastewater irrigation on the environment can be positive and negative. The positive impacts concern water conservation and avoidance of pollution effects. However, while some of the effluent's substances (nitrogen, phosphorus, and potassium) in the wastewater are beneficial, others (nitrate, heavy metals, and salinity) can have a negative impact on soil and groundwater. Similarly, the nutrients that contribute to plant growth may also cause eutrophication in case they run off into surface water. A significant problem for determining the net environmental impact is the lack of consensus on the methodologies for the quantification of these impacts. Therefore, qualitative ranking is often used because even when the physicochemical composition of the wastewater is known, the long-term impacts they will have on the environment are still uncertain (Johnson, 2002).

In general, the environmental costs of reuse in agriculture are small compared to those associated with effluent discharge. The discharge of poorly treated wastewater into the environment creates numerous concerns, such as: (i) pathogens, (ii) increase in suspended solids, (iii) significant nutrient discharge and concomitant eutrophication, and (iv) anoxia in the receiving water which may in turn cause fish kill. In many countries, the sustainable use of freshwater contributes significantly to the economy and the social well being of the population. For instance, the income and nutrition of many people, especially in poor countries, depend directly on the use of coastal and marine resources; e.g., fishing and tourism (UNEP, 1993). If the effluent is discharged, it is preferable that nitrogen and phosphorus are removed to avoid eutrophication, which adds considerably to the costs. The level of wastewater treatment required for irrigation is not necessarily higher than that for direct discharge; on the contrary, it may be cheaper (Friedler, 2001). For example, according to Haruvy (1997), irrigation with wastewater in the center of Israel saves US\$0.5-0.6/m^3 compared with the conventional river discharge alternative.

5.3.4.3 Pricing of freshwater and reclaimed wastewater

Pricing policies that emphasize economic efficiency and reducing of overall water use are especially relevant for regions with increasing water scarcity such as the MENA region. Appropriate pricing entails reducing the costs of water supplies and charging the consumers the true cost of these supplies (CSWSME, 1999). However, all MENA countries avoid effective pricing of freshwater and reclaimed wastewater as well as agricultural-urban water transfers, because of institutional and political influences (Saghir *et al*., 2000). In most of the

Gulf countries, the reclaimed wastewater is fully subsidized and supplied to farmers free of charge (Banks, 1991). In Jordan and Tunisia, the current tariffs that farmers pay for reclaimed wastewater can barely cover even the operational costs of conveyance and distribution (Table 5.9). The current pricing polices that adopt low pricing of reclaimed wastewater as a tool to make wastewater reuse attractive (Bahri and Brissaud, 1996; MWI, 1999; ONAS, 2001) are ineffectual since the prices of freshwater for irrigation are relatively low as well; freshwater tariffs for irrigation are about 10 times lower than for domestic and industrial consumption (Faruqui, 2000). Water pricing has been successively used as a tool to reduce water use and raise revenues in many parts of the world, e.g. Israel and Germany (Sanz, 1999; Ahmad, 2000). Thus, the prices of freshwater could be increased to a level that, first, does not jeopardize feasibility of agriculture, and, second, makes reclaimed wastewater more competitive. In the case studied, even the prices of reclaimed wastewater could be somewhat increased without negative effects, as long as the underlying principle is maintained. The financial aspects and the practicality of the water-pricing tool are discussed in greater detail in Chapters 6 and 7.

5.3.5 Institutional and legal framework

5.3.5.1 Intra- and inter- sectoral conflicting interests

Reuse projects are pre-eminently multi-sectoral. Thus, the proper identification of the stakeholders, as individuals and as institutions, is particularly important. Stakeholders involve the public, the health, environment, agriculture, and water resources officials and decision-makers, the wastewater infrastructure managers, the farmers, and many others. A proper institutional arrangement for wastewater reuse projects entails integrated views and cooperation at intra and inter (sub-) sectoral levels of the various institutions so as to optimize the use of physical, financial, and human resources (Alaerts *et al*., 1991; Khouri *et al*., 1994). However, skills and administrative responsibilities are often spread over a large number of institutional structures that have own interests to protect even while intending to be cooperative (UNDP *et al*., 1992; Mills and Asano, 1996). The visits to Jordan and Tunisia have identified the following institutional standpoints with respect to quality standards and cropping restriction, which reflect institutional conflicting interests:

- From the standpoints of health institutions, strict quality standards and cropping restriction is a powerful means to safeguard public health that must not be compromised under any circumstances, which is praised by crop consumers.

- From the standpoint of water resources managers and water scarcity specialists, strict standards and restricted cropping contradict national efforts that aim at augmenting water availability and maximizing the beneficial use of reclaimed wastewater. Although they admit to the risks of health impacts associated with reclaimed wastewater, they claim that the health institutions exaggerate, and call for adopting more rational approaches and revise the existing standards.

- From the standpoint of wastewater management institutions (“the suppliers”), the use of the treated effluents for restricted irrigation is favored since it increases credibility and economic feasibility of the existing wastewater treatment facilities. In contrast, unrestricted irrigation is perceived as a burden since it entails producing high quality effluents through advanced and expensive treatment; which decreases the credibility of the existing treatment policies.

However, these institutions anticipate producing effluents that are suitable for unrestricted irrigation.

- From the standpoint of agricultural institutions (supposedly representing “the users”), any use of reclaimed wastewater has to comply with the national standards and regulations in such a way that benefits agriculture at lowest risk to public health. These institutions are concerned about the reliability of supplies and the quality of the treated wastewater and its impact on irrigated soils and crops. Therefore, reclaimed wastewater is commonly directed for use for restricted irrigation only because on average the effluent quality does not satisfy the standards for unrestricted irrigation, although these institutions recognize the farmers’ dislike for restricted irrigation because it usually leads to a shift from high value crops to lower value crops. However, many parts of the region practice unrestricted irrigation with treated wastewater after it is mixed with surface and groundwater.

In addition to the institutional controversy on quality standards and cropping restriction, there are other conflicting interests among the key stakeholder institutions. In Tunisia for instance, one autonomous institution is in charge of wastewater treatment and another is in charge of effluent reuse for agricultural purposes: the ONAS, which is part of the Ministry of Environment and Land Use (MOELU), is responsible for wastewater collection and treatment, and the Ministry of Agriculture is responsible for the conveyance and distribution of the reclaimed wastewater to the agricultural land. The ONAS supplies the treated effluents to the MOA free of charge in order to cope with the mission of the mother institution (MOELU), which is protection of the coast and water resources. The MOA charges the farmers a flat price (20 TD Mills = 0.014 US$, per m^3) for reclaimed wastewater. The use of water meters is common in Tunisia. Nevertheless, the reliability of quantity and quality of the reclaimed-wastewater supplies is a serious cause of conflict between the two institutions. For example, MOA wants the ONAS to improve the quality of its treated effluents and regulate the flow variations, which would impose substantial new technical and financial burdens on ONAS.

In Jordan, the situation is different as the Ministry of Water and Irrigation (MWI) is the only institution responsible for wastewater collection, treatment, and reuse in addition to the provision of potable water. The MWI collects sanitation revenues from households and industries for connecting to the sewerage system and charges the farmers a flat price (10 JD Fils = 0.014 US$, per m^3) for using reclaimed wastewater. Although the conflicting interests are minimal at cross-sectoral level, they loom large at inter-sectoral level within the MWI itself. Each of the large number of departments within the WMI has its own priorities and interests to protect, particularly the Jordan Valley Authority and the Water Authority (Chapter 3).

In conclusion, weaknesses in the institutional arrangement are among the factors that limit most the growth of wastewater reuse for agricultural irrigation.

5.3.5.2 Farmers’ involvement

The top-down or supply-driven approach has been the conventional one in water, wastewater, and reuse projects for many decades. This approach, as described for water projects in general by Alaerts *et al*. (1991), is very typical for wastewater reuse projects. Typically, two main actors are identified in the process of planning, implementation, and operation of a water project: the government working through the administration or an agency and the beneficiary community. The roles of these actors are rather straightforward, with the agency playing the leading role and defining the policies, managing the funds, having the technical expertise, but also being burdened with exhausting tasks. By comparison, the beneficiary community is assumed ignorant, incapable, and inactive. As a result, the beneficiary is bypassed in the hurry to "get the job done". As previously discussed, this type of approach is very common in the MENA region where reuse is often considered as an afterthought after implementation of WWTPs; the needs, perceptions, and capabilities of the beneficiaries, and the market economics that define their decisions, are routinely ignored.

The modern participatory and demand-driven approach is becoming more accepted, however, in which the actors remain the same but the roles change. The agency remains the project initiator, but the beneficiaries play a more prominent and decisive role in all project phases (Alaerts *et al*., 1991). With regard to wastewater reuse projects, this type of approach is likely to support safer and more efficient use of reclaimed wastewater, and maximize the reuse rate (Khouri *et al*., 1994; Bahri, 1999). This approach was successively applied in the Wardanine reuse scheme of Tunisia (Chapter 3). In this scheme, farmers were involved from the early stages of the project planning and implementation in 1996. A water user association was formed representing 25 farmers that irrigate with reclaimed wastewater. This association is headed by a committee of 7 elected members. The main tasks of the committee at the implementation phase were to:

- Contribute to the construction of the project by solving design and operational difficulties between the contractor and the local population.
- Contribute to the opening of new agricultural roads.
- Help in selecting the sites of reservoir and pumping station.
- Coordinate between the equipment providers and the farmers.

Now, after five years of project implementation, the main tasks of the farmers committee are to:

- Supervise distribution of the reclaimed wastewater; the irrigation scheme utilizes 800–1,000 m^3/day which is the entire treated effluent from the Wardanine WWTP that is 3 km away. There is a reservoir that has a capacity of 500 m^3 and a pumping station adjacent to the WWTP. About 95 % of the reclaimed wastewater is used to irrigate fruit trees (mainly peaches and apricots) and only 5 % irrigates fodders. However, due to the small capacity of the WWTP and reservoir, water is mainly supplied between 7 am and 7 pm, which is not practical and insufficient for irrigation that often occurs at night. Therefore, this is an unresolved point of conflict between the water users association and the ONAS.
- Collect water revenues from the farmers; as an incentive from MOA, the committee can use the collected revenues (about US$700/year) for O&M purposes.
- Do some O&M works such as cleaning of the reservoir.
- Represent the farmers with the Agricultural Bank for loans and subsidies.

The participatory approach did not only facilitate the implementation and management of the reuse project but it also increased the willingness of farmers to use and pay for reclaimed wastewater. It has to be mentioned that the Wardanine reuse scheme is indeed the only scheme out of the surveyed schemes that made an attempt to, and succeeded in involving farmers. Therefore, there is a strong argument that farmers' involvement in all project phases does increase the opportunities for sustainability and reduce the managerial and financial burden on the government institutions. It is worth mentioning that most of the surveyed administrators and farmers in Jordan and Tunisia perceive the importance of farmers' involvement in all phases of a reuse project (Table 5.1).

5.3.5.3 Participation of private sector

In the MENA region, involving the private sector in infrastructural projects is very new (Saghir *et al*., 2000). The limited role of the private sector in wastewater treatment has been discussed in Chapter 4. Likewise, involving the private sector as a financier in wastewater reuse projects is not common, which can be attributed to the following factors: (i) high capital requirement, (ii) stringency of quality standards, (iii) weak regulatory and enforcement systems, (iv) low cost recovery, (v) price setting for reclaimed wastewater as well as freshwater by governmental decree, with a strong tendency to keep tariffs low, and (vi) thus, unattractive economic prospects.

5.3.6 Survey of the socio-cultural factors in wastewater reuse for irrigation

5.3.6.1 Introduction, objective, and methodology

Wastewater reuse projects are too often planned and implemented based upon only technical and financial feasibility studies. Planners tend to discard the relevance of the beliefs and values of a culture that basically determine the perceived need for reclaimed wastewater and the degree of acceptability of reuse by the people who will be affected by the project; farmers and crop consumer (Khouri *et al*., 1994; Bahri and Brissaud, 1996). Many studies that apply the contingent valuation survey technique (see Chapter 7) have identified the following important factors that influence public perceptions with regard to wastewater reuse (Bruvold, 1988; Khouri *et al*., 1994; Nexus Australia, 1999, Al-Hamdi, 2000): (i) degree of body contact, (ii) water conservation and environmental benefits, (iii), health effects, (iv) treatment and distribution costs, (ii) educational and awareness level, (iii) age, (iv) income, (v) religious prohibition, (vi) opinion of reference or peer group. These factors are among the most decisive factors that determine success or failure of reuse projects, and vary widely from one part of the world to another. Thus, it may not be possible to generalize conclusions related to socio-cultural aspects in the context of wastewater reuse. Therefore, a thorough assessment of the local socio-cultural aspects is always necessary before promulgating general guidelines. Unfortunately, there are few in-depth studies of the socio-cultural aspects of reuse projects in the developing countries; thus, more research is needed (Thanh and Visvanathan, 1991; Khouri *et al*., 1994; Rowe and Abdel-Magid, 1995; Al-Hamdi, 2000).

The main objective of this part of the research is to quantify (i) the acceptance of farmers to use reclaimed wastewater, (ii) the acceptance of public to buy crops watered with reclaimed water, and (iii) the factors that might change attitudes of farmers and public (crop consumers). Major parts of the questionnaires that targeted 96 farmers and 326 crop consumers were devoted to achieve this objective (Chapter 1, Annexes D3 and D4). The interviewed farmers were asked to rate their acceptance to use reclaimed wastewater for both restricted and unrestricted irrigation as "accept", "uncertain", or "reject". The unwilling and uncertain farmers were asked dichotomous (yes/no) questions for the reasons behind their decisions. The interviewed public were asked to rate their acceptance to buy crops as "accept" or "reject". Those who gave "reject" responses were asked dichotomous questions for the reasons behind their decisions. For both groups, these reasons were pre-identified based on the pilot testing of the questionnaires. Both questionnaires also presented a list of factors that might change current attitudes of farmers and crop consumers. This question was presented to all respondents irrespective of their acceptance to use water and buy the crops (Section 5.3.6.7).

A descriptive analysis is employed for the results in the forthcoming sections since attempts to build significant regression models between acceptance and other variables did not succeed.

5.3.6.2 Acceptance of farmers to use reclaimed wastewater

Khouri *et al*. (1994) attributed farmers' acceptance or rejection to use reclaimed wastewater to personal, rather than a cultural, bias. They reported that although in certain areas some farmers have rejected to substitute treated wastewater for available freshwater, other farmers of similar background in the same area have readily accepted wastewater irrigation. In our study, in Jordan and Tunisia, all the surveyed administrators and farmers assent that finding reliable users for the reclaimed wastewater is the most critical factor for success of reuse projects, which is often ignored. Mills and Asano (1996) emphasize that only identifying the potential water users for planning purposes is not enough, but there must be some assurance before embarking on design and construction of reuse projects that the intended users (farmers) will use and pay for reclaimed wastewater. Planners of the eighties have rarely recognized the necessity for assessing the potential market for the reclaimed wastewater, which explains in part the existing gap between the planned and practiced reuse (Bahri and Brissaud, 1996).

ONAS in 1992 launched an assessment of the wastewater market through surveying farmers of seven schemes irrigated with reclaimed wastewater in Tunisia to quantify the willingness of farmers to use the reclaimed wastewater (Bahri and Brissaud, 1996). The main findings are:

- About 40% of the farmers were worried about the quality of the irrigation water and its health impacts on field workers.
- A slightly higher percentage perceives reclaimed wastewater as damaging irrigated soils and threatening cultivated crops.
- On most schemes, farmers were asking for more reliable water supply.
- About 47% of the farmers were unwilling to use reclaimed wastewater if it is for restricted irrigation only.
- Farmers lacked information about wastewater quality, associated health risks, and impacts on crops and soil.

According to our field survey, the percentages of Jordanian farmers that accept to use the reclaimed wastewater for restricted and unrestricted irrigation are about 30% and 80%, respectively, compared with about 67% and 82%, respectively, in Tunisia (Table 5.10). The percentages of farmers who are uncertain are about 28% and 18%, respectively. Farmers clearly prefer to use wastewater in an unrestricted fashion rather than for restricted irrigation only as they correlate the cropping freedom with increased profit. On the other hand, only about 22% and 7% of the Jordanian farmers were found to reject reclaimed wastewater for restricted and unrestricted irrigation, respectively, compared with about 10% and 8% of that in Tunisia; these appear to be mainly farmers who have access to freshwater (surface water, and owners of groundwater wells). These results are more optimistic than the abovementioned findings of ONAS survey, which demonstrate that the farmers' acceptance has improved over the last 10 years. Thus, the results suggest a more promising era for reclaimed wastewater use for both restricted and unrestricted irrigation. However, more effort is still needed in order to improve the farmers' acceptance level through addressing the various disincentives that influence their perceptions and attitudes. The field survey (Tables 5.11, 5.12 and Figures 5.4, 5.5) identified the following prominent disincentives that fuel the farmers' rejection and hesitation in these two countries: (i) availability of or accessibility to freshwater, which is discussed in Section 5.3.2, (ii) distrusted water quality, and (iii) farmers' worries about crop marketing and acceptance of public to buy crops irrigated with wastewater. In addition to these, the survey identified other disincentives of less influence: (i) concern for public criticism, (ii) concern for health impacts, (iii) religious prohibition, and (iv) psychological aversion. These disincentives are discussed in the forthcoming sections.

Table 5.10: Acceptance of the Jordanian and Tunisian farmers to use reclaimed wastewater.

Country	*For restricted irrigation*						*For unrestricted irrigation*					
	Accept		*Uncertain*		*Reject*		*Accept*		*Uncertain*		*Reject*	
	Count	*%*	*Count*	*%*	*Count*	*%*	*Count*	*%*	*Count*	*%*	*Count*	*%*
Jordan (n=46)	14	30.4	22	47.8	10	21.7	31	67.4	12	26.1	3	6.5
Tunisia (n=50)	40	80.0	5	10.0	5	10.0	41	82.0	5	10.0	4	8.0

Table 5.11: Reasons for farmers' rejection and hesitation to use reclaimed wastewater for restricted irrigation.

Factors	*Jordan*				*Tunisia*			
	Uncertain (n=22)	*Reject (n=10)*	*Total (n=32)*		*Uncertain (n=5)*	*Reject (n=5)*	*Total (n=10)*	
	Count	*Count*	*Count*	*%*	*Count*	*Count*	*Count*	*%*
Availability/accessibility of freshwater	22	10	32	***100***	5	5	10	***100***
Distrusted water quality	21	9	30	***94***	3	5	8	***80***
Concern for public criticism	8	2	10	*31*	2	1	3	*30*
Worries about crop marketing	4	6	10	*31*	8	1	9	***90***
Concern for health impacts	2	4	6	*19*	1	3	4	*40*
Religious prohibition	5	1	6	*19*	1	1	2	*20*
Psychological aversion	2	3	5	*16*	1	4	5	*50*

Table 5.12: Reasons for farmers' rejection and hesitation to use reclaimed wastewater for unrestricted irrigation.

Factors	*Jordan*				*Tunisia*			
	Uncertain (n=12)	*Reject (n=3)*	*Total (n=15)*		*Uncertain (n=5)*	*Reject (n=4)*	*Total (n=9)*	
	Count	*Count*	*Count*	*%*	*Count*	*Count*	*Count*	*%*
Availability/accessibility of freshwater	12	3	15	***100***	5	4	9	***100***
Distrusted water quality	11	3	14	***93***	4	4	8	***89***
Worries about crop marketing	8	2	10	*67*	5	2	7	***78***
Concern for public criticism	6	2	8	*53*	4	2	6	*67*
Concern for health impacts	4	2	6	*40*	3	1	4	*44*
Religious prohibition	3	1	4	*27*	1	0	1	*11*
Psychological aversion	1	2	3	*20*	1	3	4	*44*

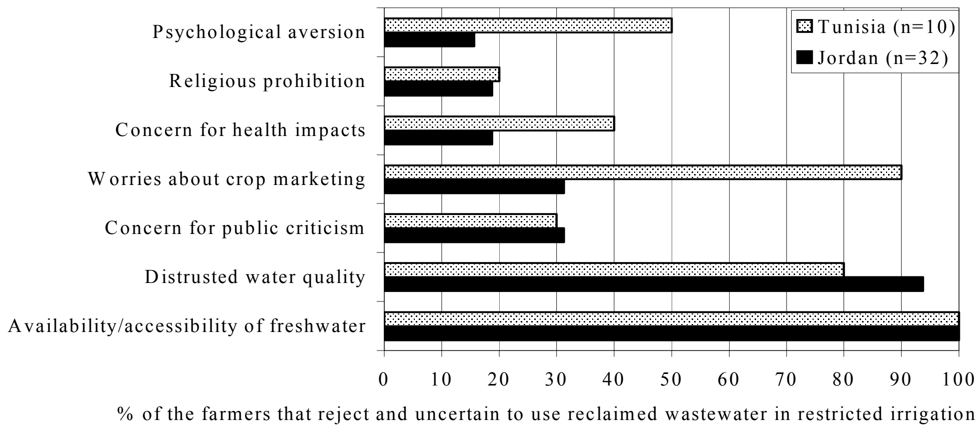

Figure 5.4: Reasons for farmers' rejection and hesitation to use reclaimed wastewater for restricted irrigation.

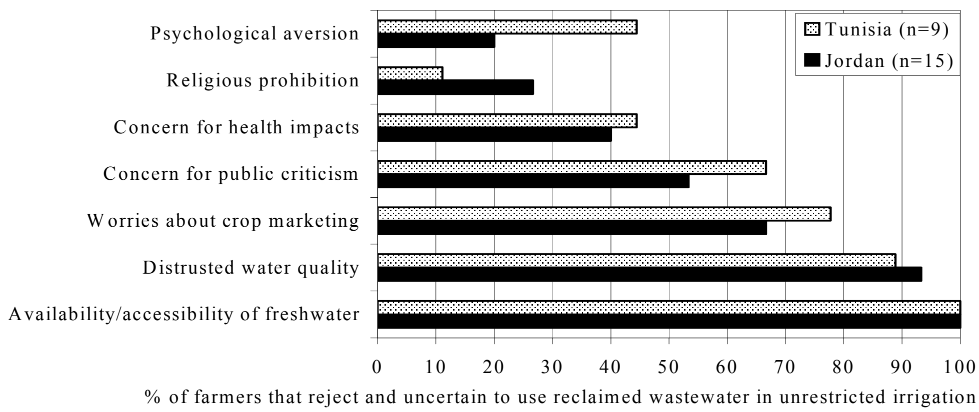

Figure 5.5: Reasons for farmers' rejection and hesitation to use reclaimed wastewater for unrestricted irrigation.

5.3.6.3 Crop marketing and acceptance of public to buy reuse-crops

Crop marketing is the last link in the sequence of wastewater reuse decisions. It is determined by public acceptance to buy the crops irrigated with reclaimed wastewater, which consecutively influences the farmers' decision to "accept" or "reject" using the reclaimed water. The crop marketing system need to be analyzed before assessing the perceptions of crop consumers.

- *Crop marketing systems*

Crop sales in the region are conducted through either wholesale or retail marketing. Under the wholesale marketing system, the farmer sells the harvest right to another farmer or merchant for a lump sum price that is determined by the quantity and quality of the harvest as well as by the demand in the market. Farmers prefer this system since it lowers their marketing risks, saves labor and time, and more importantly, provides financial liquidity. Under the retail marketing system, on the other hand, farmers themselves pack, transport, and sell the produce (Al-Hamdi, 2000). Wholesale and retail marketing systems imply one or more of the following:

i) *Farmers' use of agricultural produce for grazing their own cattle*. As a result of cropping restriction, irrigation with reclaimed wastewater is widely applied for production of fodders and cereals that are used for feeding the farmers' cattle. Most of the interviewed farmers recognize the value of the nutritional value of such crops.

ii) *Central markets through middlemen*. In central crop markets in general, middlemen or merchants are the key players; and the role of farmers is secondary. Two types of middlemen can be identified (Type A and Type B). Type A middlemen transport the harvest from a number of farms and sell it in the central markets on behalf of the farmers. The farmers are charged a commission and a transport cost. Type B is a distributor, and buys the crops in the central markets and sells them to small merchants and groceries after which they reach the consumer. This is applicable for freshwater crops as well as blended-water crops. Formally, the central markets do not visibly separate crops that are irrigated with freshwater from those irrigated with reclaimed water. However, in practice Type B middlemen are experienced enough to recognize Type A middlemen since both are frequent customers in the market, thus, they are knowledgeable about the origin of the crops and take advantage to pay lower prices for these crops.

iii) *Central markets without middlemen*. Some farmers take their crops to the central markets and sell it to the Type B middlemen, thus, avoiding Type A middlemen and saving on the transport costs and commission. In general, central crop marketing does satisfy neither farmers nor crop consumers. Freshwater farmers complain that reclaimed-wastewater crops compete with their crops and lower prices. Reclaimed-water farmers, claim that the availability of subsidized freshwater crops lowers the market prices of all crops. Farmers who illegally irrigate vegetables and cash crops with raw wastewater abuse this system and sell their crops as freshwater crops, which causes inconvenience to crop consumers and makes them suspicious about all crops.

iv) *On-farm crop marketing*. It is very common that farmers sell part of their produce on the farm. Crop merchants prefer this system because they can choose the best quality of crops at low price. Farmers also prefer it since it avoids the considerable transport cost in addition to taxes and middlemen's commission.

v) *Roaming marketing*. Some farmers and merchants avoid selling crops in the central markets searching for better prices. Therefore, a variety of crops are taken in small lorries to the urban and peri-urban localities where they directly sell crops to the citizens. Consumers of fruits and vegetables often inquire about the source of cops, but purveyors promote all crops as freshwater crops, which is sometimes not true.

vi) *Export*. The MENA countries have not yet reached a stage where the crops irrigated with reclaimed wastewater can be exported. This is mainly because the quality of reclaimed wastewater does not comply with the standards and regulations for unrestricted cropping and because of the stringent export requirements.

In conclusion, the existing system for crop marketing in which reclaimed-water crops are on offer together with freshwater crops is a good incentive to farmers to use reclaimed wastewater. Unfortunately, such marketing systems might tempt farmers to irrigate with raw sewage. Therefore, the crop marketing has to be monitored to safeguard public health.

- *Public acceptance to buy reuse-crops*

The field survey results revealed that 81.7% and 71.5% of the interviewed public in Jordan and Tunisia, respectively, are willing to buy crops irrigated with treated wastewater, which is a high level of acceptance (Table 5.13). In contrast, the willingness of the same respondents to buy crops irrigated with raw (untreated) sewage dropped significantly to 2.9% and 0.7% in these two countries, respectively. The unwilling respondents were asked for the reasons or "disincentives" that drive their decisions (Table 5.14 and Figures 5.6, 5.7). The most prominent disincentive was the availability of freshwater crops. There are other disincentives, but they are more pronounced for use of raw-sewage crops than that of treated-sewage crops: (i) concern for health impact, (ii) psychological aversion, (iii) affordable prices of freshwater crops, (iv) religious prohibition, and (v) concern for public criticism. These results allow for drawing generalized conclusions since there is no significant difference between responses in Jordan and that in Tunisia. These factors are discussed within the context of this Chapter.

It can be concluded that the crop marketing systems and the high public acceptance to use reclaimed-wastewater crops are incentives for reuse, and, thus, farmers' worries with this regard are not justified. Thus, more effort is needed to make farmers realize this incentive.

Table 5.13: Acceptance of the Jordanian and Tunisian public to use crops (n=326).

Country	*Crops irrigated with raw sewage*				*Crops irrigated with treated sewage*			
	Accept		*Reject*		*Accept*		*Reject*	
	Count	*%*	*Count*	*%*	*Count*	*%*	*Count*	*%*
Jordan (n=175)	5	2.9	170	97.1	143	81.7	32	18.3
Tunisia (n=151)	1	0.7	150	99.3	108	71.5	43	28.5

Table 5.14: Reasons for public reluctance to buy crops irrigated with raw and treated wastewater.

Factors	*Crops irrigated with raw sewage*				*Crops irrigated with treated sewage*			
	Jordan (n=170)		*Tunisia (n=150)*		*Jordan (n=32)*		*Tunisia (n=43)*	
	Count	*%*	*Count*	*%*	*Count*	*%*	*Count*	*%*
Availability of freshwater crops	166	***98***	150	***100***	32	***100***	42	***98***
Concern for health impacts	152	***89***	150	***100***	14	*44*	26	*60*
Psychological aversion	137	***81***	146	***97***	7	*22*	15	*35*
Affordable prices of freshwater crops	129	***76***	40	*27*	22	*69*	40	***93***
Religious prohibition	42	*25*	25	*17*	6	*19*	2	*5*
Concern for public criticism	32	*19*	11	*7*	9	*28*	4	*9*

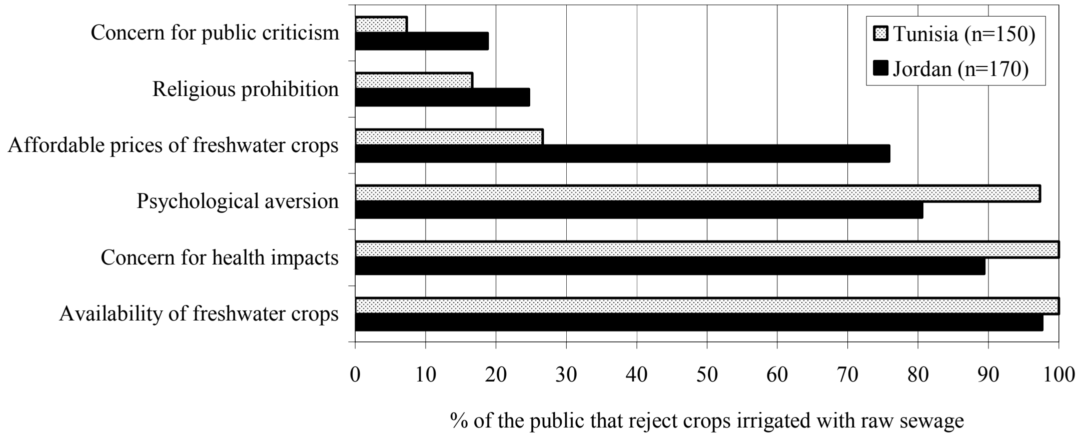

Figure 5.6: Reasons for public reluctance to buy crops irrigated with raw sewage.

Figure 5.7: Reasons for public reluctance to buy crops irrigated with treated wastewater.

5.3.6.4 Religious prohibition

"In Islamic societies, direct contact with excreta is abhorred, since by Koranic edict it is regarded as containing impurities (najassa). Its use is permitted only when the najassa have been removed. Thus the agricultural use of untreated excreta would not be tolerated, and any attempt to modify this would be futile.... .... On other hand, excreta use after treatment would be acceptable if the treatment is such that the najassa are removed– for example, after thermophilic composting which produces a humus-like substances that has no visual or odorous connection with the original material" (Mara and Cairncross, 1989).

The effect of religion on the feasibility of reuse in Islamic countries is frequently cited as an example of socio-cultural factors that can limit the application of wastewater reuse in these countries (Khouri *et al.*, 1994). The results of the study reveal that in Jordan and Tunisia, about 3% and 0% of the surveyed administrators, respectively, as well as 13% and 4% of the surveyed farmers, respectively, think that religion prohibits irrigation with reclaimed wastewater (Table 5.1 and Figures 5.1, 5.2). The farm-surveys also show that religious prohibition is a reason for about 19% and 20% of the farmers that are unwilling and uncertain to use reclaimed wastewater for restricted irrigation in Jordan and Tunisia, respectively, against 27% and 11% for unrestricted irrigation, respectively. The percentages of consumers who reject crops irrigated with raw sewage due to the same reason are about 25% and 17% in the two countries, respectively, against 19% and 5%, respectively, for treated wastewater. These results, even though small, are unrealistic since the Islamic religion does not, in principle, forbid wastewater reuse. The Organization of the Eminent Scholars of Saudi Arabia has approved the reuse of wastewater, after adequate treatment, for all purposes including *Wodoo'* for Islamic prayers (Wilkinson, 1978; Farooq and Ansari, 1983). According to Al-Hamdi (2000), Islam characterizes water into three main categories, namely *tahur*, *taher*, and *mutanajjas*. *Tahur* is the cleanest of the three and fits all uses including ritual purposes. *Taher* is considered to be clean enough to be used for domestic uses such as cooking, washing, and bathing but not fit for ritual purposes. *Mutanajjas* is considered unclean and not fit for use due to contamination that has changed one or more of its properties (color, taste, or odor). Nevertheless, both *taher* and *mutanajjas* water can be converted into *tahur* water if adequate dilution with *tahur* water takes place, and if impurities are removed through treatment. However, untreated wastewater is used in many Islamic countries where extreme water scarcity conditions prevail, such as Palestine and Yemen.

It can be concluded that the attitude of Islam towards reuse of wastewater should not be considered an impediment for acceptance of farmers and crop consumers.

It is worth mentioning that a number of Arabic terminologies are used for wastewater, its treatment and reuse. Although all terminologies serve the same purpose, they may have different interpretations in the Arabic and Islamic cultures. For instance, in Tunisia, the treatment of wastewater is called *Tat-heer* which is a common terminology in the teachings of Islam that means removing the impurities *(najassa)* and making water fit for all uses. In Jordan and many other MENA countries, treatment sometimes is called *Tanqueyah* (purification) and often it is called *Mu'alajah* (treatment). In the reviewed studies, many different terms were used, such as reclaimed water or effluent or water recycling, or repurified water. These terms can be confusing if not well defined. San Diego's use of the term "repurification" appears to be one of the better terms to overcome emotional responses (Nexus Australia, 1999).

5.3.6.5 Psychological aversion

Some of the interviewed farmers and crop consumers expressed psychological aversion towards reclaimed wastewater and crops irrigated with this water, respectively. This aversion is a resultant of (i) the questionable origin of the reclaimed wastewater, (ii) health concerns, (iii) religious beliefs, and (iv) cultural values and traditions. The results of this study demonstrate that in Jordan and Tunisia, about 3% and 9% of the surveyed administrators, respectively, as well as 13% and 8% of the farmers, respectively, think that people have psychological aversion to wastewater irrigation and related crops (Table 5.1 and Figures 5.1, 5.2). The results also show that psychological aversion is a reason for about 16% and 50% of the farmers that are unwilling and uncertain to use reclaimed wastewater for restricted irrigation in Jordan and Tunisia, respectively, against 20% and 44% for unrestricted irrigation, respectively (Tables 5.11, 5.12 and Figures 5.4, 5.5). However, this is particularly observed among freshwater farmers who did not yet experience irrigation with reclaimed wastewater; i.e., those who don't know are most likely to have negative prejudice. Thus, education and awareness are capable of mitigating this disincentive. Likewise, in the two countries, the percentages of public that reject raw-sewage crops due to psychological considerations are about 81% and 97%, respectively, against 22% and 35%, respectively, for treated-wastewater crops (Table 5.14 and Figures 5.6, 5.7). These results reveal that psychological aversion to wastewater-irrigated crops stems from concerns for quality of the irrigation water. Thus, improving the quality of treated wastewater together with public awareness might overturn this disincentive.

5.3.6.6 Opinion of reference/peer groups and concern for public criticism

The majority of people in the MENA region are Muslims. Farmers are mostly located in rural and peri-urban areas where the social and traditional ties are stronger than in urban areas. Therefore, farmers' attitudes and perceptions, and any changes thereof, tend to be strongly influenced by religion, culture, politics, and influential reference groups within the society. This factor was identified by about 13% and 6% of the administrators as well as by 87% and 48% of the farmers in Jordan and Tunisia, respectively. There is no specific classification of these reference/peer groups since they vary from one society to another, and one individual may feel guided by other reference groups than another individual. However, our study could tentatively identify three categories of reference groups to farmers and crop consumers: (i) community leaders that include religious preachers, clan leaders (*Hamolah Sheiks*), and local politicians, (ii) relatives, and (iii) friends. The results of the field survey show that in Jordan, about 31% and 53% of the farmers that are unwilling and uncertain to irrigate with reclaimed wastewater for restricted and unrestricted irrigation, respectively, attribute their decisions to concern for public criticism; in Tunisia, it is 30% and 67%, respectively (Tables 5.11, 5.12 and Figures 5.4, 5.5). The results also show that the percentages of farmers who feel concern for the opinions of community leaders, relatives, and friends in Jordan are about 93%, 46%, and 17%, respectively, and in Tunisia are about 42%, 28%, and 28%, respectively (Table 5.15 and Figure 5.8). For crop consumers, they are about 51%, 43%, and 34%, respectively in Jordan and 45%, 29%, and 17%, respectively, in Tunisia (Table 5.16 and Figure 5.9). There is no significant difference between the two countries, except for more tribute to community leaders by the Jordanian farmers than the Tunisians, which may be attributed to the strong tribal ties in the Jordanian rural communities. The significant difference between the responses of farmers and crop consumers with respect to opinions of community leaders can be attributed to the fact that all the surveyed farmers were located in rural and peri-urban areas while the surveyed crop consumers where from rural, peri-urban, and urban areas. Results also show that concern for public criticism is a strong disincentive to some users of reclaimed wastewater and related crops. Although the influence of this disincentive is diminishing, it still exists and has to be taken into account. These results suggest that involving the reference groups in decision-making and planning of a reuse project as well as in awareness campaigns might mitigate the socio-cultural disincentives.

5.3.6.7 Public awareness and attitude change

Often, public knowledge is very limited about the risks and benefits of wastewater reuse. This has been confirmed by all the surveyed administrators and farmers in Jordan and Tunisia. Therefore, raising public awareness and changing public attitudes on wastewater reuse are common objectives worldwide, even though it is recognized that there is no straightforward relationship between awareness and attitude change (see, e.g., the attempts to have people quit smoking [Nexus Australia, 1999]).

Two main approaches are distinguished for attitude change: spontaneous learning and premeditated awareness. Spontaneous learning, which is very common in the developing countries, would commence in the case of a wastewater reuse scheme after the project is implemented, when first the practitioners' knowledge develops mainly based on "learning by trial and error", supported by occasional awareness or training programs for the practitioners. Thus, as the practitioners try to operate the scheme properly, the public starts experiencing the risks and benefits, and new (positive or negative) perceptions develop. If operation and regulation are not properly implemented from the beginning, the public may be confronted with more negative than positive experiences, which can seriously undermine the reuse's credibility, especially if public health is jeopardized. In the premeditated approach on the other hand, the knowledge of concerned public develops based on better guided awareness development and systematic education.

The results of this study show that perceptions and attitudes towards irrigation with reclaimed wastewater are not rigid but subject to conditional change except for some fundamental postulates and taboos. An attempt was made to understand what might change the perceptions and attitudes of farmers and crop consumers, besides the direct disincentives that have been identified in the previous sections. A list of potential factors was presented to all interviewed individuals in the sample (farmers and crop consumers) in the form of dichotomous questions since respondents were not able to scale these factors. Results suggest a number of factors that might be capable of improving perceptions as discussed below (Tables 5.15, 5.16 and Figures 5.8, 5.9). Most of these factors are applicable to both farmers and crop consumers, but some are group-specific. Although many of these factors have been discussed within the context of this and previous Chapters, they are briefly re-iterated here.

Table 5.15: Factors that might change farmers' attitudes in Jordan and Tunisia.

Factors	*Jordan (n=46)*		*Tunisia (n=50)*	
	Count	*%*	*Count*	*%*
Availability or shortage of freshwater	44	***96***	50	***100***
Improved water quality and cropping freedom	44	***96***	48	***96***
Community leaders	43	***93***	21	*42*
Regulations and enforcement	42	***91***	49	***98***
Water prices and profit	41	***89***	48	***96***
Specialists	36	***78***	50	***100***
Farmers' involvement	35	***76***	48	***96***
Potential fertilizers saving	32	***70***	39	***78***
Media (TV, Newspapers, radio)	29	*63*	20	*40*
Reports, studies, brochures	27	*59*	34	*68*
Relatives	21	*46*	14	*28*
Friends	8	*17*	14	*28*

Table 5.16: Factors that might change public attitudes in Jordan and Tunisia.

Factors	*Jordan (n=175)*		*Tunisia (n=151)*	
	Count	*%*	*Count*	*%*
Regulations and enforcement	167	***95***	145	***96***
Public involvement	150	***86***	54	*36*
Specialists	149	***85***	133	***88***
Media (TV, Newspapers, radio)	96	*55*	116	*77*
Community leaders	89	*51*	68	*45*
Relatives	76	*43*	44	*29*
Friends	59	*34*	26	*17*
Reports, studies, and brochures	42	*24*	62	*41*

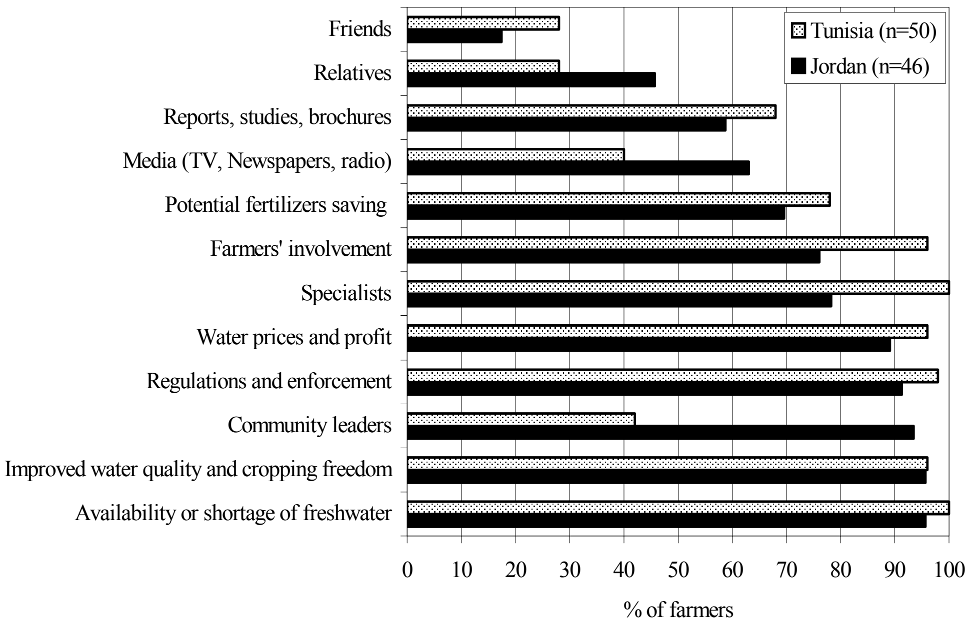

Figure 5.8: Factors that might change farmers' attitudes in Jordan and Tunisia.

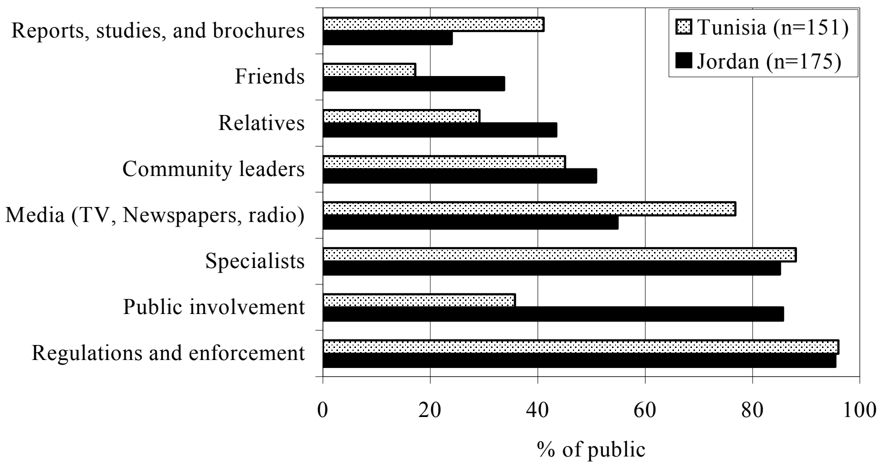

Figure 5.9: Factors that might change public attitudes in Jordan and Tunisia.

• *Availability of freshwater and freshwater-irrigated crops*. As discussed before, the availability of cheap freshwater for irrigation makes reclaimed wastewater less attractive and less competitive. The survey results show that 89% and 96% of the surveyed farmers in each country confirm that shortages of freshwater have the power to make them reconsider their decisions with respect to irrigation with reclaimed wastewater (Table 5.15 and Figure 5.8). Likewise, the availability of cheap freshwater-irrigated crops depresses consumer demand for crops irrigated with reclaimed wastewater (Table 5.14 and Figures 5.6, 5.7). However, this may turn out to be a trivial disincentive since analysis of the crop marketing systems in Section 5.3.6.3 shows that in reality consumers are never certain about the source of the crops they consume.

• *Improved water quality and cropping freedom*. As mentioned before, most of the direct reasons for the farmers' unwillingness to irrigate with reclaimed wastewater stem from quality concerns, especially the possible impacts on health, cropping restrictions (with the associated reduced income), psychological aversion, religious prohibition, and public criticism. Moreover, farmers perceive the degree of cropping restriction as an indicator of the quality of the reclaimed wastewater. For about 96% of the surveyed farmers in each country (Table 5.15 and Figure 5.8), improving the quality of treated wastewater and allowing unrestricted irrigation have the power to change the negative attitudes of farmers with respect to reuse. This suggests the need for raising the technical understanding of farmers.

• *Regulations and enforcement*. According to the World Bank (2001), the weak regulatory and enforcement mechanisms in the MENA region aggravate the environmental problems. Although the region has made progress by establishing ministries of the environment, and by preparing or enacting environmental legislation, the institutions are under-funded and generally lack credibility and political power. Cross-sectoral linkages between government and public institutions are weak. The legal framework relies too much on a command-and-control approach of which the effectiveness is further jeopardized by weak monitoring and enforcement. The role of civil society in environmental management remains limited, in part because existing NGOs are small, young, local in nature, and often dependent on the government and international donors for budgetary support. Interestingly, our survey shows that farmers and crop consumers are very responsive to regulations and enforcement, as more than 91% and 96%, of the farmers and crop consumers, respectively, report that their behavior is influenced by them (Tables 5.15, 5.16 and Figures 5.8, 5.9).

• *Water tariffs*. The price of the reclaimed wastewater is a key part of the cost structure of farming and thus determines the financial profit the farmer can make. Both the tariffs of freshwater and reclaimed wastewater are very low, making in effect the reclaimed wastewater less competitive given the crop restriction and the market discounts associated with its use. Therefore, it is necessary to revise the water tariff policies. This is discussed further in Chapters 6 and 7.

• *Involvement of farmers and public*. Participation of users and key stakeholders is becoming increasingly important to ensure success in water programs such as reuse projects. Participation has been shown to improve, on one hand, the perceptions and attitudes of farmers and crop consumers, and on the other, to provide information to planners and designers on how to attune their designs to meet real demand. Farmers' involvement has been discussed in Section 5.3.5.2. Involvement of the crop consumers and public is at least as important because they are the identified financiers for the wastewater treatment/sanitation and reclamation. The public surveyed in this study in Jordan and Tunisia showed enthusiasm for participation in decision making with respect to water and sanitation in general and with respect to tariffs in particular; about 86% and 36% of the public in Jordan and Tunisia, respectively, consider this factor as influential to attitude change (Table 5.16 and Figure 5.9).

• *Potential fertilizers saving*. About 70% and 78% of the surveyed farmers in Jordan and Tunisia, respectively, consider that the nutrient contents in reclaimed wastewater, and the potential saving in artificial fertilizers, would influence farmers' attitudes (Table 5.15 and Figure 5.8). However, as shown previously many farmers who irrigate with reclaimed wastewater still apply expensive fertilizers. This suggests that the level of knowledge of farmers on the nutrients value in wastewater is limited, and that more education and awareness can lead to savings and thus further improved acceptance of reuse.

• *Opinion of reference groups*. As discussed in Section 5.3.6.6.

• *Awareness through media and publications*. As a result of urbanization, TV, newspapers, and radio have become very common in urban as well as rural communities. The field surveys revealed that such media could be more effectively utilized to raise the level of public awareness and education. In both countries studied, the media is already often used to inform farmers and the public on various agricultural issues, and on water conservation. However, in all cases, it was observed that there is still little attention for wastewater reuse. Reports, studies, and brochures or leaflets that emphasize the risks and benefits associated with wastewater reuse are common in most countries. In Jordan and Tunisia, many framers reported that they receive occasional publications that are often not easy to understand because they require a certain level of education. Therefore, having publications in simpler language might increase the awareness level amongst farmers. On the other hand, publications that target crop consumers are very few and, if any, lack simple, clear messages.

• *Demonstration sites and specialist advice.* A final factor is having demonstration sites where farmers can observe and learn "best practices" from model farms and pilot plants. This factor was not included in the study's questionnaires because it was identified as an educational tool only at later stages of the fieldwork in Tunisia at the Al-Taweel and Cebala scheme. Indeed, at the time of project implementation, most farmers in this scheme were unwilling to use the reclaimed wastewater for irrigation of fodders and cereals. The one event that changed the attitude of many farmers was that they could witness the positive effects of the reclaimed water on plant growth in the vicinity of leaking junctions in the distribution system that occurred during testing. Personal contacts through farm visits and seminars directed by specialists are reported to be one of the most influential awareness tools. The Ministries of Agriculture in Jordan and Tunisia, as well as a number of agricultural research centers and institutes, are very active in this regard. However, these efforts often remain too general since they focus on agricultural irrigation and production, without emphasis on the benefits and risks associated with reclaimed wastewater.

5.3.6.8 Land fragmentation

This factor was identified by 3% and 18% of the surveyed administrators as well as by 15% and 24% of the farmers in Jordan and Tunisia, respectively. The fast population growth and high demand for land have increased land value. Consequently, the area of land available for agriculture continuously decreases, especially in peri-urban areas. Simultaneously, urbanization opened up new job opportunities that compete with farming jobs. Finally, the traditional inheritance system in the Arabic/Islamic cultures causes progressive land fragmentation. It also encourages a reduction in the agricultural land acreage since some of the new landowners prefer to move to the cities leaving their land uncultivated or used for housing and other investment projects. Thus, the new landowners do not necessarily have the same attitudes and perceptions as the preceding generation.

5.4 Conclusions and recommendations

A large number of factors can increase (as incentive) or lower (as disincentive) the demand for reclaimed wastewater. Depending on the local conditions, each incentive or disincentive can work out to a larger or smaller degree. As a result, the positive influence of a certain incentive may be compensated by a certain disincentive, and vice versa. Therefore, the desire to reuse reclaimed wastewater depends, in resultant, on a series of incentives and disincentives. In order to maximize reuse, all possibly relevant factors have to be identified and considered in an integrated manner. In this chapter, the technical, regulatory, financial, institutional, and socio-cultural factors have been analyzed and the following conclusions and recommendations are derived:

- Freshwater availability/accessibility at scheme level is the most crucial disincentive for reuse as reclaimed wastewater cannot compete with freshwater. This disincentive can be mitigated through enforcing restrictions on irrigation with freshwater wherever reclaimed wastewater can cover the agricultural water demand, and through strengthening the incentives that make reclaimed wastewater competitive with freshwater.
- The existing quality standards and regulations for irrigation with reclaimed wastewater are overly restrictive although their makeup is based on other international practices. Therefore, there is great need for establishing milder standards and guidelines that take into consideration the scheme and country specific conditions. In this case, there is no need for establishing flat standards but a set of inclusive guidelines that enable establishing site-specific standards for each irrigation scheme. The determining effect of standard is important and an area where government should do something.
- The health impact associated with reclaimed wastewater can be very severe; therefore, public health must not be compromised through maximizing reuse rates. Nonetheless, majority of the surveyed farmers do not perceive the actual health risks; on the contrary, they claim no impacts. Some farmers persist to irrigate with raw wastewater. However, more research is needed in order to study the long-term impacts on users of reclaimed wastewater and related crops as well as beneficiaries of the affected water resources.
- The conveyance and distribution can be major disincentives for irrigation with reclaimed wastewater, especially where the infrastructural requirements are high and the financial resources are limited. In such case, as far as possible, using the reclaimed wastewater in the vicinity of the WWTPs overturns this disincentive and even makes wastewater irrigation more attractive.
- Reclaimed wastewater is often a financially-expensive water resource because of the high investment and operational costs related to collection and treatment of influent, and conveyance and distribution of treated effluents. However, the economic benefits overturn this disincentive and make reclaimed wastewater more competitive than other water

sources. The benefits include the added-value to water resources, agriculture and the environment, and the avoided-costs related to wastewater reuse such as prevention of health risks and environmental degradation.

- This study shows that there is about 65% saving in actual fertilizer expenditure when irrigating fruit trees with reclaimed wastewater compared to irrigating with fresh groundwater. Also, interestingly, many farmers irrigating with blended water behave like those irrigating with freshwater and still spend almost equal sums on artificial fertilizer despite the high nutrient content in the reclaimed wastewater. These farmers seem to not have confidence in the quality of reclaimed wastewater, or they unconsciously attribute their high crop yield and agricultural profit to the application of the artificial fertilizer; this is consistent with the observation that they tend to use less fertilizer for low-value fodder crops than for fruit trees and vegetables. Thus, more effort is needed to raise farmers' awareness on the nutrient content in reclaimed wastewater.
- The regulatory, financial, and socio-cultural (dis)incentives were shown in the field surveys to be of great relevance in the shaping of the decisions of both the farmers – who have to buy the reclaimed water and apply certain agronomic approaches – and the public – that must decide whether to buy the crops watered with reclaimed wastewater. These incentives could be possibly more influential than the technical ones.
- Weakness of the institutional makeup, poor coordination at intra and inter (sub-) sectoral levels, low farmers' involvement, and lack of private sector participation are amongst the major factors that limit the growth of wastewater reuse. This entails better formulation of national strategies and efficient reallocation of responsibilities in such a way that intensifies all efforts for maximizing wastewater reuse without altering the identity of one institution on the expense of another. Besides, there is immense need for involving farmers as well as the private sector in all project phases in order to ensure its sustainability and reduce some burden from the top institutions. This would also help in improving the willingness of farmers to use and pay for reclaimed wastewater.
- Farmers and public seem, in general, in these two countries, reasonably positive towards reuse. There is some evidence to state that perceptions towards acceptance have improved over the past decade. Increasing acceptance means that reuse should not be approached as a technical issue only; the role of the markets, of price incentives, and of other perceptions are crucial. For example, understanding how the crop marketing system operates is necessary because our study showed that in reality the consumers often cannot distinguish between crops irrigated with freshwater and reclaimed wastewater. The effects of the presence on the market of reclaimed-water-irrigated crops needs further study. Also, to improve farmers' acceptance, it is necessary to understand better how they can get more or more reliable income, i.e., how things like crop restriction and competition by too cheap freshwater defeat reuse's purpose.
- The crop marketing systems and the high public acceptance to use reclaimed-wastewater crops are incentives for reuse, and, thus, the worries of farmers with this regard are not justified. Thus, more effort is needed to make farmers realize this incentive.

- The attitudes of Islam can be considered as an incentive for irrigation with reclaimed wastewater. However, some farmers and rural dwellers are not aware of this and still conceive religion as an obstacle.
- Awareness and education can be very effective if properly executed. Farmers and crop consumers are very responsive to the various means of awareness and education. These means include: TV, Radio, newspapers, brochures, seminars, personal visits, and religious breaching. Proper execution of awareness and education entails (i) easy language, (ii) well focused content, (iii) conducted by specialists who are esteemed by beneficiaries, and (iv) supported by demonstration of benefits and of proper management to mitigate risks.

5.5 References

Abu Rizaiza, O. (1999). Modification of the standards of wastewater reuse in Saudi Arabia. *Wat. Res.*, **33**(11): 2601-2608.

Ahmad, M. (2000). Water pricing and markets in the Near East: Policy issues and options, Water *Policy*, **2**: 229-242.

Alaerts, G., Blair, T., and Hartvelt, F. (1991). A Strategy for water sector capacity building. IHE report series, 24, Delft.

Al-Hamdi, M. (2000). Competition for scarce groundwater in Sana'a plain, Yemen: a study on the incentives system for urban and agricultural water use. PhD thesis, IHE-Delft, The Netherlands.

Al-Lafi, M. (1996). Legislation, regulations and standards for wastewater reuse in Jordan. Workshop on wastewater treatment and reuse in Jordan. Aqaba, Jordan.

Al-Salem, S. (1996). Environmental considerations for wastewater reuse in agriculture. *Wat. Sci. Tech*., **33**(10-11): 345-353.

Angelakis, A. N., Marecos do Monte, M. H. F., Bontoux, L., and Asano, T. (1999). The status of wastewater reuse practice in the Mediterranean Basin: need for guidelines. *Wat. Res*., **33**(10): 2201-2217.

Asano, T. and Levine, A. (1996). Wastewater reclamation, recycling and reuse: past, present, and future. *Wat. Sci. Tech*., **33**(10-11): 1-14.

Ayers, R. S. and Wescot, D.W. (1985). Water quality for agriculture. Food and Agricultural Organization of the United Nations, FAO Irrigation and Drainage, Paper 29, Rome.

Bahri, A. (1987). Utilization of treated wastewater and sewage sludge in agriculture in Tunisia. *Desalination*, **67**: 233-244.

Bahri, A. (1998). Fertilizing value and pollution load of reclaimed water in Tunisia. *Wat. Res*., **32**(11): 3484-3489.

Bahri, A. (1999). Agricultural reuse of wastewater and global water management. *Wat. Sci. Tech*., **40**(4-5): 339-346.

Bahri, A. and Brissaud, F. (1996). Wastewater reuse in Tunisia: assessing a national policy. *Wat. Sci. Tech*., **33**(10-11): 87-94.

Banks, P. (1991). Wastewater reuse case studies in the Middle East. *Wat. Sci. Tech*., **23**: 2141-2148

Bartone, C. (1994). Urban sanitation, sewerage, and wastewater management: Responding to growing household and community demand. ESD, World Bank, Washington DC.

Blumenthal, U. J., Mara, D. D., Peasey, A., Ruiz-Palacios, G., and Stott, R. (2000). Guidelines for the microbiological quality of treated wastewater used in agriculture: recommendations for revising WHO guidelines. *Bulletin of the World Health Organization*, **78**(9): 1104-1116.

Bouwer, H. (1991). Role of groundwater recharge in treatment and storage of wastewater for reuse. *Wat. Sci. Tech*., **24**(9): 295-302.

Bruvold, W. (1988). Public opinion on water reuse options. *Water Pollution Control Federation*, **60**(1); 45-49.

Cost-Benefit Handbook. (1998). A guide for New York State's regulatory agencies. Chapter 4, Measuring health and environmental benefits. http://www.gorr.state.ny.us/gorr/cba-hdbk.html. Revised 6/98.

CSWSME (Committee on Sustainable Water Supplies for the Middle East). (1999). Water for the future: The West Bank and Gaza Strip, Israel, and Jordan. Israel Academy of Sciences and Humanities, Palestine Academy for Science and Technology, Royal Scientific Society, Jordan, U.S. National Academy of Sciences. National Academy Press, Washington, D.C.

Eden, R. (1996). Wastewater reuse – limitations and possibilities. *Desalination*, **106**: 335-338.

FAO. (1985). Water quality for agriculture. FAO Irrigation and Drainage Paper No. 29 Rev.1, Food and Agriculture Organization of the United Nations. Italy.

Fardous, A. and Jamjoum, K. (1996). Corn production and environment effects associated with the use of treated wastewater in irrigation of Khirbet Al-Samra Region. Annual report, National Center for Agricultural Research and Technology Transfer (NCARTT). Amman.

Farooq, S. and Ansari, Z. (1983). Wastewater reuse in Muslim countries: An Islamic perspective. *Env. Mang*., **7**(2): 119-123.

Faruqui, N. (2000). Wastewater treatment and reuse for food and water security. www.idrc.ca/waterdemand/SpecialPapers_e.html, IDRC, Ottawa, Canada.

Feachem, R., Bradley, D., Garelick, H., and Mara, D. (1983). Sanitation and disease-health aspects of excreta and wastewater management. Published for the World Bank, John Wiley and Sons, Chicester, Great Britain.

Friedler, E. (2001). Water reuse – an integral part of water resources management: Israel as a case study. *Water Policy*; **3**, 29-39.

Gunnerson, C., Shuval, H., and Arlosoroff, S. (1985). Health effects of wastewater irrigation and their Control in Developing Countries. Future of Water Reuse. AWWA. Denver, CO USA.

Haruvy, N. (1997). Agricultural reuse of wastewater: nation-wide cost-benefit analysis. *Agriculture, Ecosystems and Environment*, **66**: 113-119.

Hussain, G. and Al-Sati, A. (1999). Wastewater quality and its reuse in agriculture in Saudi Arabia. *Desalination*, **123**: 241-251.

Idelovitch, E. (2001). Wastewater reclamation for irrigation: The Dan Region Project in Israel. Prepared for the World Bank, Washington.

Jimĕnez, C. B. (1995). Wastewater reuse to increase soil productivity. *Wat. Sci. Tech*., **32**(12): 173-180.

Johnson, J. (2002). An outline of wastewater irrigation planning. Water and Sanitation Infrastructure. 11.479 Term Paper. May 12, 2002.

Khouri, N., Kalbernatten, J. M., and Bartone, C. R. (1994). Reuse of wastewater in agriculture: A guide for planners. Water and Sanitation Report No. 6, UNDP - World Bank Water and Sanitation Program. Washington, USA.

Mara, D. and Cairncross, S. (1989). Guidelines for the safe use of wastewater and excreta in agriculture and aquaculture. WHO, Geneva, Switzerland.

Mills, R. and Asano, T. (1996). A retrospective assessment of water reclamation projects. *Wat. Sci. Tech*., **33**(10-11): 59-70.

MWI. (1999). Annual report of the Ministry of Water and Irrigation. Amman.

Nexus Australia. (1999). Education needs background report. Study report one in a series of eleven, January 1999. Prepared on behalf of Queensland Water Recycling Strategy.

ONAS. (2001). Annual report of the National Agency for Sewerage. Tunisia.

Ongerth, J. J. and Jopling, W. F. (1977). Water reuse in California. Water renovation and reuse, edited by Shuval, H. Academic Press, New York.

Pearson, H. and Mara, D. (1993). Wastewater reuse and storage for reuse in coastal regions. *Wat. Sci. Tech*., **25**(12).

Rowe, D. R. and Abdel-Magid, I. M. (1995). Handbook of wastewater reclamation and reuse, Lewis Publishers, USA.

RSS. (1997). Monitoring the quality of inflow and outflow water from Khirbet Al-Samra and Wadi Al-Zarqa, and studying it impact on quality of groundwater. Final report (1996-1997) presented by the Royal Scientific Society to the Water Authority (in Arabic). Amman, Jordan.

Saghir, J., Schiffler, M., and Woldu, M. (2000). Urban water and sanitation in the Middle East and North Africa Region: The way forward. The World Bank, Middle East and North Africa Region, Infrastructure Development Group.

Sanz, L. (1999). Irrigated agriculture in the Guadian River High Basin (Castilla-La Mancha, Spain): Environmental and socioeconomic impacts, *Agricultural Water Management*, **40**: 171-181.

Shatanawi, M. and Fayyad, M. (1996). Effect of Khirbet As-Samra treated effluent on quality of irrigation water in the Central Jordan Valley. *Wat. Res*., **30**(12): 2915-2920.

Shelef, G. (1991). Using water of marginal quality for crop production: major issues. *Agricultural Water Management*, **25**: 233-269.

Shelef, G. and Azov, Y. (1996). The coming era of intensive wastewater reuse in the Mediterranean region. *Wat. Sci. Tech*., **33**(10-11): 115-125.

Shuval, H. (1991) The development of health guidelines for wastewater reclamation. *Wat. Sci. Tech*., **24**(7): 149-155.

Shuval, H. I., Adin, A., Fattal, B., Rawitz, E., and Yekutiel, P. (1986). Wastewater irrigation in developing countries: Health effects and technical solutions. Technical Paper No. 51. The World Bank, Washington, DC, USA.

Siebe, C. (1995). Heavy metal availability to plants in soils irrigated with wastewater from Mexico City. *Wat. Sci. Tech*., **32**(12): 29-34.

Thanh, N.C. and Visvanathan, C. (1991). Wastewater reuse gains momentum in Mediterranean and middle eastern regions. Wastewater, WWI/February 1991: 19-26.

UNDP, FAO, The World Bank, and WHO. (1992). Wastewater treatment and reuse in the MENA region – Unlocking the potential, Review Draft, Report of a joint mission to Cyprus, Egypt, Jordan, Kuwait, Morocco, Saudi Arabia, Syria, Tunisia, Turkey, and Yemen. Project RAB/88/009, July 1992.

UNEP. (1993). Costs and benefits of measures for the reduction of degradation of the environment from land-based sources of pollution in coastal areas. A - Case study of the Bay of Izmir. B – Case study of the Island or Rhodes. MAP Technical Reports Series No. 72.

USEPA. (1992). Manual guidelines for water reuse. U.S. Environmental Protection Agency, Washington D.C.

WERSC. (1989). Treated wastewater for agriculture. Bulletin No. 13. Water and Environment Research and Study Center (WERSC), University of Jordan.

WERSC. (1996). Quality of irrigation water in the Middle Jordan Valley. Bulletin No. 20. Water and Environment Research and Study Center (WERSC), University of Jordan.

WERSC. (1998). Jordan experience in treated wastewater reuse in irrigation. Technical Bulletin No. 22. Water and Environment Research and Study Center (WERSC), University of Jordan, in collaboration with the National Center for Agricultural Research and Technology Transfer (NCARTT), Amman.

Wilkinson, J. (1978). Islamic water law with special reference to oasis settlements. *Arid Environments*, **1**: 87-96.

World Bank. (2001). Middle East and North Africa Region: Environment strategy update 2001-2005. Draft.

World Health Organization. (1973). Reuse of effluents: Methods of wastewater treatment and health safeguards. Tech. Rep. Ser. 517, WHO, Geneva, Switzerland.

World Health Organization. (1989). Health guidelines for use of wastewater in agriculture and aquaculture. Tech. Rep. Ser. 778, WHO, Geneva, Switzerland.

Wright, A. M. (1997). Toward a strategic sanitation approach: Improving the sustainability of urban sanitation in developing countries. International Bank for Reconstruction and Development/The World Bank, Washington, DC. USA.

Chapter 6: Viability of Increasing the Tariff of Freshwater for Irrigation as a Tool to Stimulate Wastewater Reuse

"*At political meetings in rural areas it is common to hear slogans such as: 'water is a gift of God'; 'water is human right'; or 'don't tax cleanliness'. Such simple, plausible statements are misleading. Water in the river may be a gift from God but pipes and pumps are paid for by people, ... However, there is no such thing as a free glass of water; even if the consumer does not pay for it, somebody, somewhere is paying"* (Cairncross *et al*., 1980).

6.1 Background

Across the world, the water policies and management practices in the last decades were often based on considering water as a free and renewable resource. As a result, water resources of many countries nowadays are under increasing pressure and suffer from scarcity. Countries started to (re)consider mechanisms to improve water use efficiency (Abu Qdais and Al Nassay, 2001). This is especially true for agricultural irrigation, a major consumer of water. Irrigation water has long been considered a public good, which is provided to the public for free or at a nominal price. Only in recent years the charging of a fee for irrigation water is receiving some attention aiming at covering system operation and maintenance cost, or recovering a portion of the initial investment. Also, only recently the basic concept emerged that water is to be treated as an economic good (UNICWE, 1992), and is being introduced in various countries. By treating water as an economic good, users can be given signals regarding the value of water to society through a variety of incentives, including pricing. Water pricing, in other words setting prices closer to their economic (or at least, financial true value), has been a relatively reliable tool to reduce freshwater consumption, ensure more efficient allocation and productive use, and simultaneously raise revenues for maintaining the infrastructure (Perry, 2001; Johansson *et al*., 2002).

Economic theory has long ago explained how correct pricing of private and public goods can lead to gains in economic efficiency. However, the extent to which these principles should be implemented remains a topic for debate. On one hand, it is argued that increased water tariff is regressive and reduces equity since it could have a negative impact on smallholder farmers and those practicing subsistence agriculture (Yoduleman, 1989). Likewise, during periods of drought or scarcity, if tariff increases to the level correctly reflecting this scarcity, lower income groups may be disproportionally negatively affected (Dinar and Subramanian, 1998). On the other hand, Rogers *et al*. (2002) argue that increasing the water tariff can improve equity. Higher water rates and, thus, higher income allow utilities to extend services to those currently not served and those currently forced to purchase water from vendors at very high prices. Besides, the price policy can help maintain the sustainability of the resource itself.

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When the tariff of water reflects its true cost, the resource will be put to its most valuable uses. Table 6.1 lists the three generally accepted effects of price policy: demand reduction, efficient reallocation of the resource, and increasing the supply. In addition, Rogers *et al.* (2002) argue that if water resources are managed in an integrated manner where the economic, legal, and environmental aspects complement each other, increased prices do improve equity, managerial efficiency, and sustainability of the resource ("water resources" meant to include surface water, groundwater, and reclaimed wastewater).

Table 6.1: Effects of price policy (Rogers *et al.*, 2002).

(a) Increased price reduces demand
(i) Substitutes become cheaper
(ii) Conservation becomes affordable
(iii) Consumption preferences change
(b) Increased prices increase supply
(i) Marginal projects become affordable
(ii) Economic incentives to reduce water losses are required
(c) Increased price facilitates re-allocation between sectors
(i) From irrigation to domestic and industrial
(ii) From off-stream to in-stream uses
(d) Increased prices improve managerial efficiency due to increased revenues by
(i) Improving maintenance
(ii) Improving staff training and education
(iii) Making modern monitoring techniques affordable
(iv) Making modern management techniques affordable
(e) Increased prices leads to sustainability
(i) Reduces demands on resource base
(ii) Reduces pollution loads due to recycling of industrial water
(f) Increased prices reduce the per unit cost of water to poor people
(i) Increases coverage of poor urban and peri-urban populations because additional water is available for extending the system
(ii) Reduces reliance by the poor on water vendors

Many researchers have investigated the relationship between the tariff of water and the consumption level. For example, Babbitt *et al.* (1962) have proposed the following relationship for describing the relation between industrial water tariff and consumption:

$$C = 21 - 10 \log Q \qquad (6.1)$$

Where

C = tariff in US$/1,000 ft^3,

Q = rate of water used in 1,000 gallons/year.

Walski *et al.* (1985) developed a model for evaluating the effectiveness of water conservation measures for domestic use in the USA (Equation 6.2). Among the conservation measures evaluated was the price of water. A reduction factor in water use was calculated as a function of water price elasticity. Although Walski *et al.* do not give the potential reduction factor that may be achieved by increasing the water price, they suggested that the price has a higher impact than other measures such as water conservation devices and public education, which means that the number of consumers that will react to price change is higher than the number of those that will react to other measures.

$$R = 1 - (P_1/P_2)^e \qquad (6.2)$$

Where

R = reduction factor (-),
P_1 = initial price (monetary unit/m^3),
P_2 = final price (monetary unit/m^3),
e = elasticity of demand; which is a measure of how strongly the quantity demanded responds to change in price (-).

Several cases of increasing the tariff of water have demonstrated a fall in consumption. In Israel, for example, a gradual 50% drop in freshwater use was reported after a series of tariff increases. Freshwater use in agriculture declined from 74% to 62% between 1986 and the early 1990s whilst use of reclaimed wastewater proportionally increased, and overall productivity per unit land doubled (Sanz, 1999; Ahmad, 2000). In Metropolitan Barcelona (Spain), the introduction of the metering system and change of the pricing system to three consumption bands that charged at a progressively higher rate, resulted in a reduction of consumption by 16.9% in 75% of the cases (Mayers, 1996). A similar experience occurred in Malvern (UK), after domestic supplies were metered. It is estimated that metering reduced the consumption by 6% (Twort *et al*., 1994). In Athens (Greece), raising the tariff of water on an increasing-block basis resulted in a monthly water consumption decline by 17-25% in 3-4 months following the introduction of the new pricing (Briassoulis, 1995). Agthe and Billings (1996) showed that an increase in the marginal price of water by one US$/m^3 increases the probability of using low-flow faucets in Tucson (USA) by 46% and low-flow showerheads by 31%. All these cases are consistent and show that consumers are usually price-responsive in their use of water, and an increase in price could lead to the use of less water and adoption of more water-conserving/efficient technologies (Rosegrant and Ringler, 1998).

6.2 Problem description

In the previous Chapter, it was emphasized that access of farmers to freshwater at low tariff is the most prominent obstacle for using the reclaimed wastewater in irrigated agriculture. Generally, the MENA countries adopt low pricing of reclaimed wastewater as a means to make its use attractive (Bahri and Brissaud, 1996; MWI, 1999; ONAS, 2001). Inconsistently, the tariffs of freshwater for irrigation are kept relatively low, which makes the tariff of reclaimed wastewater less competitive. In all MENA countries, effective pricing of freshwater and reclaimed wastewater as well as agricultural-urban water transfers is very uncommon (Saghir *et al*., 2000). The average share of the water bill in income is around two percent and the urban water supply and sanitation are subsidized. In the MENA region in general, freshwater tariffs for irrigation are about 10 times lower than those for domestic and industrial consumption (Faruqui, 2000). According to the World Bank (1996), the urban water tariffs in Morocco range from US$0.44 to 1.35/m^3, while the average tariff of water for irrigation is about US$cent2.0/m^3. In Tunisia, farmers pay about US$cent5.0/m^3 for irrigation water, whereas the total cost for production and distribution is about seven times higher (Table 6.2). In the Jordan Valley where surface water is the major resource, the total estimated cost of irrigation water is about US$cent5.2/m^3 of which about US$cent2.9/m^3 as O&M costs (Table 6.3). The tariff is about US$cent1.6/m^3 while about US$cent3.8/m^3 is a subsidy from the government. Table 6.4 summarizes the actual water tariff in 96 surveyed farms in Jordan and Tunisia under the study (Chapter 1). The slight difference between the water tariff that has been discussed in Chapter 3 and the actual tariff paid by the surveyed farmers may be attributed to (i) statistical errors, (ii) the block tariff structure, (iii) inaccurate data provided by the interviewed farmers, and/or (iv) some farmers use energy for in-farm water pumping.

Table 6.2: Average O&M costs and tariffs of irrigation water by region in Tunisia (Hamdane, 2002).

Region	1991			2000		
	Tariff (US$cent/m^3)	Cost (US$cent/m^3)	% of recovery	Tariff (US$cent/m^3)	Cost (US$cent/m^3)	% of recovery
North	3.15	4.13	76	7.07	5.95	119
Sahel	3.43	6.09	56	8.12	10.01	81
Center	2.52	5.67	44	4.76	4.41	107
South	1.47	2.45	60	2.45	2.94	83
Tunisia	*3.01*	*4.27*	*70*	*6.58*	*5.74*	*115*

Table 6.3: Costs and revenues per one cubic meter of surface water for irrigation in the Jordan Valley (US$cent/m^3).

Year	O&M cost	Capital cost	Total cost	Revenues	Deficit/subsidy
1990	2.5	2.6	5.1	0.6	-4.5
1991	2.3	2.4	4.6	0.4	-4.2
1992	2.0	1.6	3.5	0.3	-3.2
1993	1.5	2.1	3.6	1.2	-2.4
1994	1.8	2.4	4.2	1.7	-2.5
1995	2.4	2.9	5.3	1.7	-3.5
1996	2.5	3.5	6.0	1.9	-4.2
1997	2.5	3.0	5.5	1.8	-3.7
1998	2.7	3.7	6.4	2.6	-3.8
1999	2.6	3.6	6.1	2.7	-3.5
2000	2.6	3.8	6.4	3.0	-3.4
Average	*2.3*	*2.9*	*5.2*	*1.6*	*-3.5*

Source: Jordan Valley Authority as cited in Shatanawi and Salman, 2002.

Table 6.4: Existing tariffs [9] of irrigation water in Jordan and Tunisia based on the field surveys (n = 96).

	Treated wastewater (n = 51)				Blended water (n = 10)				Surface water (n = 20)				Groundwater (n = 15)			
Water tariff (US$cent/m^3)	Min	Max	Mean	STD	Min	Max	Mean	STD	Min	Max	Mean	STD	Min	Max	Mean	STD
	0.13	5.71	1.41	0.73	3.33	8.57	6.08	2.03	5.00	26.19	10.02	4.74	0.97	57.14	29.35	24.68

In Jordan and Tunisia, agricultural irrigation consumes about 0.75 and 2.4 billion m^3/year, respectively (World Bank, 1996). The existing tariffs of irrigation water in Jordan and Tunisia vary from one scheme to another even for the same type of water (Chapter 3 and Table 6.4). Increasing the tariff of freshwater by US$cent5.0/m^3 would secure extra revenues of about US$37.5 and 120 million/year for Jordan and Tunisia, respectively. These figures would double if tariffs were increased by US$cent10.0/m^3. The extra revenues are capable of improving the agricultural infrastructure, especially for use of reclaimed wastewater. However, the consequences of this tariff increase on agricultural profitability to farmers are questionable.

In the MENA countries, it is not always the public authorities that supply irrigation water. Many farmers have their own facilities for meeting their water needs from surface as well as

[9] These tariffs include the energy costs that some farmers pay for storage and pumping in order to cope with the daily demand variations.

ground resources. For instance, many farmers in Jordan have their own groundwater wells where they do not pay any tariff for water, but they pay for energy (electricity and diesel) and for O&M of their pumps. In the same way, in the Jordan Valley, many farmers install their pumps on the banks of the King Abdullah Canal. In such instances, increasing the tariffs of water will have no influence on those farmers' behavior. However, another approach that has been applied in many parts of the world is increasing the energy prices and reducing subsidies. According to Al-Hamdi (2000), previous research on the effects of rising energy prices on groundwater abstraction is inconclusive. He argues that while some studies indicate a strong direct correlation between rising energy prices and water use, others have concluded that other factors play a more significant role than energy prices in determining the level of water use in agriculture. In the region in general, the water tariffs are comparatively small and thus other factors are likely to influence groundwater use more strongly. Schiffler (1998) concluded that any realistic increase in energy tariffs will simply reduce farmers' profit, but will not have a significant impact on groundwater abstraction. In areas under severe water stress, the social value of water may be higher than that incurred by the marginal cost of energy and consequently, even marginal cost pricing of energy may not create a strong disincentive for groundwater use (Al-Hamdi, 2000). In this case, additional approaches might be needed through regulations and enforcement that restrict freshwater pumping.

6.3 Objective and methodology

6.3.1 Objective

It is hypothesized that increasing the tariffs of freshwater for irrigation might make reclaimed wastewater competitive and increase revenues as well as resource sustainability without jeopardizing farming feasibility. In this scenario, even the tariffs of reclaimed wastewater could be comparatively raised. Accordingly, the objective of this Chapter is to understand the effect of increasing the tariffs of freshwater and reclaimed wastewater for irrigation on agricultural profitability or profit.

6.3.2 Methodology

This research depends mainly on the data collected through a field survey in 96 farms in Jordan and Tunisia (The field survey is described in Chapter 1, while the questionnaires used are in Annex D). Simple algebraic spreadsheet calculations are applied for analysis of farmers' profit at different incremental increases to the existing water tariffs. The spreadsheet calculates the farmers' profit for a set of incremental increases of US\$cent5.0/m^3 to the existing tariffs of irrigation water (groundwater, surface water, blended water, and treated wastewater).

In this study, agricultural profitability is analyzed from two different perspectives: (1) from economic standpoint, profitability is the balance between gross income and total agricultural expenditures including labor value of farmers and their kin, and (2) from farmers' standpoint, their own labor value and its opportunity cost are barely considered, therefore usually not included. The total farming expenses are the sum of annual expenditures on (i) water, (ii) fertilizer, (iii) paid and unpaid labor wages, (iv) land preparation, and (v) use of pesticides and other inputs. The unit US$/Donum/year[10] is used for comparison of agricultural profitability.

6.4 Results and discussion

6.4.1 Agricultural profitability at the existing water tariffs

Results of this study show that agricultural profitability at existing water tariffs varies substantially from one farm to another (Tables 6.5-6.8 and Figures 6.1 and 6.6). Certain crops are more profitable than others. Profitability, however, does not only depend on crop type but also on (1) soil fertility , (2) effectiveness of irrigation, (3) effective use of fertilizers and pesticides, (4) farmer's technical and managerial skills, (5) crop marketing (6) climate, (7) availability and price of water, (8) land size (economies of scale), and (9) labor input and cost. In other words, each of these factors affects agricultural profitability. Profitability of using secondary treated wastewater for irrigation of fodder and cereal crops averages about US$–16 and 97/Donum/year when including, and excluding the unpaid labor, respectively. Profitability of using secondary treated wastewater for irrigation of fruit trees averages about US$80 and 343/Donum/year, respectively, compared with that irrigated with fresh groundwater that averages about US$271 and 323/Donum/year, respectively. Profitability of using reclaimed wastewater that is blended with fresh surface water for irrigation of vegetables averages about US$255 and 477/Donum/year, respectively, compared with that irrigated with fresh groundwater that averages about US$37 and 316/Donum/year, respectively, and that irrigated with fresh surface water that averages about US$–91 and 395/Donum/year, respectively. These results show that irrigation with reclaimed wastewater, especially when blended with fresh surface water, can yield similar, and sometimes better than, profit to farmers than freshwater irrigation.

Table 6.5: Agricultural profitability of the surveyed farms at existing water tariffs.

Water type	*Existing water tariffs (US$cent/m³)*				*Profit incl. farmers' own labor (US$/Donum/year)*				*Profit excl. farmers' own labor (US$/Donum/year)*			
	Min.	*Max.*	*Avg.*	*STD.*	*Min.*	*Max.*	*Avg.*	*STD.*	*Min.*	*Max.*	*Avg.*	*STD.*
Groundwater (n = 15)	1.0	57.1	29.3	24.7	-303	507	144	224	57.0	619	323	185
Surface water (n = 20)	5.0	26.2	10.0	4.7	-871	695	-82.6	375	157.0	1,076	388	227
Blended water (n = 10)	3.3	8.6	6.1	2.03	-106	695	255	257	33.3	914	477	312
Reclaimed wastewater (n = 51)	0.1	5.7	1.4	0.7	-357	943	39.4	214	8.1	1,086	230	229

Results also show that about 39% of the surveyed freshwater farms and 57% of the reclaimed wastewater farms are running in loss (negative profit) when recognizing the economic value of farmers' own labor. The difference between these two percentages is due to the high dependency of reclaimed wastewater farmers on paid labor, which might be attributed to the fact that farmers may not like their kin to work in farms irrigated with reclaimed wastewater. The question that arises at this point is: what makes such farmers persist despite their loss? Apparently, farmers conceive profit differently; for them, profit calculations do not necessarily include the unpaid labor that is provided locally. They do not recognize any opportunity cost of their kin's labor, most likely because opportunity itself does not exist, especially for wives, daughters, and children. Consequently, agriculture performs as an

[10] One Donum = 1,000 m^2 = 0.1 ha.

employer to the whole farmer's family at provisional salaries. It has to be mentioned that the number of workers from farmers' family members is usually large while labor productivity is low, which is a major cause of loss when recognizing the economic value of farmers' own labor.

Table 6.6: Gross income of the surveyed farms in Jordan and Tunisia.

Crops	*Income (US$/Donum/year)*			
	Min.	*Max.*	*Avg.*	*STD.*
Fodders and cereals (WW) (n =23)	48	670	187	136
Fruit trees (WW) [11] *(n=28)*	238	1,250	546	246
Fruit trees (GW) (n=6)	429	1,143	696	250
Vegetables (GW) (n=9)	879	1,786	1,396	321
Vegetables (SW) (n=20)	357	1,905	939	368
Vegetables (BW) (n =10)	556	1,714	1,042	419

WW: reclaimed wastewater; GW: fresh groundwater; SW: fresh surface water; BW: blended water.

Table 6.7: Net profitability of the surveyed farms including unpaid labor.

Crops	*Profit incl. farmers' own labor (US$/Donum/year)*			
	Min.	*Max.*	*Avg.*	*STD.*
Fodders and cereals (WW)	-357	193	-16	131
Fruit trees (WW)	-304	943	80	253
Fruit trees (GW)	74	507	271	171
Vegetables (GW)	-304	320	37	198
Vegetables (SW)	-871	695	-91	384
Vegetables (BW)	-106	693	255	257

Table 6.8: Net profitability of the surveyed farms excluding unpaid labor.

Crops	*Profit excl. farmers' own labor (US$/Donum/year)*			
	Min.	*Max.*	*Avg.*	*STD.*
Fodders and cereals (WW)	8	303	97	79
Fruit trees (WW)	27	1,086	343	246
Fruit trees (GW)	117	543	323	152
Vegetables (GW)	57	619	316	207
Vegetables (SW)	157	1,076	395	231
Vegetables (BW)	33	914	477	312

[11] Fodders include berseem, alfalfa, and sorghum; Fruit trees include apples, peaches, apricots, pears, and citrus; Vegetables include squash, tomatoes, potatoes, cucumber, cupflowers, and cabbages.

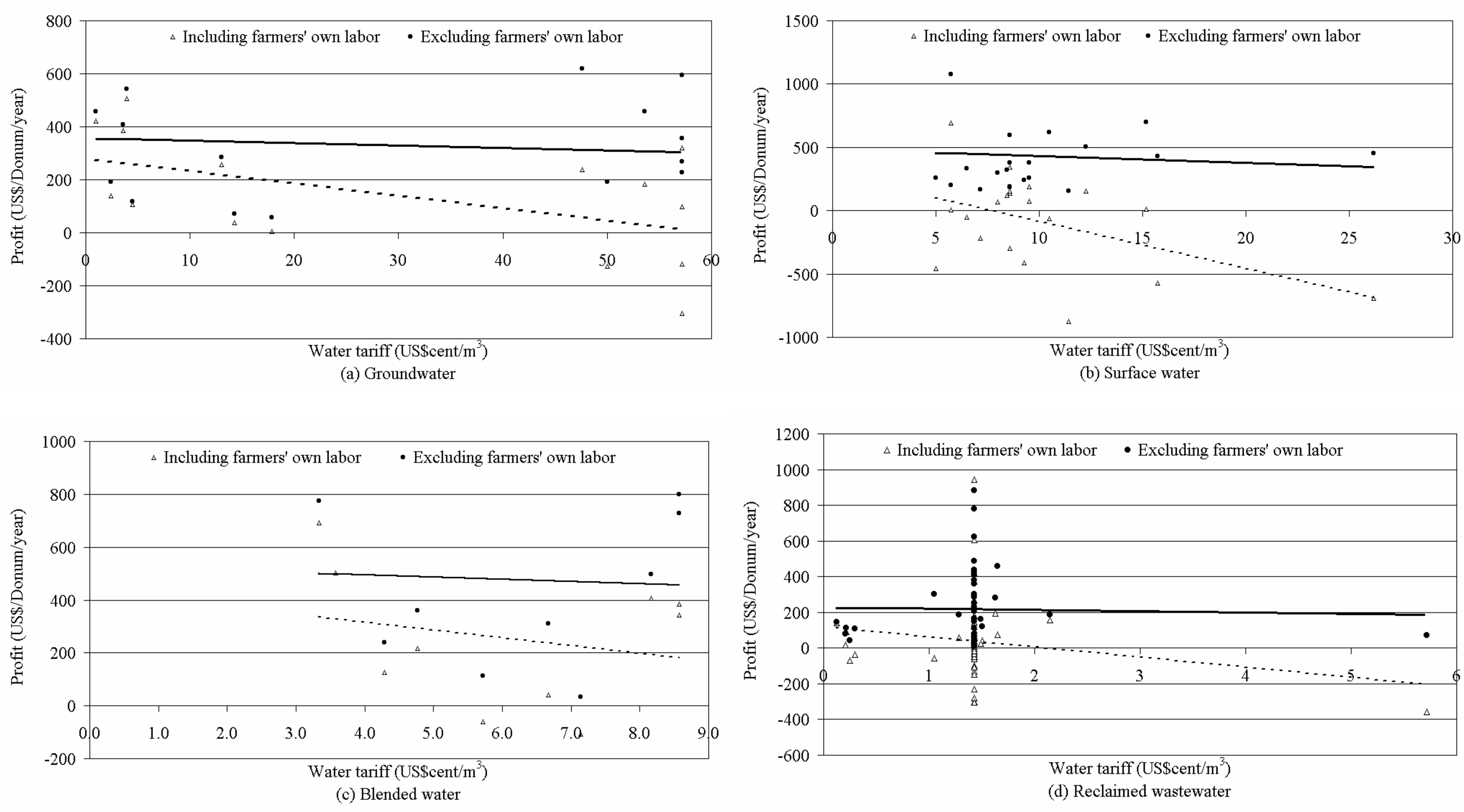

Figure 6.1: Agricultural profitability as a function of existing tariff and type of irrigation water: (a) groundwater, (b) fresh surface water, (c) blended water, and (d) reclaimed wastewater.

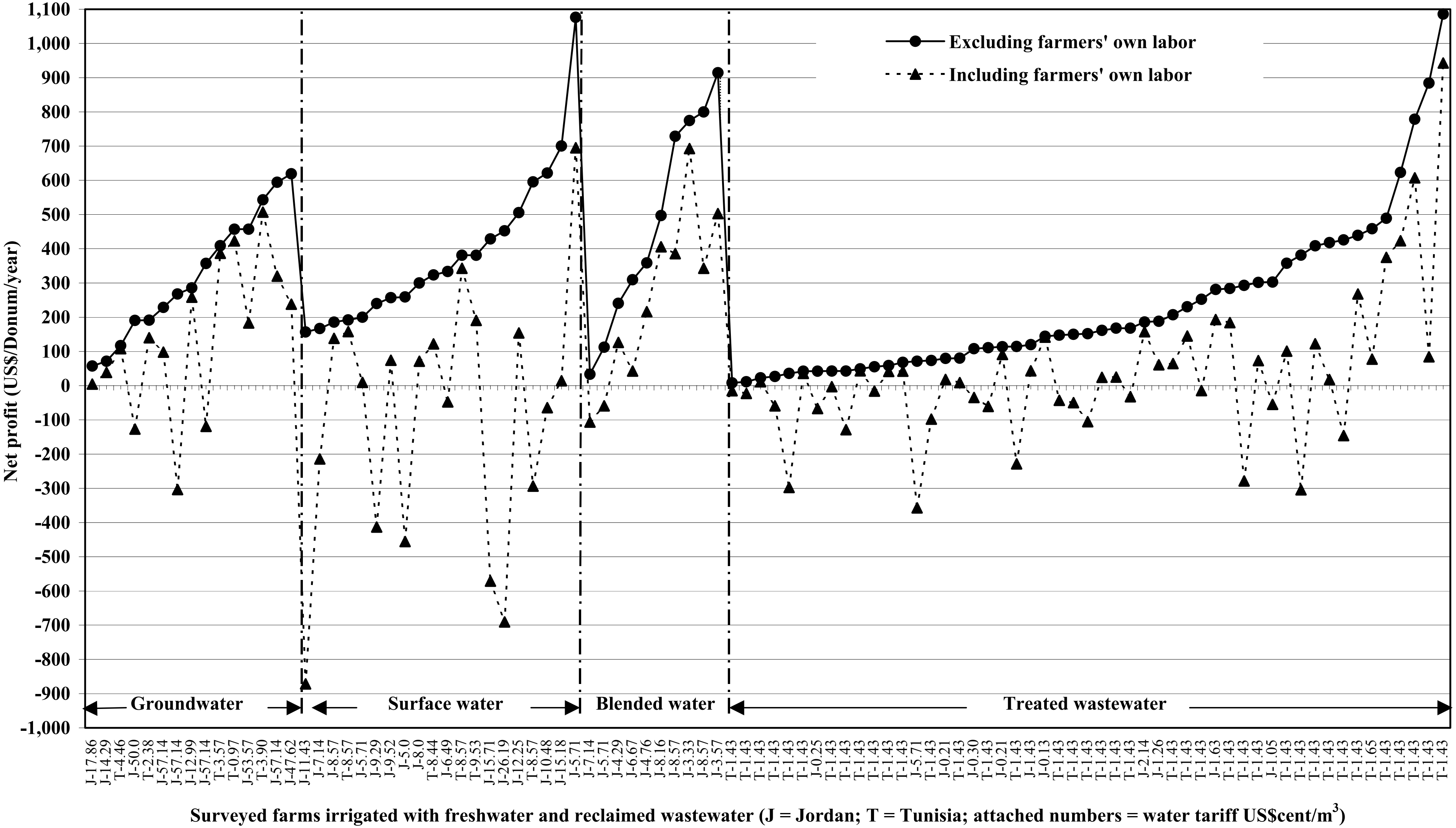

Figure 6.2: Agricultural profitability (incl. and excl. farmers' unpaid labor) as a function of type of irrigation water used: sorted according to profit excluding labor.

6.4.2 Effect of increased irrigation water tariffs on agricultural profitability

In addition to its cultural value, agriculture contributes to the national economy and food security. Besides, farmers are mostly poor. This partly justifies the large subsidy given by governments to the agricultural sector in all countries of the region. However, this contradicts the efforts that aim at stimulating the use of reclaimed wastewater. If the existing tariffs of freshwater remain unchanged, reclaimed wastewater can be attractive only if given to farmers at a very low tariff or free of charge. The benefits of a rational increase of freshwater tariffs are threefold. First, it would increase the gap between the tariffs of freshwater and reclaimed wastewater making the latter more attractive. Second, it might help in water saving and release pressure on the groundwater resource. Third, it could be used as a financial resource to recover the investment costs of conveyance and distribution for reclaimed wastewater. The first and second objectives might be viable at scheme level, while the third might be viable at national level. This is because the number of farmers using freshwater is much higher than that of farmers using reclaimed wastewater. As previously mentioned, many farmers control their own water resources through direct pumping of groundwater or surface water. In those cases, farmers do pay the full cost of water used since they have to pay for installing pumps and pipes as well as for energy and maintenance.

Based on the discussion in the previous Section, the existing water tariffs have minor influence on agricultural profitability, mainly because these tariffs are very low. Increasing these tariffs by US$cent5.0/m^3 reduces farmers' profit by US$25-70/Donum/year (Figures 6.3-6.6). Increasing the existing water tariffs by US$cent10.0/m^3 would double the aforementioned reduction in farmers' profit. Such a reduction in agricultural profitability is crucial for some farmers and trivial for others. Increasing the reclaimed wastewater tariffs by US$cent5.0/m^3 makes irrigation of fodders and cereals unfeasible, even when excluding farmers' own labor. On contrary, farmers of fruit trees irrigated with reclaimed wastewater and farmers of vegetables irrigated with blended water as well as freshwater can withstand tariff increase by US$cent5.0-10.0/m^3. Profitability becomes intolerable when water tariffs are increased by US$cent15.0/m^3 or higher.

In conclusion, the existing water tariffs are too low. Increasing these tariffs by US$cent 5.0-10.0/m^3 is not likely to jeopardize farming feasibility. Increasing tariffs beyond this limit would make agricultural irrigation unfeasible and might enforce farmers to shift to using reclaimed wastewater if tariffs are maintained low and if its supply and quality are reliable.

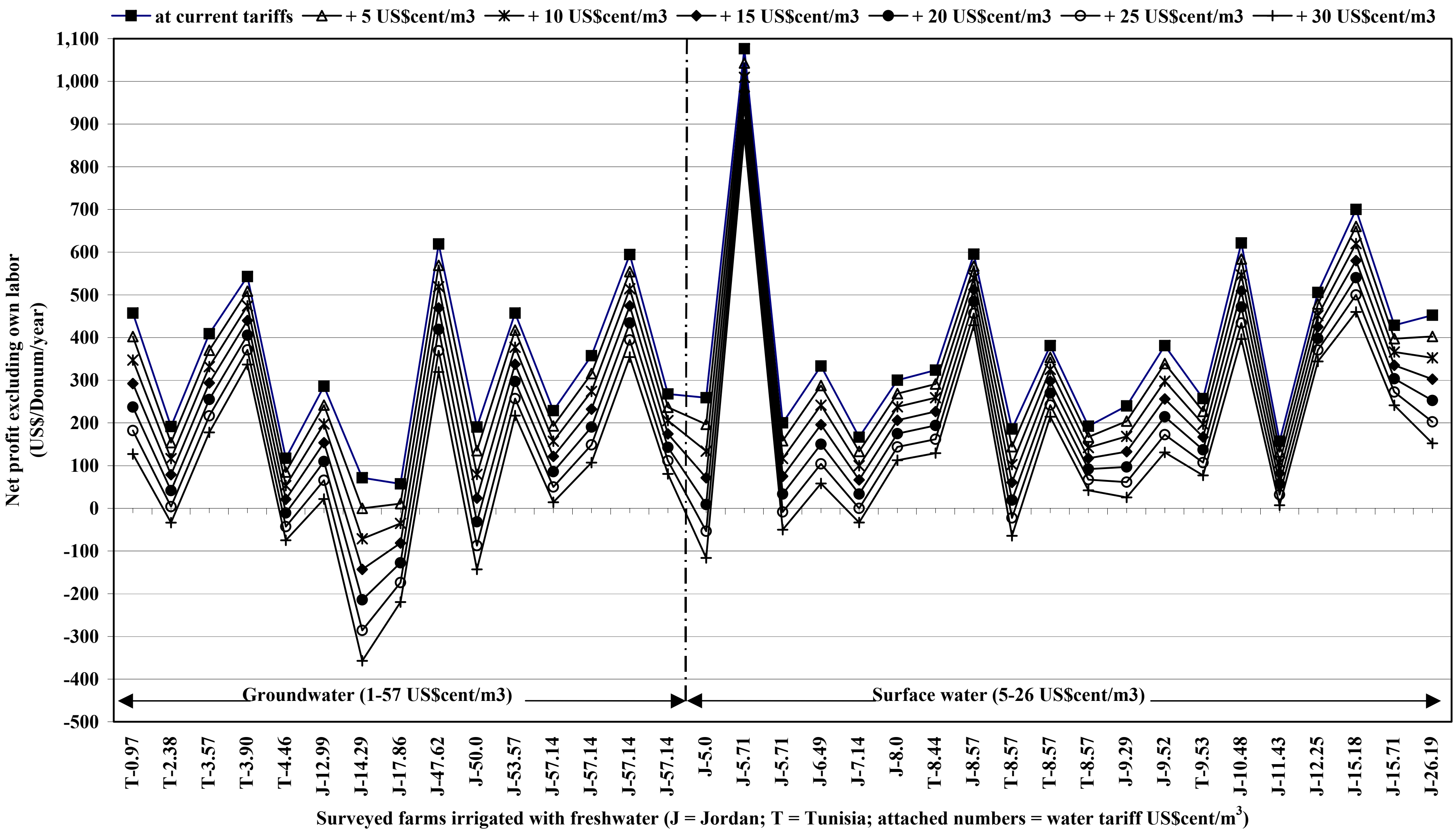

Figure 6.3: Effect of increased freshwater tariffs on agricultural profitability (excl. farmers' unpaid labor).

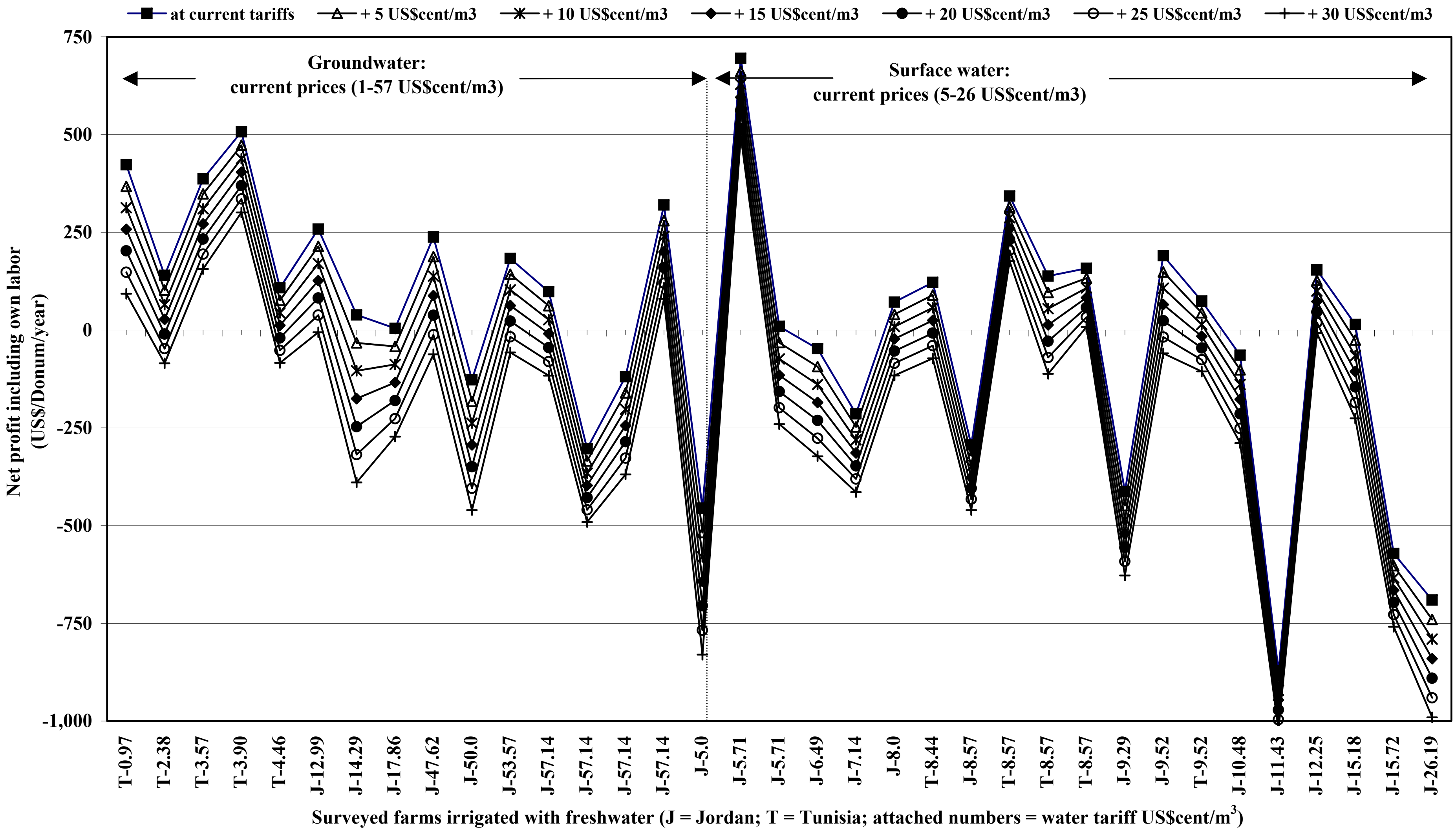

Figure 6.4: Effect of increased freshwater tariffs on agricultural profitability (incl. farmers' unpaid labor).

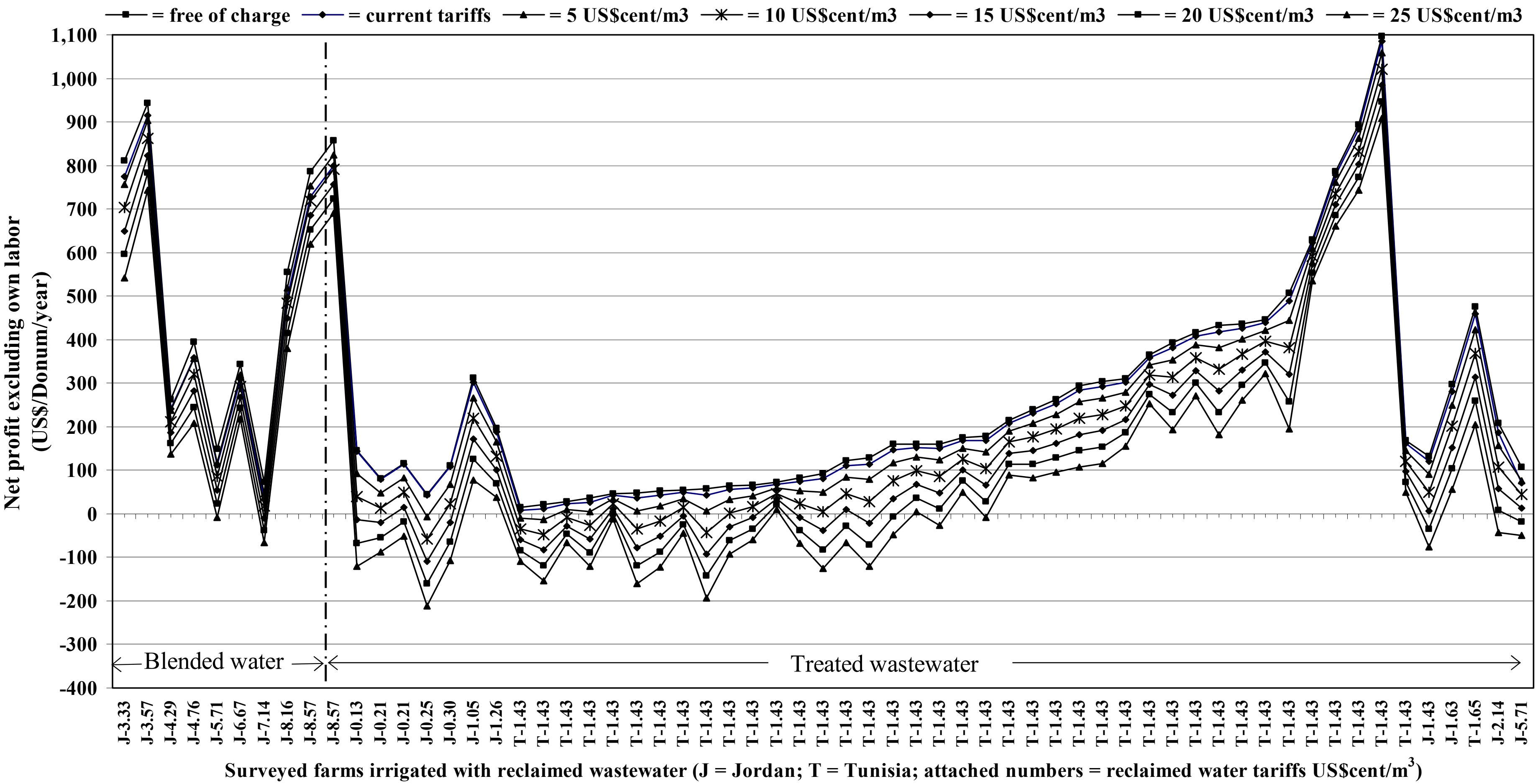

Figure 6.5: Effect of increased tariffs of reclaimed wastewater on agricultural profitability (excl. farmers' unpaid labor).

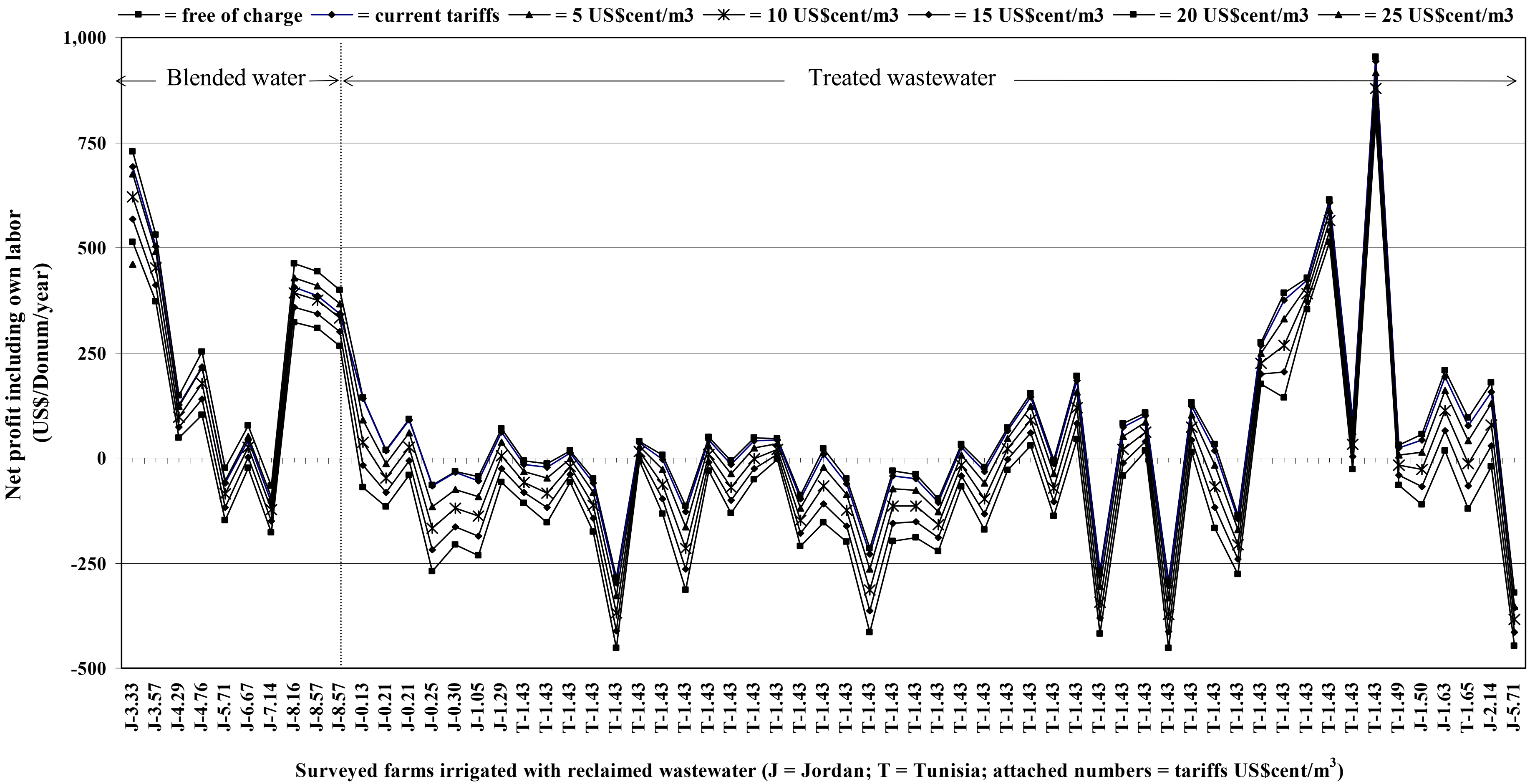

Figure 6.6: Effect of increased tariffs of reclaimed wastewater on agricultural profitability (incl. farmers' unpaid labor).

6.5 Conclusions and recommendations

Water pricing is a major factor in the incentive system that might make or break the proposition of agricultural irrigation with reclaimed wastewater. The existing tariffs of freshwater for irrigation are too low, which makes reclaimed wastewater uncompetitive. Increasing the tariffs of freshwater for irrigation would increase the gap between freshwater and reclaimed wastewater, on one hand, and increase revenues that could be employed for subsidizing reclaimed wastewater on the other hand. Results of this study show that water tariffs have a significant influence on farmers' profit. The MENA countries are recommended to review their water pricing policies and increase the tariffs of freshwater for irrigation. Wherever reclaimed wastewater exists, irrigation with freshwater has to be abandoned if the supplies of reclaimed wastewater can meet the agricultural demand. Where no reclaimed wastewater is available or where its supplies are not sufficient, access to freshwater can be unrestricted but tariffs have to be increased.

This study revealed that irrigation with reclaimed wastewater even for restricted irrigation can yield similar, and sometimes better than, profit to farmers than freshwater irrigation. Some of the permitted crops such as fruit trees can be more profitable than vegetables irrigated with freshwater. However, it appears that the level of knowledge of farmers and others on the benefits of reclaimed wastewater is still limited. Thus, the perception that couples cropping restriction with low value crops needs to be changed. Awareness, education, and dissemination of results from other experiences are needed to help change attitudes (see Chapters 5). However, improving the quality of reclaimed wastewater in compliance with the standards for unrestricted irrigation improves the receptive market for this water.

At existing water tariffs, about 39% of the farms irrigated with freshwater and 57% of the farms irrigated with reclaimed wastewater are running a loss if the value of unpaid labor (farmers' input) is monetarized in the profit analysis. Apparently, farmers conceive profit differently, which contradicts with the economic theory. They neglect the opportunity cost or the economic value of their own labor. The only justification is that opportunity does not exist for farmers' wives, daughters, and children. Freshwater farmers are tolerable to increasing the present water tariffs by US\$cent5.0-10.0/m^3. Increase of freshwater tariffs by more than US\$cent10.0/m^3 makes irrigation unfeasible, which would force farmers to shift from use of freshwater to reclaimed wastewater, where available. However, imposing restrictions on the use of freshwater would be unjustified where the supply and quality of the reclaimed wastewater do not meet the agricultural demand within a specific irrigation scheme.

Farmers that irrigate fruit trees (especially apricots and peaches) with secondary treated wastewater and farmers that irrigate vegetables with blended water gain more profit than farmers that irrigate fodder crops and cereals. Farmers of fruits and vegetables are tolerable to increasing the tariffs of reclaimed wastewater to a level close to freshwater tariffs. Farmers of fodders and cereals can barely withstand the existing water tariffs.

6.6 References

Abu Qdais, H. A. and Al Nassay, H. I. (2001). Effect of pricing policy on water conservation: a case study. *Water Policy*, **3**: 207-214.

Agthe, D. E. and Billings, R. B. (1996). Water-price effect on residential and apartment low-flow fixture. *Water Resources Planning and Management*, **122**(1): 20-23.

Ahmad, M. (2000). Water pricing and markets in the Near East: Policy issues and options. *Water Policy*, **2**: 229-242.

Al-Hamdi, M. (2000). Competition for scarce groundwater in Sana'a plain, Yemen: a study on the incentives system for urban and agricultural water use. PhD thesis, IHE-Delft, The Netherlands.

Babbitt, H. E., Donald, J. J., and Cleasby, J. L. (1962). Water supply engineering (6th ed.). New York: McGraw-Hill Book Company.

Bahri, A. and Brissaud, F. (1996). Wastewater reuse in Tunisia: assessing a national policy. *Wat. Sci. Tech*., **33**(10-11): 87-94.

Briassoulis, H. (1995). Effectiveness of water conservation measures in greater Athens area. *Water Resources Planning and Management*, **120**(6): 746-777.

Cairncross, S., Carruthers, I., Curtis, D., Feachem, R., Bradley, D. and Baldwin, G., (1980). Evaluation for village water supply planning. John Wiley and Sons, UK.

Dinar, A. and Subramanian, A. (1998). Policy implications from water pricing experiences in various countries. *Water Policy*, **1**: 239-250.

Faruqui, N. (2000). Wastewater treatment and reuse for food and water security. www.idrc.ca/waterdemand/SpecialPapers_e.html, IDRC, Ottawa, Canada.

Hamdane, A. (2002). Valuation of irrigation water: the case of Tunisia. Water Demand Management Forum, Water Valuation, Beirut, Lebanon.

Johansson, R., Tsur, Y., Roe, T., Doukkali, R., and Dinar, A. (2002). Pricing irrigation water: a review of theory and practice. *Water Policy*, **4**: 173-199.

Mayers, C. (1996). Water conservation: A metered approach. *World Water and Environmental Engineering*, **19**(4): 40-40.

MWI. (1999). Annual Report, Ministry of Water and Irrigation. Amman.

ONAS. (2001). Annual Report, National Sewerage Agency. Tunis.

Perry, C. (2001) Water at any price? Issues and options in charging for irrigation water. *Irrigation and Drainage*, **50**: 1-7. John Wiley and Sons, Ltd.

Rogers, P., de Silva, R., and Bhatia, R. (2002). Water is an economic good: How to use prices to promote equity, efficiency, and sustainability. *Water Policy*, **4**: 1-17.

Rosegrant, M. W. and Ringler, C. (1998). Impact on food security and rural development of transferring water out of agriculture, *Water Policy*, **1**: 567-586

Saghir, J., Schiffler, M., and Woldu, M. (2000). Urban water and sanitation in the Middle East and North Africa Region: The way forward. The World Bank, Middle East and North Africa Region, Infrastructure Development Group.

Sanz, L. (1999). Irrigated agriculture in the Guadian River High Basin (Castilla-La Mancha, Spain): Environmental and Socio-economic impacts. *Agricultural Water Management*, **40**: 171-181.

Schiffler, M. (1998). The economics of groundwater management in arid countries: theory, international experience and a case study of Jordan. Frank Class, London.

Shatanawi, M. and Salman, A. (2002). Impact of full cost recovery on irrigation water in the farming economics in the Jordan Valley. University of Jordan, Amman.

Twort, A. C., Law, F. M., Crowley, F. W., and Ratnyak, D. D. (1994). Water supply (4th ed.). London UK: Edward Arnold.

UNICWE. (1992). International Conference on water and the Environment. World Meteorological Organization, Dublin.

Walski, T. M., Richards, W. G., McCall, D. J., Deb, A. K., and Morgan, J. M. (1985). Calculating effectiveness of water conservation measures. *Environmental Engineering*, **111**(2): 209-221.

World Bank. (1996). From scarcity to security: Averting a water crisis in the Middle East and North Africa. Report. Washington, DC.

Yoduleman, M. (1989). Sustainable and equitable development in irrigated environments. Environment and the Poor: Development Strategies for a Common Agenda, H. Jeffrey (ed.), US Third World Policy perspectives, No. 11, Overseas Development Council, Washington D.C.

Chapter 7: Willingness of Farmers to Pay for Reclaimed Wastewater

7.1 Background

Sanitation and wastewater reuse are interrelated making their financial sustainability very faraway. Wastewater reuse projects often are high in capital costs due to expensive sewerage, treatment, and conveyance and distribution of the treated water. Thus, *who pays for these costs*? Adapting the "polluter pays" rule might be an answer if wastewater collection and treatment are considered as services for which beneficiaries have to be charged, while the agricultural users will have to pay only the cost of handling and conveyance of the reclaimed wastewater (Haruvy, 1994). The previous Chapters revealed a high level of farmers' acceptance to use, in principle, the reclaimed wastewater. This part of the research studies the willingness of framers to pay for a scale of tariffs of the reclaimed wastewater.

In 1992, a wastewater market assessment in Tunisia was conducted by ONAS. It concluded that farmers would accept water tariffs ranging between US\$0.014-0.04/m^3 (Bahri and Brissaud, 1996). Surprisingly, a similar study that was conducted in the Jordan Valley concluded that farmers would accept water tariffs ranging between US\$0.013-0.052/m^3 of reclaimed wastewater (Shatanawi and Salman, 2002). These tariffs are not that different from the existing tariffs in 2002, which vary from one scheme to another. Therefore, some of the operational costs are recovered. Al-Hamdi (2000) concludes that contributions of farmers to recover part of the costs of reclaimed wastewater may only be successful if farmers accept the principle of cost recovery and if alternative water resources are scarce and expensive.

7.2 Problem description

Financial management of wastewater infrastructure investment is one of the most difficult tasks. This is mainly because it is a multi-disciplinary task in which many stakeholders are involved. In the case of wastewater reuse, applying the "polluter pays" and "user pays" principles implies charging the producers of wastewater for the collection and treatment of wastewater, while charging farmers for, for example, the conveyance and distribution of the reclaimed wastewater (Haruvy, 1994). Applying these principles in practice poses many challenges. First, the cost of wastewater collection and treatment is five to six times higher than that of drinking water supply, whereas the willingness of people to pay for sanitation is much lower than that for water supply (Gijzen, 2001). Gunnerson and French (1996) show that the ratio disposal/supply costs increases with increased service levels and water consumption (Figure 7.1). In the West Bank (Palestine), the water supply and sanitation tariffs vary substantially from one community to another ranging between 2.6-12.2% of the households' income (Abu Madi *et al*., 2000). Thus, increasing the sanitation tariffs to full cost recovery level may not be affordable. For that reason, governments and donor agencies

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bear a large financial burden. This partially explains the low level of success in improving sanitation coverage compared to water supply as well as the small rates of wastewater that receive treatment worldwide (Gijzen, 2001). Second, the costs of conveyance and distribution of reclaimed wastewater are very high compared to that of collection and treatment (Chapters 4 and 5). Besides, as discussed previously, the tariffs of freshwater for irrigation are very low. In such cases, would farmers accept to pay the true cost of reclaimed wastewater?

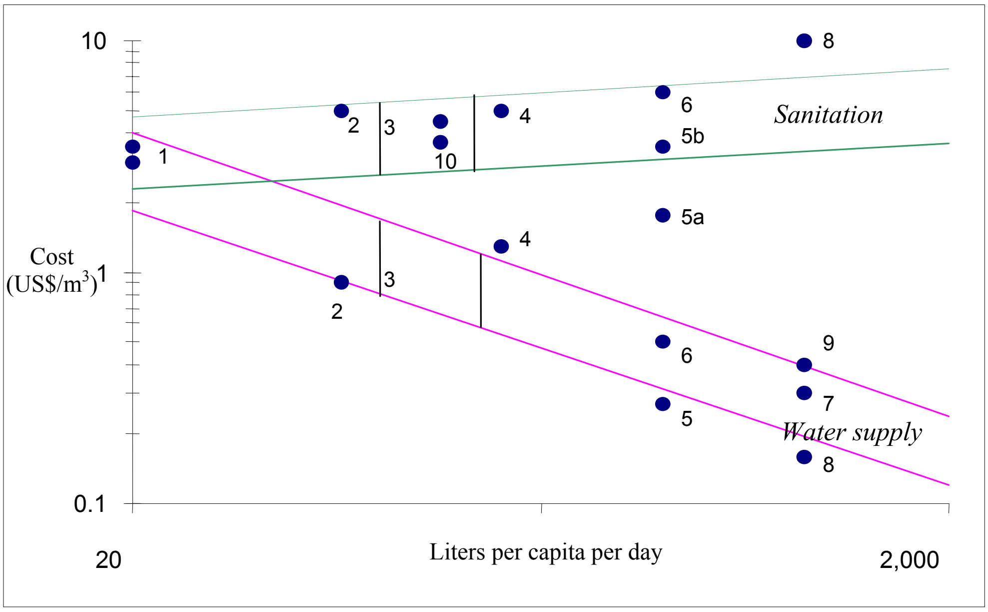


Figure 7.1: Water consumption versus costs for water supply and sanitation systems (Gunnerson and French, 1996 as cited in Gijzen, 2001). Costs include distribution/collection and treatment. Numbers refer to: 1) Village scale hand pump and household latrines, 2) Jakarta, 3) World Bank basic needs level, 4) Malace, Malaysia, 5) Kyoto, Japan (5a =household vault and vacuum truck to truck sewer; 5b = conventional sewer), 6) Washington, 7) Boulder, Colorado, 8) Chicago, 9) Los Angeles, 10) The Netherlands.

Nevertheless, the wastewater tariffs are usually much lower than those of water supply, and in most countries of the MENA region the operation and maintenance costs of sanitation services are not recovered (Table 7.1). In Jordan and Tunisia, the tariff of reclaimed wastewater has been fixed by governmental decrees at JD0.01/m^3 and TD0.02/m^3, respectively (using the exchange rates of 2001, both values are equal to US$cent1.43/m^3). The 2002 tariffs of reclaimed wastewater are similar in both countries ranging between US$0-0.014/m^3 when used directly, and about US$0.07/m^3 when blended with fresh surface water. These tariffs barely recover the operational costs of conveyance and distribution of reclaimed wastewater. The oil-rich Gulf States deliver the treated wastewater to the farmers free of charge with full government subsidy because they can afford to construct the necessary infrastructure. Within these countries, the incentive for such projects may include pollution control, water resource conservation, and an encouragement policy towards agricultural production. As consequence, there is also limited incentive to conserve water, or to reserve it for optimal economic use. The reuse projects of these countries do not aim at cost recovery, while projects elsewhere typically incorporate partial or full cost recovery. However full cost recovery is usually not realized in the developing countries (Thanh and Visvanathan, 1991). Cost recovery policies and sustainability of projects implies increasing the tariffs of reclaimed wastewater.

Table 7.1: Current tariffs and costs (US\$/m^3) of reclaimed wastewater in Jordan and Tunisia.

Country	*Existing tariffs for use in irrigation*	*Conveyance and distribution costs*$^{(*)}$		*Treatment costs*$^{(**)}$	
		Operational costs	*Total costs incl. investment*	*Operational costs*	*Total costs incl. investment*
Jordan	0–0.08	0.04–0.12	0.10–0.21	0.02–0.34	0.05–0.95
Tunisia	0.014–0.08	0.09–0.15	0.13–0.25	0.03–0.17	0.04–0.93

* Prices and costs are based on the data provided by Tunisian Ministry of Agriculture and the Jordanian Ministry of Water and Irrigation.
** The treatment costs are based on results in Chapter 4.
All costs and prices are converted from Tunisian and Jordanian Dinars into US$ using the exchange rates of year 2001; One US$ = 0.7 JD = 1.4 TD.

7.3 Objective, hypotheses, and methodology

7.3.1 Objective

The main objective of this Chapter is to (1) test some hypotheses concerning willingness of framers to pay for reclaimed wastewater as an alternative or competitive to freshwater, and (2) to understand what costs of reclaimed wastewater may be recovered.

7.3.2 Hypotheses

The research hypotheses are as follows: (i) farmers may not pay the true cost of reclaimed wastewater, (ii) WTP is expected to decrease as the tariffs of reclaimed wastewater increase, (iii) WTP is expected to increase as farmers' income or profit increases, (iv) WTP is expected to increase as the tariffs of current irrigation water (competitive water) increase, and (v) WTP is expected to increase as the availability/accessibility of freshwater decreases (Bahri and Brissaud, 1996; Al-Hamdi, 2000).

7.3.3 Methodology

The contingent valuation (CV) method is used to test the aforementioned hypotheses of the study. The CV method has been a controversial empirical tool since it does not identify revealed preferences that are known to be consistent with utility theory (Mitchell and Carson, 1989). In other words, one is asking a person what he would be hypothetically willing to pay for something rather than observing his behavior (Hanneman and Kanninen, 1996). CV is sometimes criticized as unreliable because it depends on what people say rather than what they do (Snell, 1997). Nevertheless, CV managed to gain increased acceptance amongst academics and policy makers as a versatile and powerful methodology for estimating the monetary value on non-market goods or services (Hanneman and Kanninen, 1996; Hanely, 2001). It seems to have become the method of choice in practical settings such as estimating respondents' WTP (Whittington, 1998; Vaughan *et al*., 1999). According to Johansson (1999), elicitation of respondents' WTP can be done in different ways: (i) in an open-ended question, (ii) in a single referendum question, or (iii) in the form of bidding game. In an open-ended question, the respondent is asked to state the maximum amount that he/she is willing to pay, while in the referendum format, the respondent is presented with a posted tariff that he/she is asked to accept or reject. The bidding game is a repeated process, which tries to bracket the respondent's maximum WTP by presenting higher and higher values (bids). A lower value for the WTP is bracketed in a similar manner (Johansson, 1999). Literature shows that most CV studies that have compared estimates of WTP obtained using the dichotomous (Yes/No) choice and open-ended formats have found that dichotomous choice yields higher estimates (Snell, 1997; Hanely, 2001; Emre *et al*., 2002). The bidding technique and dichotomous choice are used in this study because they are more reliable.

Prior to presenting the WTP questions respondent farmers were told that as a consequence of water scarcity tougher laws would lead to higher tariffs of freshwater for irrigation, meanwhile treated wastewater of high quality would be provided for unrestricted cropping. Subsequently, farmers were asked to respond to sequential dichotomous questions; if they would vote or not in favor of paying the pre-selected tariff (bid) for treated wastewater ranging from US\$0 to 0.25/m^3. The bid values were pre-selected based upon the preliminary results of the first round of fieldwork in Jordan, which was specified for pilot testing of questionnaires and collecting background data. Literature recommends that extreme bids should be avoided, since they can lead to efficiency losses, and that the number of bids used should be six at a maximum (Cooper, 1993; Alberdin, 1995; Hanemann, and Kanninen, 1996). Each time, the bid was increased by US\$0.05/m^3 to ensure a bid range that approximately covers (i) current tariff of treated wastewater, (ii) the operational costs for transport and distribution of the treated wastewater to the irrigation sites, (iii) the total costs (including investment depreciation) for transport and distribution, and (iv) operational costs of treatment (the investment costs of treatment were not included because they imply very high bid values). An additional independent question was if farmers would accept to pay any price/tariff if freshwater would not be available anymore and reclaimed wastewater would be the only source of water available.

Responses to the CV question provide only qualitative information about WTP. Thus, from the raw responses alone, one cannot obtain a quantitative measure of WTP (Hanemann and Kanninen, 1996). Therefore this study employs two methodologies for analysis of the field survey. The first is descriptive and presents farmers' WTP as frequencies (count and percentile) of farmers that accept or reject each proposed bid. The second embeds the data in a statistical model in an attempt to link the qualitative responses to monetary and other stimuli that induced them (Hanemann and Kanninen, 1996). The SPSS software package is used for data analysis.

7.4 Results and discussion

7.4.1 Descriptive analysis of WTP

The total number of sample was 96 farmers representing the use of four types of irrigation water: groundwater, surface water, blended wastewater with surface water, and treated wastewater (Tables 7.2 and 7.3). These results are graphically represented in Figures 7.2 and 7.3). Farmers in general have a high WTP for treated wastewater if the unit price (tariff) is low, the quality is high, and cropping is unrestricted. This means that the existing tariffs are highly perceived by farmers as suitable. Higher water tariffs, allowing coverage of the operational costs of transport and distribution, leads to lower WTP. Ambitious attempts in cost recovery will inevitably fail to recover the cost, not only of the treatment costs, but also of the capital costs for conveyance and distribution.

About 97% of farmers show interest to take reclaimed wastewater if given to them for free and if its supplies are reliable and if allowed for unrestricted irrigation. Farmers' responses started to change with introducing the concept of water tariff (Figure 7.2 and 7.3). The WTP declined to 84% and 47% when the proposed tariffs were US$0.05 and 0.10/m^3, respectively. Such tariffs can barely recover the operational costs of supplying a secondary treated wastewater (Figure 7.2). Making this water comply with farmers' requirements for unrestricted irrigation implies additional treatment costs. Therefore, ambitious attempts to recover costs through increasing the tariffs of reclaimed wastewater might not succeed because farmers still have easy and cheap access to the competitive freshwater. This justifies the need for increasing tariffs of freshwater for irrigation and using revenues from freshwater to subsidize reclaimed wastewater.

The subdivided models show that farmers irrigating with groundwater have higher WTP than the users of other water types (Figure 7.3). This is likely because they already pay high water tariffs.

Table 7.2: Farmers' WTP for reclaimed wastewater.

Wastewater tariff scenarios	*Responses (n = 96)*	
	Count	*%*
If the reclaimed wastewater is given to farmers free of charge	93	*96.9*
If the tariff of reclaimed wastewater is 0.05 US$/m^3	81	*84.4*
If the tariff of reclaimed wastewater is 0.10 US$/m^3	45	*46.9*
If the tariff of reclaimed wastewater is 0.15 US$/m^3	24	*25.0*
If the tariff of reclaimed wastewater is 0.20 US$/m^3	8	*8.3*
If the tariff of reclaimed wastewater is 0.25 US$/m^3	3	*3.1*
If freshwater would not be available anymore, farmers accept to pay any tariff for reclaimed wastewater	36	*37.5*

Table 7.3: WTP according to the type of water currently used for irrigation.

Bid (US$/m^3)	*Groundwater (n = 15)*		*Surface water (n = 20)*		*Blended water (n = 10)*		*Treated wastewater (n = 51)*	
	Count	*%*	*Count*	*%*	*Count*	*%*	*Count*	*%*
0.00	12	80	20	100	10	100	51	100
0.05	12	80	14	70	9	90	46	90
0.10	10	67	13	65	7	70	15	29
0.15	9	60	10	50	2	20	3	6
0.20	6	40	1	5	0	0	1	2
0.25	3	20	0	0	0	0	0	0
Any tariff	8	53	9	45	4	40	15	29

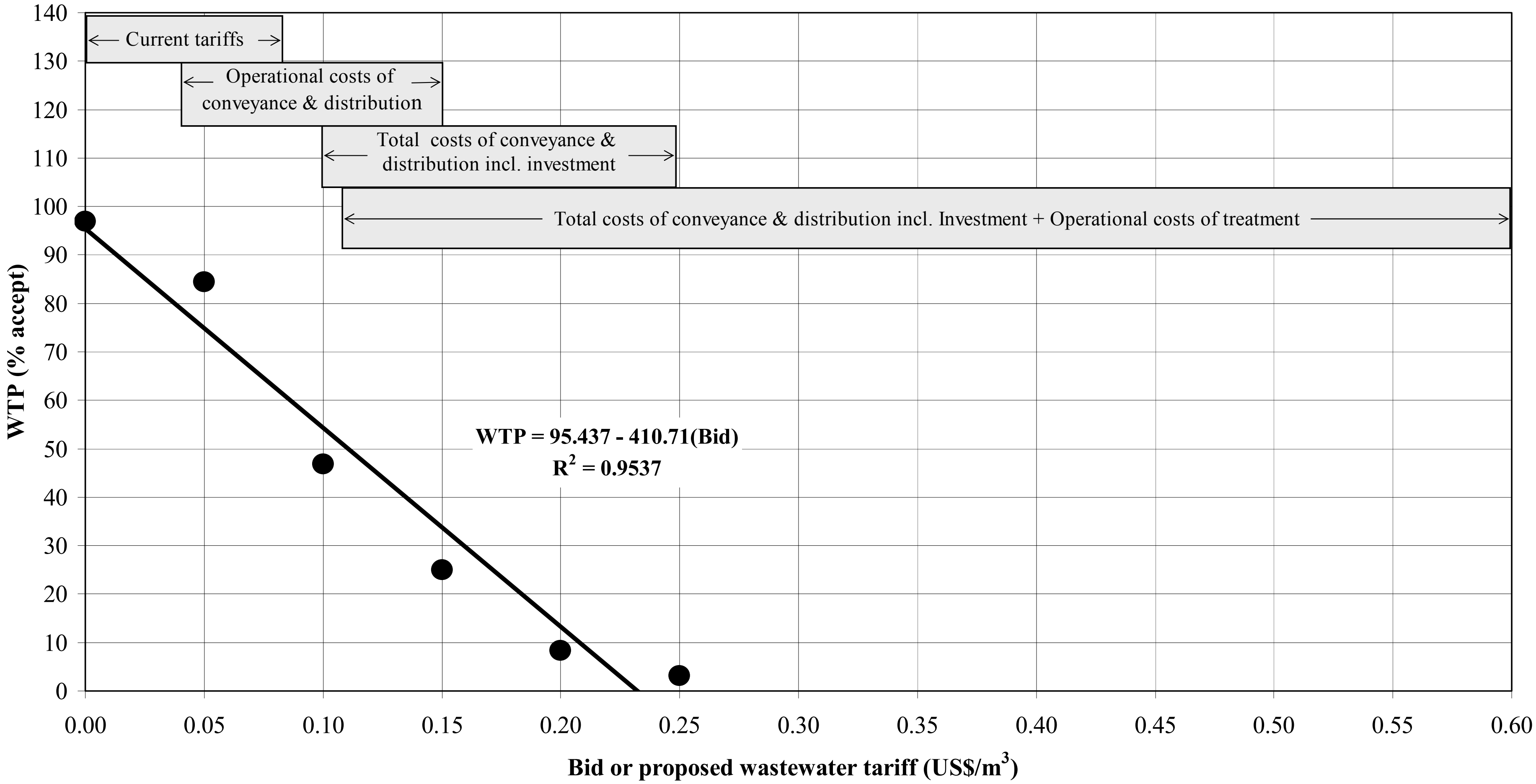


Figure 7.2: Willingness of farmers to pay for proposed tariffs and costs (gray areas) of reclaimed wastewater.

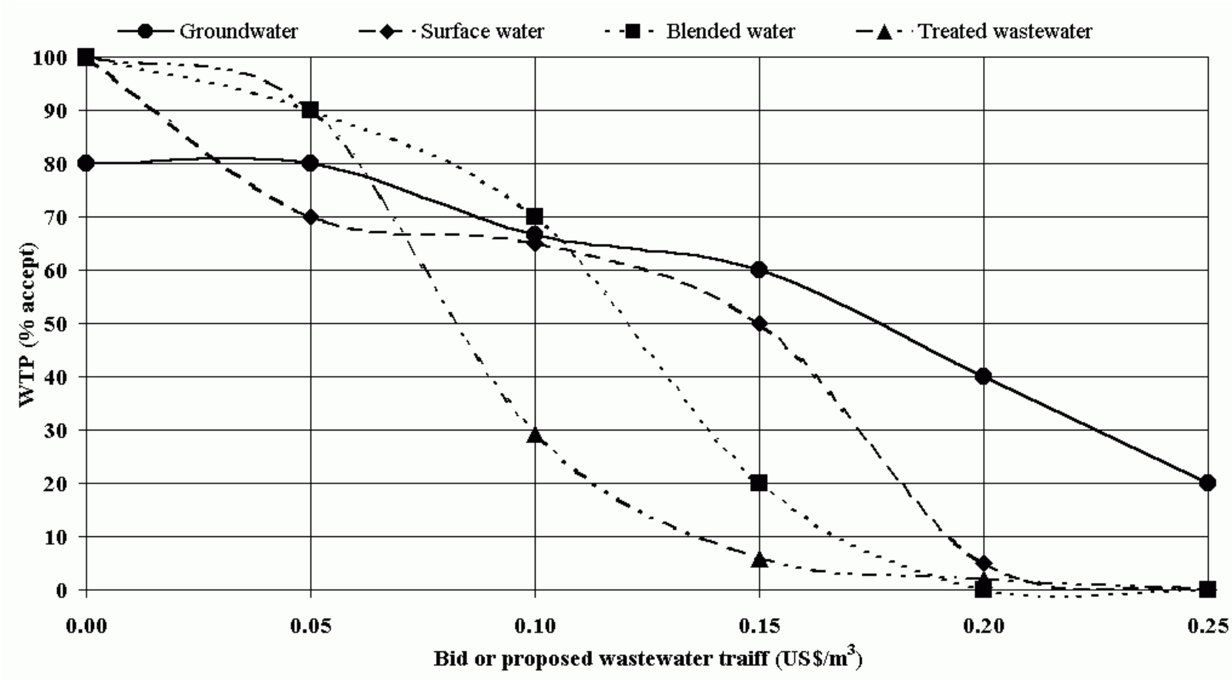


Figure 7.3: Willingness of farmers to pay for reclaimed wastewater according to the type of water currently used for irrigation.

7.4.2 Regression analysis of WTP

7.4.2.1 Model building

Farmers' responses were analyzed using models for discrete (qualitative) dependent variables, where we may relate the probability of making a certain choice ("pay" or "not pay") to some explanatory variables (independents). The discrete structure of WTP surveys implies the adoption of logistic regression (*logit analysis*) procedures (Maddala, 1983; Creel, 1998; Hanemann and Kanninen, 1996; Ardila *et al*., 1998; Emre *et al*., 2002). The goal of logistic regression is to correctly predict the category of outcome for individual cases using the most parsimonious model. In this way, logistic regression estimates the probability of a certain event occurring. To accomplish this goal, a model is created that includes all predictor variables that are useful in predicting the response variable. Several methods are available for selecting independent variables. One is the forced entry method where any variable in the variable list is entered into the model. The other is the stepwise method where logistic regression can test the fit of the model after each coefficient is added or deleted. Stepwise regression is used in the exploratory phase of research or for purposes of pure prediction, not theory testing (Menard, 1995). Exploratory testing makes no a-priori assumptions regarding the relationships between the variables, thus the goal is to discover relationships. Theory testing is the testing of priori theories or hypotheses where selection of the variables is based on theory, not on a computer algorithm. Menard (1995) writes, "there appears to be general agreement that the use of computer-controlled stepwise procedures to select variables is inappropriate for theory testing because it capitalizes on random variations in the data and produces results that tend to be idiosyncratic and difficult to replicate in any sample other than the sample in which they were originally obtained". Therefore, the entry method is applied in this study to test the following hypotheses concerning farmers' WTP for treated wastewater as competitive source to fresh water: (X_1) WTP is expected to increase as farmers' income or profit increases, and (X_2) WTP is expected to increase as the tariff of current irrigation water (competitive water) increases.

The sequential nature of dichotomous questions for the various bid values entails considering the sample size separately for each bid being studied as in Table 7.4 (Maddala, 1983). The **WTP_0** is estimated by considering the whole sample (n = 96) and partitioning it into those who accept (YES response) to use treated wastewater for zero bid and those who reject it. The parameter **$WTP_{0.05}$** is estimated by considering the sub-sample (n = 93) of farmers who accept the 0 bid and partitioning it into those who accept the 0.05 bid and those who reject it. The parameter **$WTP_{0.10}$** is estimated by considering the sub-sample (n = 81) of farmers who accept the 0.05 bid and partitioning it into those who accept the 0.10 bid and those who reject it. The parameter **$WTP_{0.15}$** is estimated by considering the sub-sample (n = 45) of farmers who accept the 0.10 bid and partitioning it into those who accept the 0.15 bid and those who reject it. The parameter **$WTP_{0.20}$** is estimated by considering the sub-sample (n = 24) of farmers who accept the 0.15 bid and partitioning it into those who accept the 0.20 bid and those who reject it. The parameter **$WTP_{0.25}$** is estimated by considering the sub-sample (n = 8) of farmers who accept the 0.20 bid and partitioning it into those who accept the 0.25 bid and those who reject it. The parameter **$WTP_{any\ tariff}$** is estimated by considering the whole sample (n = 96) of farmers and partitioning it into those who accept or reject to use reclaimed wastewater at any tariff, if freshwater would not be available/accessible anymore. The sequential models are easy to handle provided we make the probability of choice at each stage independent of the choice at previous stage (Maddala, 1983). In other words, different models are needed to explain farmers' responses to each of the presented bids.

Table 7.4: Distribution of sample size for the sequential responses of farmers.

Bid value	*WTP_0*	*$WTP_{0.05}$*	*$WTP_{0.10}$*	*$WTP_{0.15}$*	*$WTP_{0.20}$*	*$WTP_{0.25}$*	*$WTP_{any\ tariff}$*
Total responses	3 No						60 No
	93 Yes	12 No					36 Yes
		81 Yes	36 No				
			45 Yes	21 No			
				24 Yes	16 No		
					8 Yes	5 No	
						3 Yes	
Sample size	*96*	*93*	*81*	*45*	*24*	*8*	*96*

The SPSS software package is employed in this study where dichotomous responses to the seven bids are entered as dependent variables. The tariff of current irrigation water (US\$cent/m^3) and the net profit including unpaid labor per unit land area (US\$/Donum) are entered as independents with which one can predict the probability of voting for a certain bid value (Table 7.5). Other independent variables that are thought influential are not included in the model. The model significantly becomes unstable each time a new independent is added. This is because some independents have majority voting (e.g. availability of freshwater) and some others cause collinearity problems to the logit model (Maddala, 1983; Hanemann and Kanninen, 1996). For instance, the type of crops is directly linked to income, the type of water used is directly linked to the water tariff, area of cultivated land is directly linked to income or profit, etc. Age and membership to farmers' unions show no significant influence on farmers' WTP. Thus, each final model comprises one dependent (WTP for each proposed bid) and two independents (water tariff and farming profit).

Table 7.5: Logistic regression models for assessing farmers' WTP.

Model	*β*	*S.E*	*Wald*[(12)]	*Sig.*	*R*	*Exp(β)*	*Goodness of fit measures*
P_0 = Probability that a farmer responds yes to Bid = 0							-2LL = 24.045 Cox & Snell R^2 = 0.027 Negelkerke R^2 = 0.112 Pseudo R^2 = 0.099 Hosmer and Lemeshow = 9.729 8 df 0.786 sig.
X_1 TARIFF	-0.043	0.026	2.664	0.103	-0.158	0.958	
X_2 PROFIT	-0.002	0.002	0.747	0.387	0.000	0.998	
K CONSTANT	4.213	0.916	21.173	0.000	-	-	
$P_{0.05}$ = Probability that a farmer responds yes to Bid = 0.05							-2LL = 59.396 Cox & Snell R^2 = 0.122 Negelkerke R^2 = 0.228 Pseudo R^2 = 0.171 Hosmer & Lemeshow = 13.072 8 df 0.109 sig.
X_1 TARIFF	0.031	0.041	0.597	0.440	0.000	1.032	
X_2 PROFIT	0.004	0.002	9.035	0.003	0.314	1.004	
K CONSTANT	1.912	0.410	21.775	0.000	-	-	
$P_{0.10}$ = Probability that a farmer responds yes to Bid = 0.10							-2LL = 88.858 Cox & Snell R^2 = 0.242 Negelkerke R^2 = 0.324 Pseudo R^2 = 0.202 Hosmer and Lemeshow = 23.059 8 df 0.003 sig.
X_1 TARIFF	0.206	0.073	7.916	0.005	0.231	1.229	
X_2 PROFIT	0.003	0.001	5.802	0.016	0.185	1.003	
K CONSTANT	-0.909	0.372	5.965	0.015	-	-	
$P_{0.15}$ = Probability that a farmer responds yes to Bid = 0.15							-2LL = 35.801 Cox & Snell R^2 = 0.444 Negelkerke R^2 = 0.592 Pseudo R^2 = 0.424 Hosmer and Lemeshow = 2.161 7 df 0.950 sig.
X_1 TARIFF	0.444	0.151	8.654	0.003	0.327	1.559	
X_2 PROFIT	0.004	0.002	6.649	0.010	0.273	1.004	
K CONSTANT	-3.059	1.002	9.330	0.002	-	-	
$P_{0.20}$ = Probability that a farmer responds yes to Bid = 0.20							-2LL = 12.056 Cox & Snell R^2 = 0.537 Negelkerke R^2 = 0.746 Pseudo R^2 = 0.605 Hosmer and Lemeshow = 14.522 8 df 0.069 sig.
X_1 TARIFF	0.169	0.090	3.511	0.061	0.222	1.184	
X_2 PROFIT	0.004	0.003	2.307	0.128	0.100	1.004	
K CONSTANT	-4.610	1.859	6.151	0.013	-	-	
$P_{0.25}$ = Probability that a farmer responds yes to Bid = 0.25							-2LL = 6.415 Cox & Snell R^2 = 0.406 Negelkerke R^2 = 0.554 Pseudo R^2 = 0.394 Hosmer and Lemeshow = 5.137 6 df 0.526 sig.
X_1 TARIFF	0.163	0.279	0.340	0.559	0.000	1.177	
X_2 PROFIT	-0.006	0.006	1.067	0.302	0.000	0.994	
K CONSTANT	-8.259	14.909	0.307	0.580	-	-	
$P_{ANY\ TARIFF}$ = Probability that a farmer responds yes to Bid = any tariff							-2LL = 111.371 Cox & Snell R^2 = 0.150 Negelkerke R^2 = 0.205 Pseudo R^2 = 0.123 Hosmer and Lemeshow = 8.351 8 df 0.399 sig.
X_1 TARIFF	0.039	0.018	4.752	0.029	0.147	1.040	
X_2 PROFIT	0.003	0.001	9.151	0.003	0.237	1.003	
K CONSTANT	-1.048	0.287	13.348	0.000	-	-	

X_1 Tariff = tariffs currently paid for irrigation water (US\$cent/m^3).
X_2 Profit = net profit including the unpaid labor (US\$/Donum/year) or (US\$/1,000 m^2/year).
β = logistic coefficient; S.E. = standard error; Wald = Wald statistic; Sig. = significance level; R = correlation; Exp(β) = exponentiated coefficient; -2LL = -2log likelihood; df = degrees of freedom.

[12] Wald statistic is a test used in logistic regression for the significance of the logistic coefficient (β). Its interpretation is like the F or t values used for the significance testing of regression coefficient.

7.4.2.2 Assessing model fit

In assessing model fit, several measures are available (Hair *et al*., 1998). First, the log likelihood value (-2LL) value; smaller values of the –2LL measure indicate better model fit. The goodness of fit measure compares the predicted probabilities to the observed probabilities, with higher values indicating better fit. There is no upper or lower limit for this measure. Next, the three measures comparable to the R^2 measure in multiple regression are available. The Cox and Snell R^2 measure operates in the same manner, with higher values indicating greater model fit. However, this measure is limited to that it cannot reach the maximum value of 1, so Negelkerke proposed a modification that had the range of 0 to 1. The third measure is the "*Pseudo*" R^2 measure[13] based on the improvement in the –2LL value.

The final measure of model fit is the Hosmer and Lemeshow value, which measures the correspondence of actual and predicted values of the dependent variable. In this case, better model fit is indicated by smaller differences in the observed and predicted classification. A good model fit is indicated by a non-significant chi-square value (Hair *et al*., 1998). In our study, the goodness-of-fit measures for each model are shown in Table 7.5.

7.4.2.3 Interpretation of the regression models

Results of three models (WTP_0, $WTP_{0.05}$, and $WTP_{0.25}$) are non-significant (Table 7.5), thus unrepresentative and cannot be interpreted. This is mainly because of super-majority voting, which according to Hanemann and Kanninen (1996), interrupts model fit; but it still may be considered ethically superior. This is the case in our study for bid values 0 and 0.05 US\$/m^3, where the majority of the interviewed farmers accept to pay up to US\$0.05/m^3 of treated wastewater. Whereas results of the model for bid value US\$0.25/m^3 are non-significant and thus rejected mainly because the sample size is too small (n = 8) as a consequence of sequential questioning and majority reject responses.

Results of the other models ($WTP_{0.10}$, $WTP_{0.15}$, $WTP_{0.20}$, and $WTP_{\text{any tariff}}$) are significant at 95% and 90% confidence. Thus, accepting the hypotheses that water tariff and profit significantly influence farmers' WTP, the positive sign indicates that higher tariffs of freshwater as well as higher farmer's profit increase the WTP. The logit model for each bid value can be written as:

$$P = \frac{e^{(K+\beta_1 X_1+\beta_2 X_2)}}{1+e^{(K+\beta_1 X_1+\beta_2 X_2)}} = \frac{1}{1+e^{[-(K+\beta_1 X_1+\beta_2 X_2)]}} \quad (7.1)$$

Where,

P = Probability that a farmer is willing to pay the presented bid value (-)
K = Model constant (-)
β = Logistic coefficient (-)
X_1 = Tariffs currently paid for irrigation water (US\$cent/m^3).
X_2 = Net profit including the unpaid labor (US\$/Donum) or (US\$/1,000 m^2).

[13] The Pseudo R^2 = $[(-2LL_{initial}) - (-2LL_{model})]/(-2LL_{initial})$.

7.5 Conclusions and recommendations

Water tariffs and agricultural profitability have a significant influence on willingness of farmers to pay for reclaimed wastewater. About 97% of farmers show interest to take reclaimed wastewater if given to them for free and if its supplies are reliable and allowed for unrestricted irrigation. This willingness declined to 84% and 47% when the proposed tariffs were US$0.05/$m^3$ and US$0.10/$m^3$, respectively. Such tariffs can barely recover the minimum operational costs of supplying a secondary treated wastewater. Making this water comply with farmers' requirements for unrestricted irrigation implies additional treatment costs. Therefore, ambitious attempts to recover costs through increasing the tariffs of reclaimed wastewater might not succeed because farmers still have easy and cheap access to the competitive freshwater. This justifies the need for increasing the tariffs of freshwater for irrigation (Chapter 6) and using revenues from freshwater to subsidize reclaimed wastewater. The existing reclaimed wastewater tariffs deem to be suitable since they are accepted by most of the farmers on one hand, and they do not jeopardize agricultural profitability on the other hand.

7.6 References

Abu Madi, M., Al-Sa'ed R., Braadbaart, O., and Alaerts, G. (2000). Selection criteria for appropriate sanitation in the Palestinian rural and semi-urban communities. Proceedings of the International Symposium on Water Sector Capacity Building and Research in Palestine, 27 March 2000, Birzeit University, Palestine.

Abu Qdais, H.A. and Al Nassay, H.I. (2001). Effect of pricing policy on water conservation: a case study. *Water Policy*, **3**: 207-214.

Agthe, D. E. and Billings, R. B. (1996). Water-price effect on residential and apartment low-flow fixture. *Water Resources Planning and Management*, **122**(1): 20-23.

Ahmad, M. (2000). Water pricing and markets in the Near East: Policy issues and options, *Water Policy*, **2**: 229-242.

Alberdini, A. (1995). Efficiency vs. bias of willingness-to-pay estimates: Bivariate and interval-data models. *Environmental Economics and Management*, **29**: 169-180.

Al-Hamdi, M. (2000). Competition for scarce groundwater in Sana'a plain, Yemen: a study on the incentives system for urban and agricultural water use. PhD thesis, IHE-Delft, The Netherlands.

Ardila, S., Ricardo, Q., and Vaughan, W. (1998). A review of the use of contingent valuation methods in project analysis. Environment Division, working paper No. ENV-126. Inter-American Development Bank. Washington, D.C.

Babbitt, H. E., Donald, J. J., and Cleasby, J. L. (1962). Water supply engineering (6th ed.). New York: McGraw-Hill Book Company.

Bahri, A. and Brissaud, F. (1996). Wastewater reuse in Tunisia: assessing a national policy. *Wat. Sci. Tech*., **33**(10-11): 87-94.

Briassoulis, H. (1995). Effectiveness of water conservation measures in greater Athens area. *Water Resources Planning and Management*, **120**(6): 746-777.

Briscoe, J. (1996). Water as an economic good: The idea and what it means in practice. International Commission on Irrigation and Drainage, Special Congress, Special Session R. 11, Cairo 1996.

Cairncross, S., Carruthers, I., Curtis, D., Feachem, R., Bradley, D., and Baldwin, G., (1980). Evaluation for village water supply planning. John Wiley and Sons, UK.

Cooper, J. (1993) Optimal bid selection for dichotomous choice contingent valuation surveys, *Environmental Economics and Management*, **24**: 25-40.

Creel, M. (1998). A note on estimation of mean WTP using a misspecified logit contingent valuation model. *Environmental Economics and Management*, **35**(3): 277-284.

Dinar, A. and Subramanian, A. (1998). Policy implications from water pricing experiences in various countries, *Water Policy*, **1**: 239-250.

Emre, A., David, C., Charles, M., and Vladimir, N. (2002). Application of benefit transfer with contingent valuation method to the root river watershed. Technical report No. 12, May 2002. Milwaukee, Wisconsin.

Faruqui, N. (2000). Wastewater treatment and reuse for food and water security. www.idrc.ca/waterdemand/SpecialPapers_e.html, IDRC, Ottawa, Canada.

Gijzen, H. (2001). Low cost wastewater treatment and potentials for reuse: A cleaner production approach to wastewater management. International symposium on low cost wastewater treatment and reuse, Cairo, February 2001.

Hair, J., Anderson, R., Tatham, R., and Black, W. (1998). Multivariate data analysis. Fifth edition. Prentice-Hall International, US.

Hanely, N., Wright, R., and Mourato, S. (2001). Choice modeling approaches: a superior alternative for environmental valuation. *Economic Survey*, **15**(3). Blackwell Publishers Ltd.

Hanemann, M. and Kanninen, B. (1996). The statistical analysis of discrete-response CV data. Working paper 794, Dept. of Agriculture and Resource Economics, University of California, Berkeley.

Haruvy, N. (1994). Recycled Water Utilization in Israel Focusing on Wastewater Pricing Versus National and Farmers Objectives. *Financial Management and Analysis*, **7**(2).

Johansson, M. (1999). Economics without markets: four papers on contingent valuation and stated preference methods. Department of Economics, Umea University, Umea. Borlange.

Johansson, R., Tsur, Y., Roe, T., Doukkali, R., and Dinar, A. (2002). Pricing irrigation water: a review of theory and practice. *Water Policy*, **4**: 173-199.

Maddala, G. S. (1983). Limited-dependent and qualitative variables in econometrics. New York, Cambridge University Press.

Mayers, C. (1996). Water conservation: A metered approach. *World Water and Environmental Engineering*, **19**(4): 40-40.

Menard, S. (2002). Applied logistic regression analysis, 2nd Edition. Thousand Oaks, CA: Sage Publications. Series: Quantitative Applications in the Social Sciences, No. 106. First ed. 1995.

Mitchell, R.C. and Carson, R.T. (1989). Using surveys to value public goods: The contingent valuation method. Resources for the Future, Washington, D.C.

MWI. (1999). Annual Report, Ministry of Water and Irrigation. Amman.

ONAS. (2001). Annual Report, National Sewerage Agency. Tunis.

Perry, C. (2001) Water at any price? Issues and options in charging for irrigation water. *Irrigation and Drainage*, **50**: 1-7. John Wiley and Sons, Ltd.

Rogers, P., de Silva, R., and Bhatia, R. (2002). Water is an economic good: How to use prices to promote equity, efficiency, and sustainability. *Water Policy*, **4**: 1-17.

Rosegrant, M.W. and Ringler, C. (1998). Impact on food security and rural development of transferring water out of agriculture, *Water Policy*, **1**: 567-586

Saghir, J., Schiffler, M., and Woldu, M. (2000). Urban water and sanitation in the Middle East and North Africa Region: The way forward. The World Bank, Middle East and North Africa Region, Infrastructure Development Group.

Sanz, L. (1999). Irrigated agriculture in the Guadian River High Basin (Castilla-La Mancha, Spain): Environmental and Socio-economic impacts. *Agricultural Water Management*, **40**: 171-181.

Schiffler, M. (1998). The economics of groundwater management in arid countries: theory, international experience and a case study of Jordan. Frank Class, London.

Shatanawi, M. and Salman, A. (2002). Impact of full cost recovery on irrigation water in the farming economics in the Jordan Valley. University of Jordan, Amman.

Snell, M. (1997). Cost-benefit analysis for engineers and planners. Thomas Telford Publications, London, UK.

Thanh, N. and Visvanathan, C. (1991). Wastewater reuse gains momentum in Mediterranean and Middle East regions. Wastewater, pp. 19-26, WWI/February 1991.

Twort, A. C., Law, F. M., Crowley, F. W., and Ratnyak, D. D. (1994). Water supply (4th ed.). London UK: Edward Arnold.

Vaughan, W., Russell, C., Rodriguez, D., and Darling, A. (1999). Willingness to pay: Referendum contingent valuation and uncertain project benefits. Inter-American Development Bank. Washington, D. C.

Walski, T. M., Richards, W. G., McCall, D. J., Deb, A. K., and Morgan, J. M. (1985). Calculating effectiveness of water conservation measures. *Environmental Engineering*, **111**(2): 209-221.

Whittington, D. (1998). Administering contingent valuation surveys in developing countries. *World Development*, **26**(1): 21-30, Elsevier Science Ltd., UK.

World Bank. (1996). From scarcity to security: Averting a water crisis in the Middle East and North Africa. Report. Washington, DC.

Yoduleman, M. (1989). Sustainable and equitable development in irrigated environments. Environment and the Poor: Development Strategies for a Common Agenda, H. Jeffrey (ed.), US Third World Policy perspectives, No. 11, Overseas Development Council, Washington D.C.

Chapter 8: Conclusions

8.1 Unbalanced reclaimed-wastewater market

Wastewater utilization in these countries is still very low, even in pioneer countries like Jordan and Tunisia, despite (i) water scarcity, high agricultural water demand, and the fast growing need for additional water supplies, (ii) increasing recognition of treated wastewater as a valuable non-conventional resource, and (iii) technological advances in wastewater collection and treatment. Understanding this phenomenon implies recognizing the reclaimed wastewater as a commodity. The market for this commodity comprises: (i) a supply side, which refers to the production, collection, and treatment of wastewater, (ii) a demand side, which refers to the use of the reclaimed wastewater in irrigated agriculture, and (iii) market control and monitoring, which refers to the regulatory and administrative framework. In conclusion, the reclaimed-wastewater market in the region is unbalanced; i.e., growing supply– which is demonstrated by the increasing sewerage coverage and number of wastewater treatment plants (WWTPs) – and stagnant demand– which is demonstrated by the quantities of wastewater that are collected but not treated and the substantial proportions of treated effluents that are not used but discharged into the receiving water bodies.

An indicator called "Wastewater Reuse Index" (*WRI*) can be used to quantify the gap between the supply and demand sides of the market. *WRI* quantifies the actual reuse as percentage of the total generation of wastewater (urban and rural). Thus, balancing the reclaimed-wastewater market implies maximizing *WRI*, which can be accomplished through increasing the rates of collection, treatment, and reuse. Most countries of the region have reasonably high rates of wastewater collection, which is driven by urbanization, public health, and environmental incentives (Table 8.1). Thus, the low *WRI* in these countries is mainly due to the low rates of wastewater treatment and/or reuse.

Table 8.1: *WRI* in selected MENA countries (MWI, 1999; Abu Rizaiza, 1999; Idelovitch, 2001; ONAS, 2001) (flow rates per annum).

Country	*G (million m^3)*	*C (million m^3)*	*T (million m^3)*	*R (million m^3)*	*x = C/G (%)*	*y = T/C (%)*	*z = R/T (%)*	***WRI (%)***
Israel	464	440	300	249	95	68.2	83.0	***53.7***
Jordan	241	239	80	67	99	33.5	83.8	***27.8***
Tunisia	395	316	148	50	80	46.8	33.8	***12.7***
Saudi Arabia	1,347	1,347	292	92	100	21.7	31.5	***6.8***

G: production; C: collection; T: treatment; R: reuse; WRI: Wastewater Reuse Index.

A large number of factors can increase (as incentives) or lower (as disincentives) the use of reclaimed wastewater. Depending on the local conditions, each incentive or disincentive can work out to a larger or smaller degree. As a result, the positive influence of a certain incentive may be compensated by a certain disincentive, and vice versa. Therefore, wastewater reuse depends, in resultant, on a series of incentives and disincentives. In order to maximize reuse, all possibly relevant factors that influence each component (collection, treatment, and reuse) have to be identified and considered in an integrated manner. This study identified and assessed the technical, regulatory, financial, institutional, and socio-cultural incentives that may lead to increase in wastewater treatment and reuse (i.e., increase in *WRI)* and, consequently, contribute to balancing the reclaimed-wastewater market in Jordan and Tunisia that are representative of the MENA region. The forthcoming Sections summarize the conclusions on each (dis)incentive that influences wastewater treatment and use in irrigated agriculture (Figure 8.1). These (dis)incentives are numbered and cross-reference is used since many of them are interrelated and influence more than one stakeholder in the reclaimed-wastewater market; it is difficult to make distinct classification of these factors since the nonexistence or low influence of a disincentive is an incentive and vice versa.

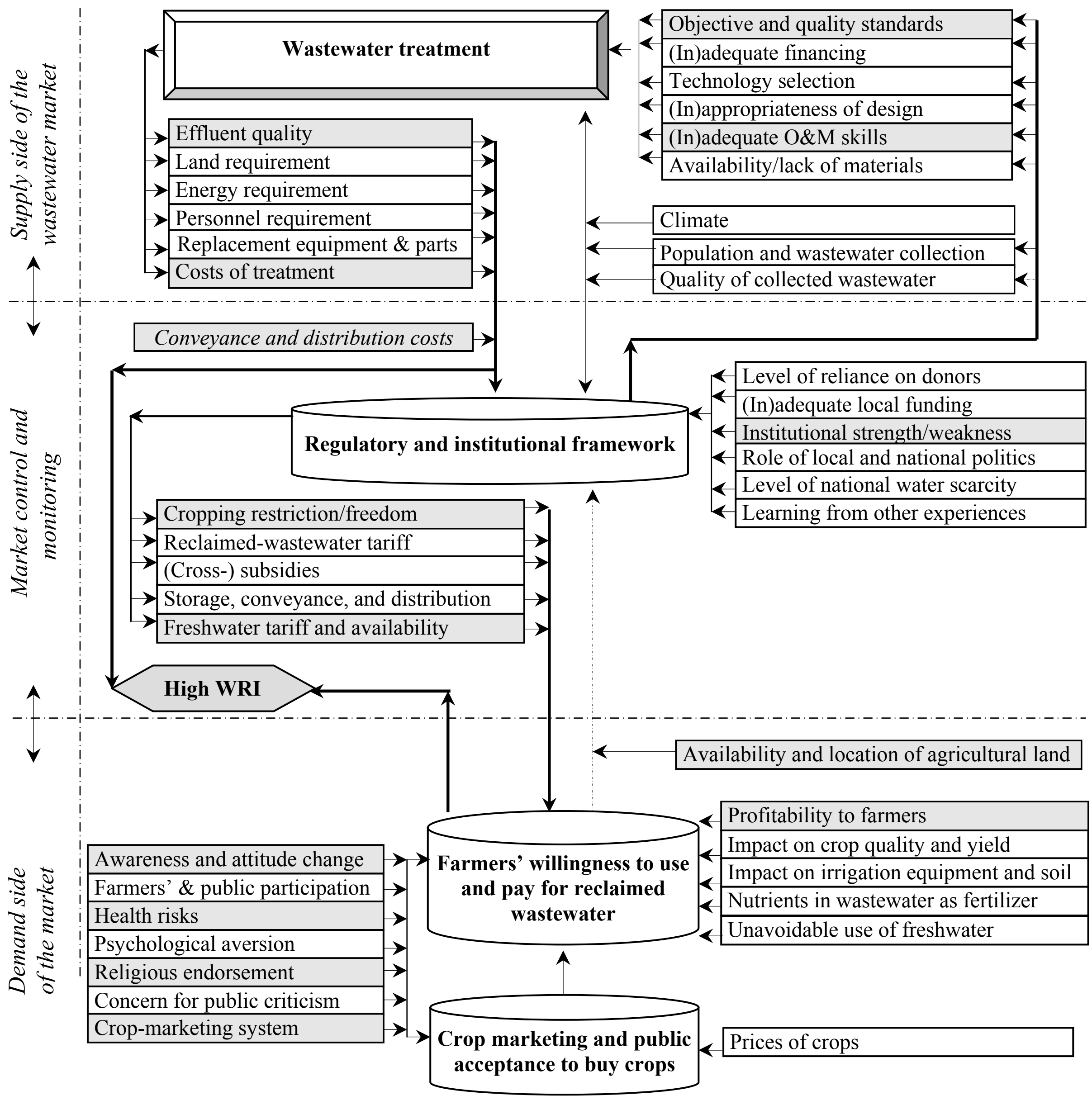


Figure 8.1: The incentive systems for use of reclaimed wastewater in irrigated agriculture in the MENA region (Shaded: found to be major factors).

8.2 The incentive systems for wastewater treatment

Improved wastewater treatment is not determined by the treatment technology itself, i.e., the hardware, but by the enabling environment for proper functioning of the technology, i.e., the software.

The enabling environment for wastewater treatment:

1. *Treatment objective and effluent quality standards*

The adopted approaches for wastewater treatment designs in the MENA region still have the disposal philosophy as the principle objective. Most of the existing WWTPs were designed for environmental protection, while reuse has rarely been recognized since the early stages of the planning and implementation of these plants. Even when reuse is considered, assessment of the actual needs of the reclaimed wastewater users is often limited. Moreover, the nutrients content in the reclaimed wastewater have rarely been considered in the design criteria for WWTPs as well as in setting up the quality standards and regulations for wastewater reuse; most countries have quality standards and regulations for effluent discharge and for reuse (see 13 and 20). Therefore, wastewater that was once conceived as only a “waste to be disposed of” have to be recognized as a sustainable alternative source of water for an increasing number of applications and viable part of the water cycle as well as a source of nutrients.

2. *Institutional framework*

Weakness of the institutional makeup, poor coordination at intra and inter (sub-) sectoral levels, and low involvement of local farmers, civil society, and private sector are amongst the major factors that limit the growth of wastewater treatment and reuse. Planning, design, implementation, operation, and maintenance of wastewater treatment and reuse facilities are usually distributed among many governmental departments, where coordination and cooperation between these bodies is lacking (see also 15). Wastewater collection (good performance) is usually decentralized and well organized. Wastewater treatment (moderate to good performance) is centralized, technocratic, and well organized. Wastewater reuse (poor performance) depends a lot on local farmers, but still controlled by the water resource organization. Moreover, the public utilities are often overstaffed and experience frequent changes in sector leadership and management. They are expected to contribute to the alleviation of unemployment by hiring and keeping a large number of low-qualified staff, some of which are not needed. At the same time, utilities are subject to civil service salary rules, restricting their ability to attract, motivate, and maintain qualified personnel that is essential to successfully perform key technical and managerial functions. Therefore, the tasks and responsibilities need to be clearly defined among the various institutions, and the performance of permanent staff needs to be improved.

3. *Financing*

The limited financial resources in the two countries have resulted in over-reliance on foreign grants and loans, which are also limited, for financing the construction of new WWTPs. Moreover, these countries barely recover the O&M costs of wastewater treatment, conveyance, and distribution since they persist to adopt expensive technologies such as activated sludge. However, other financing options such as recovery of the incurred costs and involvement of public and the private sector may help inject additional funds and might (partly) overcome the financial and institutional difficulties facing the wastewater sector. These funds will allow for design and construction on new WWTPs and optimize the performance of existing ones.

Involving the private sector in the wastewater business in the region is still at infancy level and mainly constrained by the high costs, low cost recovery, the weak regulatory and institutional framework, and the high political interference. In order to successfully attract the private sector and to improve the level and the efficiency of services, the role of the public authorities and utilities has to be redefined. It is also essential that governments demonstrate a strong political commitment, create an adequate legal and institutional framework, promote a high degree of technical skill among the civil servants regulating the operator, and ensure a fair and transparent bidding process. However, involving the private sector should be accompanied by consideration of the alleviation of poverty.

4. *Technology selection and availability of design and O&M skills*

Despite the wide range of treatment technologies practiced worldwide, engineers and decision-makers in the region stick to few technologies that they know - activated sludge, trickling filter, and lagoon systems - and don't have exposure to too much variety. This is attributed to cost considerations and lack of finances, inadequate skills, time limitations, and more importantly, reliance on external funding and expertise. Even when local funds and design expertise are involved, the role of foreign engineers and consultancy offices can still be recognized. Skilled personnel needed to O&M the wastewater facilities are abundant, but effective performance of those personnel is constrained by the top-level institutional weaknesses represented by poor enforcement and lack of incentives. The MENA countries have to provide more incentives to their personnel and encourage research, innovations, and experiencing other treatment systems. Moreover, dissemination of results and national and regional sharing of experiences, which is limited to the efforts put in by the external aid agencies, shortens the learning curve and improves performance of available skills.

5. *Local availability of materials and equipment*

The local availability of materials and equipment does not seem to be a limiting factor for construction or O&M of wastewater treatment facilities. The MENA countries have good foreign trade systems where most of the essential equipments and materials are available in the local market; although they are often imported from other countries (see also 9).

Technology performance:

6. *Compliance of effluent quality with the prescribed standards*

The existing WWTPs have moderate to good performance and can potentially be improved. Almost all the surveyed activated sludge (AS) and trickling filter (TF) systems in Jordan and Tunisia are efficient in reducing the concentrations of BOD, COD, and TSS consistent with the guidelines for restricted irrigation in the two countries. On the other hand, none of the surveyed lagoon (L) systems complies with these guidelines, mainly because the L systems are older and overloaded. Although disinfection systems exist in most of the surveyed plants, all, except for three AS plants in Jordan, fail to reduce the concentration of faecal coliforms to permissible levels (<1000/100 ml). However, lagoons are not necessarily poor performers since their relatively low BOD and COD is irrelevant within the context of reuse policy; the existing WHO guidelines allow such treated effluents with high faecal coliforms for restricted irrigation. Nonetheless, tertiary or advanced treatment has to be considered to improve the removal of pathogens especially when the effluent to be used for unrestricted irrigation.

7. *Land requirement*

The land requirement is a crucial factor in selection of treatment technologies when land is not available at reasonable opportunity cost. The AS and TF systems require less space than L systems, at the expense of more equipment, construction, and O&M. The L systems require relatively large land area (1.4-4.5 m^2/PE) compared with the AS plants (0.2-1.3 m^2/PE) and the TF plants (0.3-0.8 m^2/PE). Therefore, the lagoon systems seem to be less commendable unless land is available at reasonable price and the current perceptions about lagoons are changed.

8. *Energy requirement*

The annual per capita energy requirement (KWh/PE/y) for the AS plants in Jordan is very high (21.8-45.0) compared with that for the TF (4.6-25) and L plants (3.4-12.5). In Tunisia, the energy requirement (KWh/PE/y) is 16.5-30.7, 3.1, and 0.8-35.0 for the AS, TF, and L plants, respectively. The per capita cost of energy (US$/PE/y) in the Jordanian WWTPs is 1.1-2.7, 0.2-1.9, and 0.2-0.6 for the AS, TF, and L plants, respectively, compared with 0.9-2.4, 0.2, and 0.1-1.9 for the three systems, respectively, in Tunisia. The energy cost in the Jordanian WWTPs represents 27%, 17%, and 15% of the annual operational costs for the AS, TF, and L systems, respectively, while in Tunisia it is 42%, 9.4%, and 24.1% for the three systems, respectively. The addition of aeration units in some of the lagoons, in order to improve their performance, makes their energy requirement close to that of mechanical systems. The annual energy requirement in the AS and TF plants drastically increases (almost 1:1) with increased treatment capacity.

9. *Replacement equipment and parts*

The annual expenditure on replacement equipment and parts (spare parts and supplies) in Jordan represents approximately 13.3%, 20.0%, and 21.2% of the annual operational costs of the AS, TF, and L plants, respectively, compared with 19.3%, 25.0%, and 11.6%, respectively, in Tunisia. The annual per capita expenditure on replacement equipment and parts (US$/PE/y) in Jordan is 0.7-1.0, 0.2-3.4, and 0.2-0.8 for the AS, TF, and L plants, respectively, compared with 0.1-2.7, 0.4, and 0.1-1.5, respectively, in Tunisia. With respect to replacement equipment 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 due to its various modifications. However, although expenditure on replacement equipment and parts is an important component of the treatment costs, it is not necessarily decisive in differentiating between treatment technologies.

10. *Personnel requirement*

The average number of personnel in each WWTP 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. When the treatment capacity exceeds 3,000 m^3/day, the number of personnel required in the three compared systems drastically decreases to less than 0.5/1,000 PE.

Apparently, the number of personnel in each WWTP does not depend on the treatment system but on the plant capacity, population served, and most importantly on institutional policy. Thus, large-capacity WWTPs are decidedly more economical in terms of manpower.

The annual expenditure on personnel is about 46-75% and 17-76% of the annual operational costs in the Jordanian and Tunisian WWTPs, respectively. These results confirm other research findings that show that in developing countries the cost of personnel in the wastewater treatment sector is proportionately higher than that for developed countries. Thus, reducing the number of personnel in each WWTP significantly decreases the treatment costs. 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. 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.

11. *Costs of treatment*

Comparison of the treatment costs (capital and operational) shows the L plants are the cheapest since their per capita total annual cost (US$/PE/y) is about 1.6-19.6 compared with that for the TF plants (2.4-27.1) and AS plants (4.7-37.6). The total per unit cost of treatment (US$/$m^3$) is low for the L plants (0.04-0.42), moderate for the TF plants (0.12-0.61), and low to high for the AS plants (0.09-0.95). Although lagoons are the cheapest, the mechanical modifications to the natural lagoon systems make the O&M requirements almost similar to that for the AS and TF systems. The treatment costs in Jordan and Tunisia vary from very low to very high compared with that around the world, even among those plants that have similar capacity and employ similar processes. Thus, the existing treatment technologies are virtually capable of producing treated effluents of acceptable quality at lower costs, depending upon the enabling environment for these technologies to function properly and cost effectively (see also 1-5). WWTPs with large capacity enjoy economies of scale. When plant capacity exceeds 3,000 m^3/day, each of the annual capital and operational costs 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.

8.3 The incentive systems for using reclaimed wastewater in irrigated agriculture

12. *Acceptance of farmers to use reclaimed wastewater*

Farmers seem, in general, reasonably positive towards reuse. There is some evidence that perceptions towards acceptance have improved over the past decade. Regulatory, institutional, financial/economic, and socio-cultural (dis)incentives shape the desire and decisions of both the farmers – who have to buy the reclaimed wastewater and apply certain agronomic approaches – and the public – that must decide whether to buy the crops watered with reclaimed wastewater.

Regulatory and institutional:

13. *Cropping restriction and quality standards and regulations*

Cropping restriction/freedom is one of the most important factors that influence the decision of farmers to irrigate with reclaimed wastewater (see also 20). The existing quality standards and regulations do not permit using reclaimed wastewater in unrestricted irrigation. The makeup of these standards and regulations is based on other international practices (see also 1). Therefore, there is great need for establishing milder standards and guidelines that take into consideration the scheme and country specific conditions. In this case, there is no need for establishing flat standards but a set of inclusive guidelines that enable establishing site-specific standards for each irrigation scheme.

14. *Freshwater availability/accessibility at scheme level*

Freshwater availability/accessibility at scheme level is the most crucial disincentive for reuse. The availability of cheap freshwater makes reclaimed wastewater less attractive and less competitive. This disincentive can be mitigated through enforcing restrictions on irrigation with freshwater wherever reclaimed wastewater can cover the agricultural water demand, and through strengthening the incentives, such as water pricing, that make reclaimed wastewater competitive with freshwater (see also 24, 25, and 26).

15. *Institutional framework and involvement of farmers, public, and private sector*

The large number of institutions involved in the wastewater treatment and reuse and the poor cooperation and coordination amongst these bodies is a major disincentive for improved wastewater utilization (see also 2 and 3).

There is a strong argument that farmers' involvement in all project phases does increase the opportunities for sustainability, reduce the managerial and financial burden on the government institutions, and most importantly, improves the willingness of farmers to use and pay for reclaimed wastewater. Out of the surveyed schemes, only the Wardanine irrigation scheme in Tunisia involved farmers. This involvement did not only facilitate the implementation and management of the reuse project but it also increased the willingness of farmers to use and pay for reclaimed wastewater.

Involvement of public (crop consumers) is at least as important because they are the ultimate financiers for the wastewater treatment/sanitation and reclamation, and they are the potential consumers for crops. The public surveyed in this study in Jordan and Tunisia showed enthusiasm for participation in decision making with respect to water and sanitation in general and with respect to tariffs in particular; about 86% and 36% of the public in Jordan and Tunisia, respectively, consider this factor as influential to attitude change.

Involving the private sector as a financier in wastewater reuse projects is not common in the region (see also 3), which can be attributed to (i) high capital requirement, (ii) stringency of quality standards, (iii) weak regulatory and enforcement systems, (iv) low cost recovery, (v) price setting for reclaimed wastewater and freshwater by governmental decree, with a strong tendency to keep tariffs low, and (vi) thus, unattractive economic prospects.

16. *Enforcement*

The weak regulatory and enforcement mechanisms in the region aggravate the water and environmental problems. The region has made progress by establishing ministries of water and the environment, and by preparing or enacting environmental legislation. However, cross-sectoral linkages between government and public institutions are weak and enforcement is often avoided due to social and political considerations. Interestingly, majority of the surveyed farmers and crop consumers reported that they are very responsive to regulations and enforcement and their behavior is influenced by them.

Technical:

17. *Conveyance and distribution*

The conveyance and distribution can be major disincentives for irrigation with reclaimed wastewater, especially where the infrastructural requirements are high and the financial resources are limited (see also 24, 25, and 26). In such case, as far as possible, using the reclaimed wastewater in the vicinity of the WWTPs overturns this disincentive and makes wastewater irrigation more attractive.

18. *Reliability of reclaimed-wastewater supplies*

The supplies of reclaimed-wastewater are continuous and what cannot be used instantly must be stored as it otherwise will be disposed and lost in some way or another. In this study, 38 out of the 51 interviewed reclaimed-wastewater farmers emphasized that they are severely affected by the absence or insufficiency of storage and the ensuing unreliability of supply. Storage of the reclaimed wastewater - which allows coping with hourly, daily, and seasonal fluctuations of water supply and demand - may overturn this disincentive. However, depending on the volume and pattern of the effluent supply and the projected reuse demand, storage requirements may have a substantial impact on the capital and operational costs of the system. For this reason, blending of reclaimed wastewater with freshwater in existing dams - not destined for potable water supply - is widely practiced in Jordan and Tunisia. The blended water is used downstream for unrestricted irrigation; thus, it increased the reliability of water supply, which eventually in turn stimulated reuse.

19. *Unavoidable use of freshwater*

The fact that reclaimed-wastewater farmers may still have to buy expensive freshwater for supplementary irrigation and/or preparing pesticide and insecticide solutions may be a disincentive for farmers to use reclaimed wastewater. Some framers will have to invest in an additional supply system for freshwater to supplement reclaimed-wastewater supplies, otherwise they rely on expensive water from private vendors. However, the influence of this factor seems to be minimal compared to the other (dis)incentives being studied.

20. *Quality of the reclaimed wastewater*

The treated effluents of the existing WWTPs can barely be used for restricted irrigation due to their high content of solids and pathogens (see also 13). However, farmers do not have direct concern for the effluent quality as much as they care about its associated impacts on health, crop quality and yield, soil, and irrigation equipment (see 19, 21, 22, and 23). There is need to improve the performance of these WWTPs in order to produce effluents of better and consistent quality, especially in terms of pathogens, and much less so in terms of BOD and COD.

21. *Impact on crop yield and quality and use of fertilizers*

This study shows that there is about 65% saving in actual fertilizer expenditure when irrigating fruit trees with reclaimed wastewater compared to irrigating with fresh groundwater.

Also, interestingly, many farmers irrigating with blended water persist to use fertilizers with the same magnitude that is used in freshwater irrigation despite the high nutrient content in the reclaimed wastewater. Those farmers seem to not have confidence in the quality of reclaimed wastewater, or they unconsciously attribute their high crop yield and agricultural profit to the application of the artificial fertilizer; this is consistent with the observation that they tend to use less fertilizer for low-value fodder crops than for fruit trees and vegetables. Some of those farmers reported that reclaimed wastewater have negative impacts on the quality of their crops; this is an important issue since crop quality is directly linked with crop marketing and profit. Thus, more effort is needed to raise farmers' awareness on the contents in reclaimed wastewater as well as on the costs and benefits associated with these contents.

22. *Health risks*

The health impact associated with reclaimed wastewater can be very severe; therefore, public health must not be compromised through maximizing reuse rates. Nonetheless, majority of the surveyed farmers do not perceive the actual health risks; on the contrary, they claim no impacts. Some farmers persist to irrigate with raw wastewater. However, more research is needed in order to study the long-term impacts on users of reclaimed wastewater and related crops as well as beneficiaries of the affected water resources.

23. *Impact on irrigation equipment and soil*

The high content of solids in the treated effluent can cause clogging of emitters in the drip irrigation system and influence - in addition to sodium, calcium, and magnesium - the structure of soil. However, in the studies cases, this does not seem to be a major disincentive for farmers to irrigate with reclaimed wastewater.

Financial:

24. *Costs, tariffs, and willingness of farmers to pay for reclaimed wastewater*

Reclaimed wastewater is often a financially-expensive water resource because of the high investment and operational costs related to collection and treatment of influent, and conveyance and distribution of treated effluents (Table 8.1). The collection and treatment costs have to be recovered from the wastewater producers. Nevertheless, the cost of conveyance and distribution is too high and its recovery, from the farmers as irrigation water tariffs, is questionable. A regression model was built which shows that water tariffs and agricultural profitability have a significant influence on willingness of farmers to pay for reclaimed wastewater. About 97% of farmers show interest to take reclaimed wastewater if given to them free of charge and if its supplies are reliable and allowed for unrestricted irrigation. This willingness declines to 84% and 47% when the proposed tariffs are US\$0.05/m^3 and US\$0.10/m^3, respectively. Such tariffs can barely recover the minimum operational costs of supplying a secondary treated wastewater (Table 8.1). Making this water comply with farmers' requirements for unrestricted irrigation implies additional treatment costs. Therefore, ambitious attempts to recover costs through increasing the tariffs of reclaimed wastewater might not succeed since farmers still have easy and cheap access to the competitive freshwater. The existing reclaimed-wastewater tariffs deem to be suitable since they are accepted by most of the farmers on one hand, and they do not jeopardize agricultural profitability on the other hand (see also 25 and 26).

Table 8.1: Existing costs and tariffs (US$/m^3) of using reclaimed wastewater for irrigation.

Tariff/cost	*Jordan*	*Tunisia*
Tariff	0.0–0.08	0.014–0.08
Treatment costs:		
Operational costs	0.02–0.34	0.03–0.17
Total costs (incl. depreciation)	0.05–0.95	0.04–0.93
Conveyance and distribution costs:		
Operational costs	0.04–0.12	0.09–0.15
Total costs (incl. depreciation)	0.10–0.21	0.13–0.25
Total costs of treatment and conveyance incl. depreciation	0.15–1.16	0.17–1.18
Conveyance and distribution costs as percentage of the total costs(incl. depreciation)	18.1–66.7%	21.2–75.8%

25. *Profitability to farmers*

At existing water tariffs, about 39% of the surveyed farms that are irrigated with freshwater and 57% of the farms irrigated with reclaimed wastewater are running a loss if the value of unpaid labor (farmers' input) is monetarized in the profit analysis. Apparently, farmers conceive profit differently, which contradicts with simple economic theory. They neglect the opportunity cost or the economic value of their own labor (unpaid). The only justification is that opportunity does not exist for farmers' wives, daughters, and children.

Profitability of using secondary treated wastewater for irrigation of fodder and cereal crops averages about US$-16 and 97/Donum/year[(14)] when including, and excluding, the unpaid labor, respectively. Profitability of using secondary treated wastewater for irrigation of fruit trees -citrus, apples, peaches, and apricots - averages about US$80 and 343/Donum/year, respectively, compared with that irrigated with fresh groundwater that averages about US$271 and 323/Donum/year, respectively. Profitability of using reclaimed wastewater that is blended with fresh surface water for irrigation of various vegetables averages about US$255 and 477/Donum/year, respectively, compared with that irrigated with fresh groundwater that averages about US$37 and 316/Donum/year, respectively, and that irrigated with fresh surface water that averages about US$-91 and 395/Donum/year, respectively. Thus, irrigation with reclaimed wastewater, especially when blended with fresh surface water, can yield similar, and sometimes better, profit to farmers when using freshwater irrigation. However, it appears that the level of knowledge of farmers and others on the benefits of reclaimed wastewater is still limited. Thus, the perception that couples cropping restriction with low value crops needs to be changed (see also 13).

26. *Viability of increasing the freshwater tariff as a tool to stimulate reuse*

If the existing tariffs of freshwater remain unchanged, reclaimed wastewater can be attractive only if given to farmers at a very low tariff or free of charge. The benefits of a rational increase of freshwater tariffs are threefold. First, it would increase the gap between the tariffs of freshwater and reclaimed wastewater making the latter more attractive. Second, it might help in water saving and release pressure on the groundwater resource. Third, it could be used as a financial resource to recover the investment costs of conveyance and distribution for reclaimed wastewater. The existing water (groundwater, surface water, blended water, secondary treated wastewater) tariffs have minor influence on agricultural profitability, mainly because these tariffs are very low. Increasing these tariffs by US$0.05/m^3 reduces

[14] One Donum = 1,000 m^2 = 0.1 ha.

farmers' profit by US$25-70/Donum/year. Increasing the existing water tariffs by US$0.10/$m^3$ would double the aforementioned reduction in farmers' profit. Such a reduction in agricultural profitability is crucial for some farmers and trivial for others. However, increasing the water tariffs beyond US$0.10/$m^3$ would make agricultural irrigation unfeasible and might enforce farmers to shift to using reclaimed wastewater if tariffs are maintained low and if its supply and quality are reliable. This incentive might be constrained by the fact that many farmers control their own facilities for meeting their water needs from surface as well as ground resources; energy prices are charged instead of water tariffs. In those cases, increasing the diesel/electricity prices and reducing subsidies remain questionable tools to stimulate less freshwater and more reclaimed-wastewater consumption.

Socio-cultural:

27. *Crop marketing systems and acceptance of public to buy crops*

Understanding how the crop marketing system operates is necessary since our study revealed that in reality the consumers often cannot distinguish between crops irrigated with freshwater and reclaimed wastewater. The existing system for crop marketing in which reclaimed-water crops are on offer together with freshwater crops is a good incentive to farmers to use reclaimed wastewater. Unfortunately, such marketing systems might tempt farmers to irrigate with raw sewage. Therefore, the crop marketing has to be monitored to safeguard public health. The effects of the presence on the market of reclaimed-water-irrigated crops needs further study. Nonetheless, the perception of public towards crops irrigated with reclaimed wastewater seems to be very positive. To improve the perception of public can be improved through awareness and education (see also 32).

The crop marketing systems and the high public acceptance to use reclaimed-wastewater crops are incentives for reuse, and, thus, the worries of farmers with this regard are not justified. Thus, more effort is needed to make farmers realize this incentive.

28. *Religious endorsement*

The attitudes of Islam can be considered as an incentive for irrigation with reclaimed wastewater. However, some farmers and rural dwellers are not aware of this and still conceive religion as an obstacle. Their perception may be changed through education, awareness, and religious teaching (see also 32).

29. *Psychological aversion towards wastewater*

Some farmers and crop consumers may express psychological aversion towards reclaimed wastewater and crops irrigated with this water, respectively. This aversion stems from cultural beliefs and origin of the irrigation water. Farmers who did not yet experience irrigation with reclaimed wastewater - those who don't know - are most likely to have negative prejudice. Thus, improving the quality of treated wastewater together with public awareness and education might overturn this disincentive. However, many of the interviewed farmers and crop consumers do not have a psychological aversion towards reuse, which is a good incentive.

30. *Land fragmentation*

The fast population growth and high demand for land have increased land value. Consequently, the area of land available for agriculture continuously decreases, especially in peri-urban areas. Simultaneously, urbanization opened up new job opportunities that compete with farming jobs. Besides, the traditional inheritance system in the Arabic/Islamic cultures causes progressive land fragmentation. It also encourages a reduction in the agricultural land acreage since some of the new landowners prefer to move to the cities leaving their land uncultivated or used for housing and other investment projects. The new landowners do not necessarily have the same attitudes and perceptions as the preceding generation.

31. *Concern for opinion of reference groups and public criticism*

Concern for opinion of reference groups and public criticism is a strong disincentive to some users of reclaimed wastewater and related crops. Although the influence of this disincentive is diminishing, it still exists and has to be taken into account. Farmers are mostly located in rural and peri-urban areas where the social and traditional ties are stronger than in urban areas. Therefore, farmers' attitudes and perceptions, and any changes thereof, tend to be strongly influenced by religion, culture, politics, and influential reference/peer groups within the society. Our study could tentatively identify three categories of reference groups to farmers and crop consumers: (i) community leaders that include religious preachers, clan leaders (*Hamolah Sheiks*), and local politicians, (ii) relatives, and (iii) friends.

32. *Awareness and attitude change*

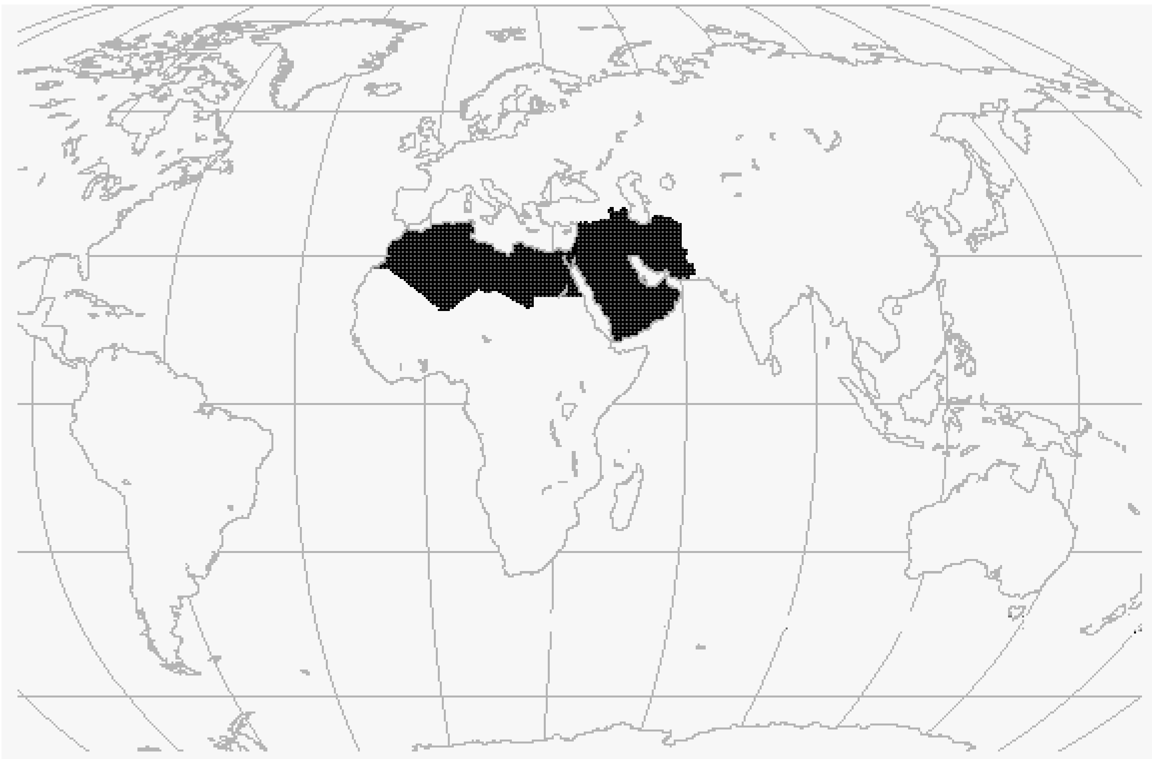
Farmers and crop consumers are very responsive to the various means of awareness if properly executed. These means include: TV, radio, newspapers, brochures, seminars, personal visits, and religious breaching. Proper execution of the awareness and educational programs entails: (i) use of easy language, (ii) well focused content, (iii) conducted by specialists who are esteemed by beneficiaries, and (iv) supported by demonstration of benefits and of proper management to mitigate risks.

8.4 The way forward?

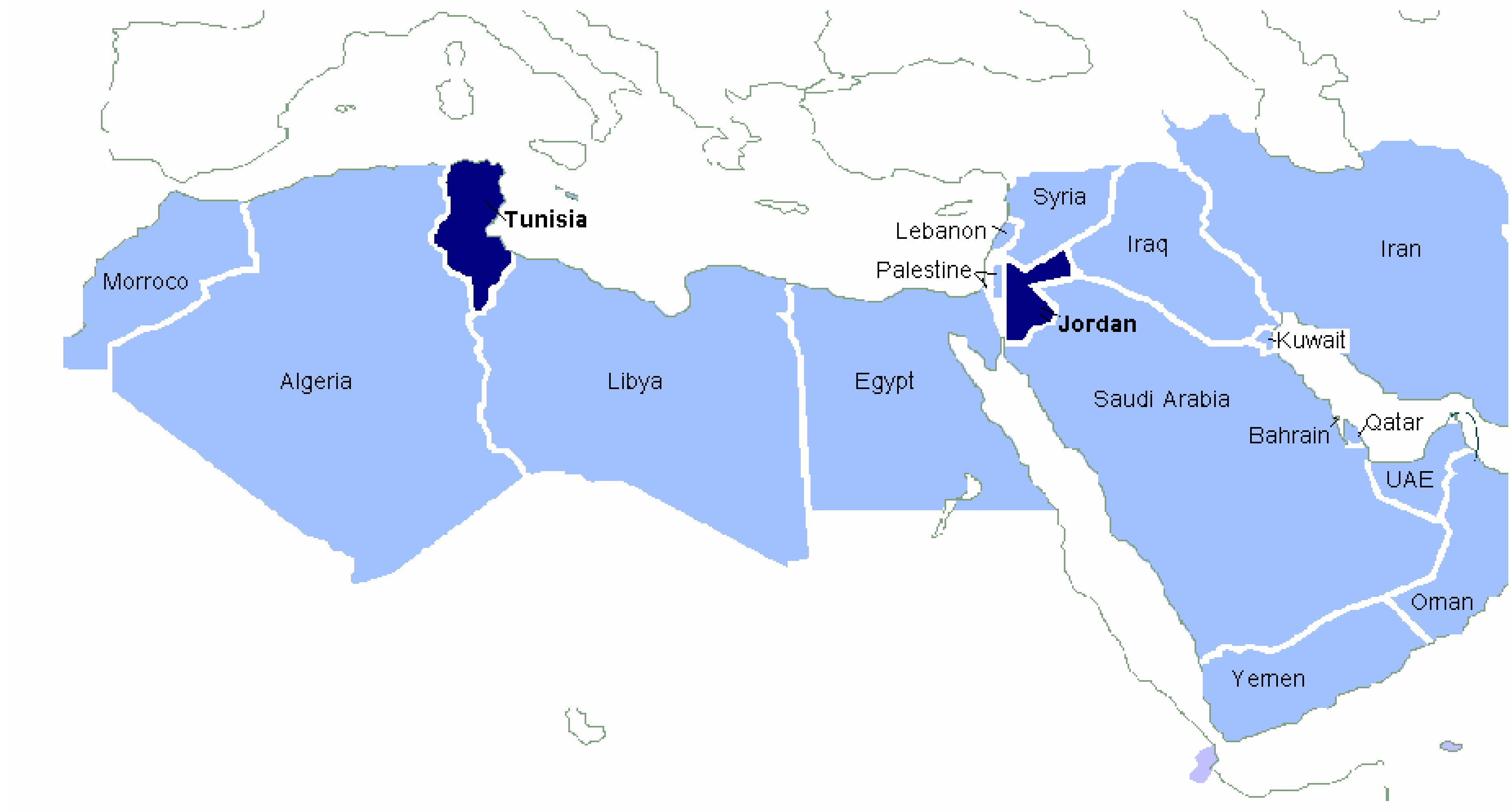
Maximization of wastewater reuse in irrigated agriculture implies analyzing the (dis)incentives that influence three pillars of wastewater utilization: collection, treatment, and reuse. In all countries of the MENA region, wastewater ***collection*** is well organized and reached reasonably high levels, which is driven by urbanization, environmental, and public health incentives. This suggests that these countries can potentially increase their Wastewater Reuse Index "*WRI*" to higher levels if they manage to treat and reuse the collected wastewater. Wastewater ***treatment*** can be improved by (i) adopting demand-driven approach instead of the existing supply-driven one, and integrating it with environmental and water resources strategies, (ii) allowing for technological innovations and experiencing new treatment systems in addition to the existing conventional ones, (iii) applying cost recovery policies that aim at generating more local funds and less reliance on donors, and (iv) institutional strengthening through availability of skilled personnel and incentives for those personnel to perform efficiently, and through better cooperation and distribution of responsibilities and amongst the involved institutions. On wastewater ***reuse***, the regulatory and socio-economic (dis)incentives are of great relevance in the shaping of the decisions of both the farmers– who have to buy the reclaimed water and apply certain agronomic approaches – and the public– that must decide whether to buy the crops watered with reclaimed wastewater. These (dis)incentives could be more influential than the technical ones. Wastewater reuse can be improved through raising the acceptance of farmers to use and willingness to pay for the reclaimed wastewater, which can be achieved by (i) providing reclaimed wastewater of acceptable quality for irrigated agriculture, (ii) minimizing the conveyance and distribution costs through constructing WWTPs near to agricultural lands with high water demand, (iii) developing local and broad guidelines for effluent quality to ease some of the restrictions and limitations on the application of reclaimed wastewater in irrigated agriculture, (iv) imposing restrictions on use of freshwater where the reclaimed-wastewater supplies can offset the agricultural demand, and (v) increasing the tariffs of pure freshwater to reflect its true scarcity, thus creating a stronger incentive for farmers to buy the reclaimed wastewater.

Annexes

Annex A: Maps



A.1: Global location of the MENA region



A.2: Countries of the MENA region

A.3: Country map of Jordan

A.4: Country map of Tunisia

Annex B: Development indicators

B.1: MENA development indicators

Indicator	*1997*	*2000*	*2001*
People			
Population, total	278.4 million	294.9 million	300.6 million
Population growth (annual %)	2.0	1.9	1.9
Life expectancy (years)	66.8	67.9	68.2
Fertility rate (births per woman)	3.7	3.4	3.3
Infant mortality rate (per 1,000 live births)	49.1	45.1	43.6
Under 5 mortality rate (per 1,000 children)	..	56.1	53.8
Child malnutrition, weight for age (% of under 5)	..	..	..
Child immunization, measles (% of under 12 mos)	88.3	91.5	92.3
Illiteracy total (% age 15 and above)	39.6	36.4	35.5
Illiteracy female (% of age 15 and above)	51.4	47.5	46.3
Primary completion rate, total (% age group)	..	..	..
Primary completion rate, female (% age group)	..	..	..
Net primary enrollment (% relevant age group)	..	82.2	..
Net secondary enrollment (% relevant age group)	..	..	..
Environment			
Surface area (sq. km)	11.1 million	11.1 million	11.1 million
Forests (1,000 sq. km)	..	167.6 thousand	..
Deforestation (average annual % 1990-2000)	..	-0.1	..
Water use (% of total resources)	..	1,413.0	..
CO2 emissions (metric tons per capita)	3.7	..	..
Access to improved water source (% of total pop.)	..	88.2	..
Access to improved sanitation (% of urban pop.)	..	93.9	..
Energy use per capita (kg of oil equivalent)	1,264.9	1,368.3	..
Electricity use per capita (kWh)	1,218.0	1,345.8	..
Economy			
GNI, Atlas method (US$)	573.3 billion	636.1 billion	668.6 billion
GNI per capita, Atlas method (US$)	2,060.0	2,160.0	2,220.0
GDP (US$)	608.0 billion	681.4 billion	698.4 billion
GDP growth (annual %)	2.8	4.2	3.0
Value added in agriculture (% of GDP)	..	..	..
Value added in industry (% of GDP)	..	..	..
Value added in services (% of GDP)	..	..	..
Exports of goods and services (% of GDP)	29.9	34.1	33.8
Imports of goods and services (% of GDP)	27.7	25.6	27.3
Gross capital formation (% of GDP)	20.4	21.6	22.3
Technology and infrastructure			
Fixed lines and mobile telephones (per 1,000 people)	75.0	122.7	153.2
Telephone average cost of local call (US$ per three minutes)	0.0	0.0	0.0
Personal computers (per 1,000 people)	18.4	29.0	32.0
Internet users	216.4 thousand	2.4 million	3.4 million
Paved roads (% of total)	54.6	..	..
Aircraft departures	408.8 thousand	442.9 thousand	436.7 thousand
Trade and finance			
Trade in goods as a share of GDP (%)	46.4	50.3	45.4
Trade in goods as a share of goods GDP (%)	76.6	82.2	78.5
High-technology exports (% of manufactured exports)	..	3.6	..
Foreign direct investment, net inflows in reporting country (US$)	6.2 billion	2.5 billion	5.5 billion
Total debt service (% of exports of goods and services)	13.3	10.1	9.5
Short-term debt outstanding (US$)	41.3 billion	46.5 billion	47.4 billion
Aid per capita (US$)	19.6	15.5	16.1

Source: The World Bank, World Development Indicators database, April 2003

B.2: Jordan development indicators

Indicators	***1997***	***2000***	***2001***
People			
Population, total	4.5 million	4.9 million	5.0 million
Population growth (annual %)	3.1	2.9	2.8
Life expectancy (years)	70.8	71.5	71.7
Fertility rate (births per woman)	3.9	3.7	3.6
Infant mortality rate (per 1,000 live births)	29.8	28.0	27.0
Under 5 mortality rate (per 1,000 children)	..	34.0	33.0
Births attended by skilled health staff (% of total)	96.7	..	..
Illiteracy total (% age 15 and above)	12.1	10.2	9.7
Illiteracy female (% of age 15 and above)	18.6	15.7	14.9
Environment			
Surface area (sq. km)	89,210.0	89,210.0	89,210.0
Forests (1,000 sq. km)	..	860.0	..
Deforestation (average annual % 1990-2000)	..	0.0	..
Water use (% of total resources)	..	143.0	..
CO_2 emissions (metric tons per capita)	3.2	..	..
Access to improved water source (% of total pop.)	..	96.0	..
Access to improved sanitation (% of urban pop.)	..	100.0	..
Energy use per capita (kg of oil equivalent)	1,073.7	1,061.1	..
Electricity use per capita (kWh)	1,164.8	1,236.4	..
Economy			
GNI, Atlas method (US$)	7.1 billion	8.4 billion	8.8 billion
GNI per capita, Atlas method (US$)	1,590.0	1,720.0	1,750.0
GDP (US$)	7.3 billion	8.5 billion	8.8 billion
GDP growth (annual %)	3.1	4.0	4.2
GDP implicit price deflator (annual % growth)	1.1	-0.1	0.3
Value added in agriculture (% of GDP)	3.3	2.2	2.1
Value added in industry (% of GDP)	25.2	24.8	24.7
Value added in services (% of GDP)	71.6	73.0	73.2
Exports of goods and services (% of GDP)	48.8	41.8	44.2
Imports of goods and services (% of GDP)	70.8	68.6	69.0
Gross capital formation (% of GDP)	25.5	27.2	25.9
Current revenue, excluding grants (% of GDP)	25.3	25.1	25.1
Overall budget balance, including grants (% of GDP)	-3.1	-2.0	-2.5
Technology and infrastructure			
Fixed lines and mobile telephones (per 1,000 people)	79.9	200.2	294.5
Telephone average cost of local call (US$ per three minutes)	0.0	0.0	0.0
Personal computers (per 1,000 people)	8.7	29.8	32.8
Internet users	27,354.0	127.3 thousand	212.0 thousand
Paved roads (% of total)	..	..	..
Aircraft departures	16,700.0	16,400.0	15,900.0
Trade and finance			
Trade in goods as a share of GDP (%)	81.1	76.2	80.8
Trade in goods as a share of goods GDP (%)	214.0	201.1	224.2
High-technology exports (% of manufactured exports)	5.6	7.8	6.9
Foreign direct investment, net inflows in reporting country (US$)	360.9 million	786.6 million	100.3 million
Short-term debt outstanding (US$)	743.3 million	705.7 million	447.1 million
Aid per capita (US$)	103.7	113.0	85.8

Source: The World Bank, World Development Indicators database, April 2003

B.3: Tunisia development indicators

Indicators	*1997*	*2000*	*2001*
People			
Population, total	9.2 million	9.6 million	9.7 million
Population growth (annual %)	1.3	1.1	1.2
Life expectancy (years)	71.9	72.1	72.4
Fertility rate (births per woman)	2.4	2.1	2.1
Infant mortality rate (per 1,000 live births)	27.6	25.8	21.0
Under 5 mortality rate (per 1,000 children)	33.0	29.0	27.0
Births attended by skilled health staff (% of total)	..	89.9	..
Illiteracy total (% age 15 and above)	32.8	29.0	27.9
Illiteracy female (% of age 15 and above)	43.8	39.4	38.1
Environment			
Surface area (sq. km)	163.6 thousand	163.6 thousand	163.6 thousand
Forests (1,000 sq. km)	..	5,100.0	..
Deforestation (average annual % 1990-2000)	..	-0.2	..
Water use (% of total resources)	..	481.0	..
CO_2 emissions (metric tons per capita)	1.8	..	..
Access to improved water source (% of total pop.)	..	80.0	..
Access to improved sanitation (% of urban pop.)	..	96.0	..
Energy use per capita (kg of oil equivalent)	751.6	824.8	..
Electricity use per capita (kWh)	783.0	938.9	..
Economy			
GNI, Atlas method (US$)	19.2 billion	20.1 billion	20.0 billion
GNI per capita, Atlas method (US$)	2,080.0	2,100.0	2,070.0
GDP (US$)	18.9 billion	19.5 billion	20.0 billion
GDP growth (annual %)	5.4	4.7	4.9
GDP implicit price deflator (annual % growth)	4.0	2.4	2.8
Value added in agriculture (% of GDP)	13.2	12.3	11.6
Value added in industry (% of GDP)	28.6	28.8	28.9
Value added in services (% of GDP)	58.2	58.9	59.5
Exports of goods and services (% of GDP)	43.8	44.0	47.6
Imports of goods and services (% of GDP)	46.2	47.6	51.6
Gross capital formation (% of GDP)	26.4	27.4	27.5
Current revenue, excluding grants (% of GDP)	28.7	28.6	..
Overall budget balance, including grants (% of GDP)	-3.6	-2.6	..
Technology and infrastructure			
Fixed lines and mobile telephones (per 1,000 people)	71.6	112.1	149.0
Telephone average cost of local call (US$ per three minutes)	0.0	0.0	0.0
Personal computers (per 1,000 people)	8.7	22.9	23.7
Internet users	4,000.0	250.0 thousand	400.0 thousand
Paved roads (% of total)	78.9	64.8	..
Aircraft departures	17,200.0	19,900.0	19,400.0
Trade and finance			
Trade in goods as a share of GDP (%)	71.3	74.1	80.8
Trade in goods as a share of goods GDP (%)	170.7	180.2	199.6
High-technology exports (% of manufactured exports)	1.6	3.4	..
Foreign direct investment, net inflows in reporting country (US$)	339.1 million	752.2 million	457.4 million
Short-term debt outstanding (US$)	1.5 billion	908.7 million	681.8 million
Aid per capita (US$)	21.0	23.3	39.0

Source: The World Bank, World Development Indicators database, April 2003

B.4: Water availability and usage in the MENA region

Country	*Annual renewable resources (x 10^9 m^3)*	*Per capita renewable availability in 1995 (m^3)*	*Annual withdrawals*		*Water usage (%)*		
			(x 10^9 m^3)	*% of annual renewable resources*	*Domestic*	*Industry*	*Agriculture*
Algeria	18.4	655	3.0	16	22	4	*74*
Bahrain	-	-	0.2	-	60	36	*4*
Egypt	58.0	1,005	56.3	97	7	5	*88*
Iraq	104.0	4,952	43.9	42	3	5	*92*
Israel	2.1	375	1.9	90	16	5	*79*
Jordan	0.8	213	1.0	125	20	5	*75*
Kuwait	-	-	-	-	64	32	*4*
Lebanon	4.8	1,200	0.8	17	11	4	*85*
Libya	0.7	130	2.8	400	15	10	*75*
Morocco	30.0	1,083	11.0	37	6	3	*91*
Oman	2.0	1,053	1.3	65	3	3	*94*
Palestine	0.2	105	0.2	100	12	13	*75*
Qatar	0.02	-	0.15	750	36	26	*38*
Saudi Arabia	2.2	118	3.6	164	45	8	*47*
Syria	5.5	385	3.3	60	7	10	*83*
Tunisia	4.4	489	3.0	68	13	7	*80*
U.A. Emirates	0.3	167	0.4	133	11	9	*80*
Yemen	3.0	176	3.9	130	5	2	*93*
Total MENA	*355*	*1,250*	*183*	*52*	*6*	*7*	*87*

Source: World Bank (1996).

B.5: Worldwide net renewable water distribution by region and per capita

Regions	*Net annual renewable water resources (million m^3)*	*Population (million)*	*Per capita (m^3)*
Oceania	769	21	36,619
Latin America	10,766	466	23,103
North America	5,379	287	18,742
Eastern Europe & Central Asia	7,256	495	14,659
Africa	4,184	559	7,485
Western Europe	1,985	383	5,183
Asia	9,985	3,041	3,283
*MENA **	*355*	*284*	*1,250*

* Totals may not add due to rounding.
Source: World Bank (1996).

Annex C: Characteristics of the surveyed wastewater treatment plants

C.1: WWTPs in Tunisia (2000)

No.	*WWTP*	*Year of operation*	*Treatment system*	*Design capacity (m^3/d)*	*Inflow average in 2000 (m^3/d)*
1	*Cherguia*	1958	AS	60,000	40,540
2	*Cotiere Nord*	1981	L	15,750	16,673
3	*Choutrana*	1986	AS	111,000	111,720
4	*Kalaat El Andalos*	1994	AL	1,500	379
5	*Sud Meliane*	1982	OD	37,500	41,780
6	*Rades*	1976	L	700	1,233
7	*SE1 Hammamet*	1980	AS	4,208	3,606
8	*SE2 Hammamet*	1980	AS	5,146	2,110
9	*Hammamet Sud*	1995	EA	11,386	5,076
10	*SE3 Nabeul*	1981	OD	3,500	2,301
11	*SE4 Nabeul*	1979	AS	9,585	8,731
12	*Kelibia*	1976	AS	7,742	3,424
13	*Soliman*	1983	OD	2,457	2,432
14	*Grombalia*	1993	OD	2,445	2,165
15	*Menzel Bozelfa*	1993	OD	1,395	2,791
16	*Beja*	1994	EA	14,000	7,262
17	*Mejdez El Bab*	1994	EA	4,500	933
18	*Teboursouk*	2000	OD	1,280	1,125
19	*Siliana*	2000	EA	4,530	2,263
20	*Bizerte*	1997	EA	26,600	4,360
21	*Menzel Borguiba*	1997	EA	11,065	3,980
22	*Jendouba*	1994	EA	8,000	4,044
23	*Kef*	1998	EA	8,500	3,896
24	*Tabarka*	1993	EA	5,500	2,110
25	*Sousse Nord*	1978	AS	17,400	18,079
26	*Sousse Sud*	1980	AS	18,700	19,058
27	*Sidi Bou Ali*	1996	L + Duckweed	644	385
28	*Msaken*	1996	EA	7,844	3,430
29	*Kalaa Sghira*	1993	OD	1,450	739
30	*Monastir El Ghadir*	1962	TF	2,600	2,576
31	*Dkhila*	1979	AS	3,100	2,773
32	*Moknine*	1986	L	6,400	5,011
33	*Jemmel*	2000	EA	6,700	2,163
34	*Wardanin*	1993	OD	1,500	1,051
35	*Sahline*	1993	OD	2,560	3,001
36	*Sayada*	1993	OD	1,660	1,626
37	*Ksour Essef*	1994	OD	1,500	669
38	*El Jem*	1994	L	1,840	1,027
39	*Mahdia*	1995	AL	10,220	3,550
40	*Monastir Frina*	1995	EA	13,500	4,577
41	*Kairouan*	1979	EA	12,000	12,154
42	*Kasserine*	1994	AL	15,000	3,500
43	*Sidi Bou Zid*	1994	L	3,125	1,756
44	*Sfax*	1983	AL	24,000	23,915
45	*Mahres*	1994	OD	780	601
46	*Gafsa*	1985	L	3,500	6,592
47	*Nefta*	1992	OD	1,335	1,114
48	*Tozeur*	2000	EA	5,324	1,689
49	*Houmt Essouk*	1991	AL	3,500	1,724
50	*Dar Jerba*	1972	AS	1,600	4,186
51	*Dar Jerba Modulaire*	1995	EA	420	537
52	*Sidi Mehrez*	1981	AL	4,000	3,991
53	*Sidi Slim*	1971	AS	1,800	4,891
54	*Tanit*	1971	TF	260	111
55	*Zarzis Souihel*	1980	AS	1,108	118
56	*Lella Meriam*	1982	AL	1,726	797
57	*Zarzis Ville*	1992	OD	1,335	569
58	*Medenine*	2000	EA	8,870	748
59	*Tatouine*	1999	EA	5,430	1,171
60	*Gabes*	1995	EA	17,300	12,055

C.2: WWTPs in Jordan (1999)

No.	*WWTP*	*Year of operation*	*Treatment system*	*Design capacity (m^3/d)*	*Inflow average in 1999 (m^3/d)*
1	*Abu Nuseir*	1986	OD + RBC	4,000	1,411
2	*Al-Samra*	1985	L	68,000	166,844
3	*Aqaba*	1987	L	9,000	8,774
4	*Baq'a*	1988	TF	6,000	10,284
5	*Central Irbid*	1987	TF + AS	11,023	4,612
6	*Fuheis*	1997	AS	2,400	1,019
7	*Jerash*	1983	EA	3,500	1,603
8	*Karak*	1988	TF	786	1,146
9	*Kufranja*	1989	TF	1,900	1,734
10	*Ma'an*	1989	L	1,590	1,738
11	*Madaba*	1989	L	2,000	3,609
12	*Mafraq*	1988	L	1,800	1,933
13	*Ramtha*	1987	L	1,920	2,174
14	*Salt*	1981	EA	7,600	3,166
15	*Tafila*	1988	TF	800	851
16	*Wadi Seer*	1997	L + aeration	4,000	5,993
17	*Wadi Arab*	1999	AS	22,000	914

AS: activated sludge; OD: oxidation ditch; EA: extended aeration; AL: aerated lagoon; L: lagoon; RBC: rotating biological contactor; TF: trickling filter.

C.2.1: Mafraq lagoons system

Parameter	*Unit*	*Rainy*						*Dry*						*Average*
		Nov	*Dec*	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	
Inf. avg. flow	m^3/d	1,679	1,522	1,906	1,643	1,924	2,232	2,644	2,545	2,139	2,186	1,481	1,291	***1,932.7***
Eff. avg. flow	m^3/d	1,679	1,522	1,406	1,369	1,424	2,032	2,644	2,545	1,760	1,762	1,481	1,613	***1,769.8***
pH inf.	-													
pH eff.	-													
Irrigation	m^3/d	1,679	1,272	956	1,369	1,424	1,488	2,211	2,040	1,760	1,762	1,956	1,613	***1,627.5***
Avg. inf. temp	^oC	14.2	9.2	6.6	6	10	19.9	19	20	21	21	19.9	19	***15.5***
Avg. eff. temp	^oC													
TDS inf.	mg/l	908	880	880	4	1,104	1,232	996	1,542	2,303	1,046	996	1,104	***1,082.9***
TDS eff.	mg/l	1,054	1,432	1,070		1,056	1,258	1,448	1,850	1,865	966	1,066	1,058	***1,283.9***
TSS inf.	mg/l	164	310	310		748	1,014	808	219	411	250	260	166	***423.6***
TSS eff.	mg/l	27	379	255		270	176	395	159	243	158	606	72	***249.1***
BOD_5 inf.	mg/l	512	232	232		673	1,734	632	292	508	409	495	510	***566.3***
BOD_5 eff.	mg/l	128	133	108		372	282	443	118	165	135	159	134	***197.9***
COD inf.	mg/l	901	436	715		1,193	2,971	1,228	1,749	1,610	2,097	1,168	868	***1,357.8***
COD eff.	mg/l	420	760	436		731	681	800	486	391	369	238	461	***524.8***
PO_4 inf.	mg/l													
PO_4 eff.	mg/l	0.2	68	98			6.5	1.1	15.5	25			13.6	***28.5***
NH_4-N inf.	mg/l													
NH_4-N eff.	mg/l	129	135				110	34		142	125		101	***110.9***
NO_3-N inf.	mg/l													
NO_3-N eff.	mg/l	0.72	2.5				1.9	91.5		0.55		127.5	0	***32.1***

C.2.2: Madaba lagoons system

Parameter	*Unit*	*Rainy*						*Dry*						*Average*
		Nov	*Dec*	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	
Inf. avg. flow	m^3/d	3,910	3,910	3,148	3,088	3,007	3,153	3,315	3,884	4,013	3,968	3,977	3,929	***3,608.5***
Eff. avg. flow	m^3/d	2,684	2,548	1,808	1,754	1,794	1,816	3,013	3,613	3,652	3,794	3,655	3,368	***2,791.6***
pH inf.	-			7.9			7.2						9.5	***8.2***
pH eff.	-			8.2			8.3						7.4	***8.0***
Irrigation	m^3/d	2,684	2,548	1,462	1,263	1,355	1,816	3,013	3,613	3,652	3,794	3,655	3,368	***2,685.3***
Avg. inf. temp	^oC													
Avg. eff. temp	^oC													
TDS inf.	mg/l	3,132	1,126	1,704	1,652	1,892	1,464	1,620		1,370	1,592	1,170	706	***1,584.4***
TDS eff.	mg/l	1,424	1,174	1,886	1,392	1,382	1,528	1,438		1,570	1,550	1,182	1,302	***1,438.9***
TSS inf.	mg/l	1,029	617	746	7,648	1,360	1,512	823		930	784	1,009	1,771	***1,657.2***
TSS eff.	mg/l	276	100	148	163	186	375	255		258	354	271	244	***239.1***
BOD_5 inf.	mg/l	642	1,088	979	5,308	1,226	2,380	948		707	892	1,035		***1,520.5***
BOD_5 eff.	mg/l	252	226	444	349	358	274	83		272	399	448		***310.5***
COD inf.	mg/l	2,785	1,933	1,951	14,625	7,812	4,690	7,934		2,303	2,169	2,360	2,509	***4,642.8***
COD eff.	mg/l	902	615	697	688	810	524	789		295	932	889	698	***712.6***
PO_4 inf.	mg/l		20	79	59		66.7	22.9		22.5	42	25.5	252.5	***65.6***
PO_4 eff.	mg/l	17.3	22.2	106	66.6		23.5	16.7		16	20	60	26.2	***37.5***
NH_4-N inf.	mg/l		96.5	78	119		115.5	77			222	81.5	92	***110.2***
NH_4-N eff.	mg/l	96.5	111.5	64	182		107.5	108		130	105	86.5	96	***108.7***
NO_3-N inf.	mg/l			4.1			0.8	0.6					0.2	***1.4***
NO_3-N eff.	mg/l	0.8	0.4	22			2	0.5			0.15	0.4	0.4	***3.3***

C.2.3: Ramtha lagoons system

Parameter	*Unit*	*Rainy*						*Dry*						*Average*
		Nov	*Dec*	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	
Inf. avg. flow	m^3/d	1,982	2,030	2,463	2,695	2,441	2,190	2,290	2,339	2,051	1,743	1,973	1,889	***2,173.8***
Eff. avg. flow	m^3/d	1,712	1,740	2,246	2,386	2,157	1,884	1,989	2,092	1,867	1,658	1,735	1,607	***1,922.8***
pH inf.	-	7.13	7.43											***7.3***
pH eff.	-	7.14	8.01											***7.6***
Irrigation	m^3/d	1,712	1,740	2,246	2,384	2,157	1,884	1,989	2,092	1,867	1,658	1,735	1,607	***1,922.6***
Avg. inf. temp	^oC													
Avg. eff. temp	^oC													
TDS inf.	mg/l	1,585	1,128	1,202				1,590	1,790	2,600	1,438		1,707	***1,630.0***
TDS eff.	mg/l	1,215	698	1,082			1,902	1,777	1,780	2,178	1,459		1,821	***1,545.8***
TSS inf.	mg/l	432	609	1,700	912	1,449	955	951	1,301	712	924		656	***963.7***
TSS eff.	mg/l	189	164	1,254	370	240	383	272	240	290	317		254	***361.2***
BOD_5 inf.	mg/l	934	954	943	1,056	2,719	1,617	1,041	1,142	810	1,011		903	***1,193.6***
BOD_5 eff.	mg/l	222	202	285	316	298	373	191	198	166	163		217	***239.1***
COD inf.	mg/l	1,551	1,964	2,835	2,234	4,225	2,551	2,637	1,645	1,647	2,488		1,357	***2,284.9***
COD eff.	mg/l	546	487	745	390	548	377	592	501	588	627		541	***540.2***
PO_4 inf.	mg/l													
PO_4 eff.	mg/l	30	20				52		68	51	44		39	***43.4***
NH_4-N inf.	mg/l													
NH_4-N eff.	mg/l	35	23				24		28	35	27		33	***29.3***
NO_3-N inf.	mg/l													
NO_3-N eff.	mg/l													

C.2.4: Aqaba lagoons system

Parameter	*Unit*	*Rainy*						*Dry*						*Average*
		Nov	*Dec*	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	
Inf. avg. flow	m^3/d	8,461	7,814	7,784	7,764	8,633	8,925	9,246	9,314	9,051	9,339	9,642	9,313	***8,774***
Eff. avg. flow	m^3/d	6583	5949	6306	6077	6814	6503	6613	6632	5989	6534	7131	7162	***6524***
pH inf.	-	7	7	7	7.1	7	6.9	6.9	6.9	6.9	7	7	7	***7***
pH eff.	-	7.9	7.5	7.5	7.5	7.5	7.5	7.6	7.5	7.6	7.7	7.6	7.8	***8***
Irrigation	m^3/d	3,000	3,000	2,000	2,000	2,000	2,500	600	2,500	2,500	2,500	3,000	3,500	***2,425***
Avg. inf. temp	^oC	27.4	19.8	8	18.5	21.7	21.9	24.4	31.2	32	29	23	22	***23***
Avg. eff. temp	^oC	19.6	16.7	15	15.4	18.8	19.8	21.1	26.1	26.9	25.7	21.8	17.8	***20***
TDS inf.	mg/l	200	898	902	904	820	864	844	790	798	743	674	725	***764***
TDS eff.	mg/l	751	951	934	493	870	889	945	896	996	1,007	915	896	***879***
TSS inf.	mg/l	196	280	326	360	275	300	280	260	257	283	196	183	***266***
TSS eff.	mg/l	373	180	393	493	670	486	480	480	255	253	273	276	***384***
BOD_5 inf.	mg/l	305	380	370	427	330	399	343	333	327	476	310	239	***353***
BOD_5 eff.	mg/l	97	90	127	152	170	129	116	156	94	82	65	51	***111***
COD inf.	mg/l	815	654	1,059	855	900	885	757	1,036	1,066	902	1,117	785	***903***
COD eff.	mg/l	352	302	413	474	577	469	438	576	340	307	363	270	***407***
PO_4 inf.	mg/l													
PO_4 eff.	mg/l													
NH_4-N inf.	mg/l	70	68	68	85	62	66	66	60	62	56	41	56	***63***
NH_4-N eff.	mg/l	43	55	60	60	43	70	73	60	60	53	41	58	***56***
NO_3-N inf.	mg/l													
NO_3-N eff.	mg/l													

C.2.5: Al-Samra lagoons system

Parameter	*Unit*	*Rainy*						*Dry*						*Average*
		Nov	*Dec*	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	
Inf. avg. flow	m^3/d	158,317	161,426	168,101	170,012	170,000	168,534	165,000	161,991	169,738	176,536	170,275	162,196	***166,844***
Eff. avg. flow	m^3/d	148,312	151,688	148,664	145,460	146,980	141,300	140,267	139,048	143,148	140,632	144,290	150,267	***145,005***
Avg. inf. temp	^oC	22.4	18.8	17.3	17	18.1	20	24.6	26.1	27.2	28.4	27.3	25.7	***23***
Avg. eff. temp	^oC	15.9	11.4	11.1	12.4	15	18.5	23.2	25.5	25.8	26.6	24.5	21.6	***19***
pH inf.	-	6.9	7.3	6.9	7.1	7	6.9	6.9	6.9	6.9	6.6	6.71	6.9	***7***
pH eff.	-	7.95	8.25	7.9	8	8.1	8	8	7.8	7.7	7.83	7.7	7.9	***8***
TDS inf.	mg/l	1,347	1,680	1,238	1,088	1,298	1,116	1,272	1,282	1,220	1,216	1,352	1,138	***1,271***
TDS eff.	mg/l	1,292	1,276	1,216	1,112	1,180	1,188	1,242	1,314	1,334	1,334	1,350	1,256	***1,258***
TSS inf.	mg/l	691	477	529	553	434	488	480	463	520	561	598	746	***545***
TSS eff.	mg/l	122	109	84	122	78	47	64	128	146	152	148	154	***113***
BOD_5 inf.	mg/l	990	725	659	793	701	843	751	696	750	730	748	730	***760***
BOD_5 eff.	mg/l	111	118	145	161	145	149	95	92	96	102	92	106	***118***
COD inf.	mg/l	2,200	1,858	1,630	1,765	1,804	2,105	2,052	1,600	1,810	1,830	1,912	1,806	***1,864***
COD eff.	mg/l	476	519	557	508	590	544	502	540	480	432	403	376	***494***
SO_4 inf.	mg/l	130	527	141	121	119	90	129	95	69	75	87	108	***141***
SO_4 eff.	mg/l	29	19	40	34	27	16	22	32	33	33	38	47	***31***
PO_4- P eff.	mg/l			18.8	16.1	13.4			19.7		19.8		17	***17***
NH_4-N inf.	mg/l	75	67	75	87	85	83	74	77	72	74	69	77	***76***
NH_4-N eff.	mg/l	88	93	94	94	96	99	94	76	72	72	74	78	***86***
NO_3-N eff.	mg/l	3.1	1.7	0.21	<0.25	<0,25	<0.25	0.27	8.3	8.4	10.9	5	1.5	***4***
Total-P inf.	mg/l	17.3		14.5	16.5	11	16	15	15.8	20	13.5	13.6	28	***16***
Total-P eff.	mg/l	23.6		21.3	17.4	15	25	20	22.1	84	20.7	14.6	20	***26***
HCO_3 eff.	mg/l	897			859		946	952	824	804	782		860	***866***
Ca eff.	mg/l		117		89		84		107		95		96	***98***
B inf.	mg/l		1.14	0.5	0.42	0,4			0.45		0.54		0.52	***1***
B eff.	mg/l		0.71	0.6	0.63	0.57			0.7		0.77		0.67	***1***
Cl^- inf.	mg/l		290	356	282	378	307		349		349		300	***326***
Cl^- eff.	mg/l		384	349	323	339	374		401		434		415	***377***
SAR eff.	mg/l				5.47		5.39		6.3		6.75		6.4	***6***
TC eff.	MPN	340,000	95,000	190,000	110,000	23,000	830,000	34,000	16,000	23,000	13,200	14,750	14,000	***141,913***
TFC eff.	MPN	23,000	76,000	91,000	93,000	11,000	380,000	1,000	16,000	220,000	5,800	10,000	8,000	***77,900***

C.2.6: Abu-Nuseir activated sludge system

Parameter	*Unit*	*Rainy*						*Dry*						*Average*
		Nov	*Dec*	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	
Inf. avg. flow	m^3/d	1,255	1,379	1,356	1,436	1,466	1,410	1,513	1,512	1,506	1,612	1,206	1,275	***1,411***
Eff. avg. flow	m^3/d	1,230	1,354	1,335	1,410	1,446	1,400	1,500	1,492	1,486	1,596	1,184	1,255	***1,391***
pH inf.	-	8	7		6.6	7.4	7.4	7.2	7.8	8.1	8	7.8	8	***8***
pH eff.	-	7.7	7.5		6.5	6.4	6.4	7.4	7.5	7.1	7.5	8.1	8	***7***
Avg. inf. temp	$^o/C$	20	17	10				12	12	23	24	25	21	***18***
Avg. eff. temp	$^o/C$	19	15	8				14	14	25	23	23	22	***18***
TDS inf.	mg/l	1,080	1,143		1,032	998	1,099	660	1,230	1,220	1,210	1,225	1,143	***1,095***
TDS eff.	mg/l	788	767		908	1126	838	510	890	885	850	778	717	***823***
TSS inf.	mg/l	618	595	630	620	500	585	540	600	625	634	654	612	***601***
TSS eff.	mg/l	27	30	31	28	26	32	29	27	32		27	26	***29***
BOD_5 inf.	mg/l	618	605	600	725	620	720	580	600	656	625	655	609	***634***
BOD_5 eff.	mg/l	21	25	17	4	5	22	14	14	19	18	22	22	***17***
COD inf.	mg/l	1,100	1,042	920	1,407	1,990	1,767	950	1,133	1,104	1,100	1,175	1,107	***1,233***
COD eff.	mg/l	82	78	66	64	135	73	63	65	65	72	93	87	***79***
PO_4 inf.	mg/l													
PO_4 eff.	mg/l													
NH_4-N inf.	mg/l													
NH_4-N eff.	mg/l													
NO_3-N inf.	mg/l													
NO_3-N eff.	mg/l													

C.2.7: Jerash activated sludge system

Parameter	*Unit*	*Rainy*						*Dry*						*Average*
		Nov	*Dec*	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	
Inf. avg. flow	m^3/d	1,665	1,653	1,975	1,979	1,901	1,676	1,588	1,348	1,448	1,332	1,318	1,358	***1,603.4***
Eff. avg. flow	m^3/d	1,562	1,504	1,880	1,809	1,779	1,554	1,472	1,299	1,324	1,227	1,191	1,256	***1,488.1***
pH inf.	-	7.08	7.9	7.07	7.09	7.08	7.4	7.07	7.18	7.05	7.09	7.08	7.03	***7.2***
pH eff.	-	7.62	8	7.42	7.5	7.52	7.5	7.55	7.5	7.66	7.44	7.11	7.9	***7.6***
Avg. inf. temp	^oC													
Avg. eff. temp	^oC													
TDS inf.	mg/l	1,207	1,127	1,215	1,227	1,288	1,095	1,288	1,204	1,255	1,223		1,241	***1,215.5***
TDS eff.	mg/l	1,168	1,155	1,027	969	1,021	1,121	1,166	1,088	1,103	1,088	1,593	1,083	***1,131.8***
TSS inf.	mg/l	902	978	987	954	1,022	911	923	821	921	887	1,138	866	***942.5***
TSS eff.	mg/l	60	60	73	65	68	59	71	68	62	61	110	62	***68.3***
BOD_5 inf.	mg/l	1,124	1,096	1,077	1,098	1,128	938	1,203	1,066	1,232	1,144	1,299	1,023	***1,119.0***
BOD_5 eff.	mg/l	32	40	33	31	30	30	35	30	33	36	34	28	***32.7***
COD inf.	mg/l	2,457	2,134	2,273	2,303	2,278	2,246	2,644	2,473	3,022	3,077	2,759	2,615	***2,523.4***
COD eff.	mg/l	115	115	120	123	118	148	133	118	116	115	142	107	***122.5***
PO_4 inf.	mg/l													
PO_4 eff.	mg/l													
NH_4-N inf.	mg/l													
NH_4-N eff.	mg/l						210							***210.0***
NO_3-N inf.	mg/l													
NO_3-N eff.	mg/l													

C.2.8: Fuheis activated sludge system

Parameter	*Unit*	*Rainy*						*Dry*						*Average*
		Nov	*Dec*	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	
Inf. avg. flow	m^3/d	1,012	1,000	894	1,079	1,001	948	920	994	1,087	1,129	1,093	1,073	***1,019.2***
Eff. avg. flow	m^3/d	1,000	980	860	1,040	960	918	900	970	1,050	1,100	1,060	1,053	***990.9***
pH inf.	-			7.6	7.6									***7.6***
pH eff.	-			7.9	7.9									***7.9***
Avg. inf. temp	^oC													
Avg. eff. temp	^oC													
TDS inf.	mg/l			800	800		917		825	884				***845.2***
TDS eff.	mg/l			710	710		838		519	568				***669.0***
TSS inf.	mg/l	557	529	1,330	1,330	349	530	844	578	724	640	617	612	***720.0***
TSS eff.	mg/l	20	21	20	20	8	29	10	21	20	30	29	24	***21.0***
BOD_5 inf.	mg/l	626	610	602	602	503	825	610	765	758	779	736	708	***677.0***
BOD_5 eff.	mg/l	14	9	6	6	6	5	13	12	17	13	18	15	***11.2***
COD inf.	mg/l			1,770	1,770				2,068	1,209	1,220	1,275		***1,552.0***
COD eff.	mg/l			43	43				161	73	49	60		***71.5***
PO_4 inf.	mg/l													
PO_4 eff.	mg/l			14	14									***14.0***
NH_4-N inf.	mg/l													
NH_4-N eff.	mg/l			0.12	0.12									***0.1***
NO_3-N inf.	mg/l													
NO_3-N eff.	mg/l													

C.2.9: Salt activated sludge system

Parameter	Unit	*Rainy*						*Dry*						*Average*
		Nov	*Dec*	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	
Inf. avg. flow	m^3/d	2,886	2,955	2,800	2,100	2,784	2,970	3,850	3,700	3,553	3,356	3,366	3,666	***3,165.5***
Eff. avg. flow	m^3/d	2,840	2,888	2,750	2,550	2,599	2,750	3,550	3,620	3,488	3,288	3,288	3,200	***3,067.6***
pH inf.	-													
pH eff.	-													
Avg. inf. temp	^oC	15	10	10	10	16	15	15	18	20	16	18	20	***15.3***
Avg. eff. temp	^oC	15	10	11	11	15	13	14	18	20	16	17	19	***14.9***
TDS inf.	mg/l	871	770	864	857	929	695	771	855	740	822	857	846	***823.1***
TDS eff.	mg/l	670	572	627	704	732	652	627	715	684	655	626	725	***665.8***
TSS inf.	mg/l	842	803	870	865	844	850	859	770	818	783	816	819	***828.3***
TSS eff.	mg/l	12	10	11	9	8	10	11	11	14	24	19	18	***13.1***
BOD_5 inf.	mg/l	839	882	800	800	860	708	848	844	815	821	955	962	***844.5***
BOD_5 eff.	mg/l	12	11	12	10	10	10	11	11	11	14	10	15	***11.4***
COD inf.	mg/l	1,314	1,533	1,420	1,720	1,200	1,249	1,810	1,600	1,420	1,350	1,607	1,227	***1,454.2***
COD eff.	mg/l	57	55	92	110	92	47	60	80	80	42	104	85	***75.3***
PO_4 inf.	mg/l													
PO_4 eff.	mg/l													
NH_4-N inf.	mg/l													
NH_4-N eff.	mg/l													
NO_3-N inf.	mg/l													
NO_3-N eff.	mg/l													

C.2.10: Baq'a trickling filter system

Parameter	*Unit*	*Rainy*						*Dry*						*Average*
		Nov	*Dec*	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	
Inf. avg. flow	m^3/d	10,633	10,466	9,711	10,127	9,803	10,001	10,278	10,336	10,549	10,382	10,638	10,488	***10,284***
Eff. avg. flow	m^3/d	10,101	9,943	9,226	9,621	9,313	9,501	9,764	9,819	10,022	9,872	10,106	9,964	***9,771***
pH inf.	-													
pH eff.	-													
Avg. inf. temp	^oC													
Avg. eff. temp	^oC													
TDS inf.	mg/l	2024		1520	1338	1378	2454	1078	1052	1080	1040	1126	1090	***1,380***
TDS eff.	mg/l	812		1,156	1,468	1,044	1,478	1,020	858	1,060	976	1,144	1,004	***1,093***
TSS inf.	mg/l	2,040	2,133	5,383	1,842	1,234	1,334	1,605	903	590	2,032	579	967	***1,720***
TSS eff.	mg/l	62	153	216	138	152	84	153	100	90	84	82	64	***115***
BOD_5 inf.	mg/l	1,750	1,427	2,422	1,081	852	3,146	671	884	817	1,396	758	2,000	***1,434***
BOD_5 eff.	mg/l	87	72	143	70	62	62	63	61	76	129	61	70	***79.7***
COD inf.	mg/l	2,000	3,219	7,789	7,759	3,432	5,277	3,363	1,761	3,121	3,502	2,954	2,890	***3,922***
COD eff.	mg/l	412	308	543	253	137	432	354	246	416	407	360	307	***348***
PO_4 inf.	mg/l													
PO_4 eff.	mg/l													
NH_4-N inf.	mg/l													
NH_4-N eff.	mg/l				129	90	61.7	60		99				***87.9***
NO_3-N inf.	mg/l													
NO_3-N eff.	mg/l													

C.2.11: Kufranjah trickling filter system

Parameter	*Unit*	*Rainy*						*Dry*						*Average*
		Nov	*Dec*	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	
Inf. avg. flow	m^3/d	3,171	1,493	2,702	2,033	1,761	1,645	1,400	1,327	1,526	1,383	1,455	1,545	***1,786.8***
Eff. avg. flow	m^3/d	2,838	1,174	2,016	2,028	1,750	1,554	1,019	899	1,295	1,192	1,224	1,382	***1,530.9***
pH inf.	-	8.22	8.2	7	7.45	7.65	7.6	7.53	7.6	8.25	8.4	8.22	8.22	***7.9***
pH eff.	-	8.1	8.1	7.4	7.33	7.5	7.4	7.39	7.45	8.16	8.3	8.1	8.12	***7.8***
Irrigation	m^3/d	200	250	50	50	120	200	300	500	500	500	400	250	***276.7***
Avg. inf. temp	^oC	24	19	20	21	20	20	26	26	27	27	26	24	***23.3***
Avg. eff. temp	^oC	20	17	19	19	19	19	21	24	25	25	24	22	***21.2***
TDS inf.	mg/l	1,549	1,392	1,056	998	1,184		1,280	1,312	1,190	1,099	960	1,549	***1,233.5***
TDS eff.	mg/l	845	752	831	841	976		1,096	1,146	1,114	1,008	781	896	***935.1***
TSS inf.	mg/l	848	903	1,263	1,100	1,050	1,220		1,063	815	1,098	840	1,048	***1,022.5***
TSS eff.	mg/l	75	79	200	207	139	176		152	132	234	121	54	***142.6***
BOD_5 inf.	mg/l	1,388	1,217	1,215	1,200	1,455	1,345	1,410	1,440	1,313	1,431	1,221	1,331	***1,330.5***
BOD_5 eff.	mg/l	47	37	74	63	82	68	68	70	81	67	72	49	***64.8***
COD inf.	mg/l	1,853	2,095	1,357	1,346	1,580	1,820	1,372	1,677	1,455	1,593	1,797	1,837	***1,648.5***
COD eff.	mg/l	160	132	188	199	243	272	266	229	218	207	219	175	***209.0***
PO_4 inf.	mg/l													
PO_4 eff.	mg/l													
NH_4-N inf.	mg/l													
NH_4-N eff.	mg/l													
NO_3-N inf.	mg/l													
NO_3-N eff.	mg/l													

C.2.12: Karak trickling filter system

Parameter	*Unit*	*Rainy*						*Dry*						*Average*
		Nov	*Dec*	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	
Inf. avg. flow	m^3/d	1,181	1,627	1,237	1,197	1,075	1,010	1,007	1,080	1,127	1,128	1,068	1,019	***1,146.3***
Eff. avg. flow	m^3/d	1,150	1,600	1,210	1,172	1,050	985	980	1,055	1,100	1,100	1,045	990	***1,119.8***
pH inf.	-	7.43	7.79	8.05	8.17	7.69	7.98	7.67	7.56	7.58	7.6	7.28	7.29	***7.7***
pH eff.	-	7.74	7.92	7.92	7.98	8.2	7.6	7.91	7.89	7.84	7.78	7.57	7.24	***7.8***
Avg. inf. temp	^oC													
Avg. eff. temp	^oC													
TDS inf.	mg/l	1,160	1,009	1,110	1,268	1,065	1,074	1,051	1,110	1,043	1,042	1,096	1,088	***1,093.0***
TDS eff.	mg/l	924	854	938	965	1,006	884	896	878	828	839	874	865	***895.9***
TSS inf.	mg/l	730	712	724	714	753	685	634	708	683	661	694	662	***696.7***
TSS eff.	mg/l	93	97	90	92	73	70	67	81	67	72	80	103	***82.1***
BOD_5 inf.	mg/l	708	838	654	674	752	760	705	712	679	678	756	828	***728.7***
BOD_5 eff.	mg/l	50	62	31	30	30	29	33	36	62	56	69	62	***45.8***
COD inf.	mg/l	2,030	2,253	1,700	1,819	1,878	1,976	1,903	1,895	1,902	1,851	1,732	2,000	***1,911.6***
COD eff.	mg/l	298	297	228	221	214	188	202	199	216	216	199	224	***225.2***
PO_4 inf.	mg/l													
PO_4 eff.	mg/l			62.3		49								***55.7***
NH_4-N inf.	mg/l													
NH_4-N eff.	mg/l			99.4	83.3	76	40.7							***74.9***
NO_3-N inf.	mg/l													
NO_3-N eff.	mg/l					10								***10.0***

C.2.13: Tafila trickling filter system

Parameter	*Unit*	*Rainy*						*Dry*						*Average*
		Nov	*Dec*	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	
Inf. avg. flow	m^3/d	801	896	1045	1132	960	850	817	806	800	615	689	804	***851***
Eff. avg. flow	m^3/d	794	888	1040	1125	954	848	811	800	791	608	661	794	***843***
pH inf.	-	7.1	7	6.8	7.1	7.3	7.3	6.7	6.9	6.4	6.8	6.2	6.1	***7***
pH eff.	-	7.3	7.4	7	7.6	7.5	7.8	7.8	7.3	7.8	7.8	7.5	7.4	***8***
Avg. inf. temp	^oC	15	13	15	13	13	14	18	16	18	20	18	16	***16***
Avg. eff. temp	^oC	12	11	14	13	13	15	17	18	16	18	14	15	***15***
TDS inf.	mg/l	1063	924	1026	981	933	943	902	969	815	1009	1005	1141	***976***
TDS eff.	mg/l	643	682	805	887	783	807	912	910	707	774	866	795	***798***
TSS inf.	mg/l	476	574	708	370	910	863	653	745	756	743	1066	536	***700***
TSS eff.	mg/l	35	39	120	76	26	30	47	43	48	36	36	24	***47***
BOD_5 inf.	mg/l	811	874	868	963	1069	919	776	898	1392	762	980	990	***942***
BOD_5 eff.	mg/l	31	40	29	61	32	21	19	37	45	34	44	29	***35***
COD inf.	mg/l	1657	1955	1814	1355	1373	1405	1464	1088	1990	1671	1360	1329	***1538***
COD eff.	mg/l	133	157	161	218	126	130	132	118	68	172	171	70	***138***
PO_4 inf.	mg/l													
PO_4 eff.	mg/l			65				1.5						***33***
NH_4-N inf.	mg/l													
NH_4-N eff.	mg/l			17.2				10						***14***
NO_3-N inf.	mg/l													
NO_3-N eff.	mg/l			53.6				16						***35***

C.3: Technical performance of surveyed WWTPs

Country	WWTP	Treatment system	BOD_5 influent (mg/l)	BOD_5 effluent (mg/l)	COD influent (mg/l)	COD effluent (mg/l)	TSS influent (mg/l)	TSS effluent (mg/l)	BOD_5 removal (%)	COD removal (%)	TSS removal (%)	Kg BOD_5 removed/d	Faecal coliforms effluent (MPN/100 ml)
Jordan	Abu Nuseir	AS+RBC*	634	17	1,233	79	601	29.00	97.3	93.6	95.2	871	222
	Aqaba	L	353	111	903	407	266	384.00	68.6	54.9	-44.4	2,123	24,330
	Baq'a	TF	1434	80	3,922	348	1,720	115.00	94.4	91.1	93.3	13,925	38,330
	Fuheis	AS	677	11	1,552	72	720	21.00	98.4	95.4	97.1	679	850
	Jerash	AS	1119	33	2,523	123	943	68.00	97.1	95.1	92.8	1,741	1,000
	Karak	TF	729	46	1,912	225	697	82.00	93.7	88.2	88.2	783	1,500
	Kufranja	TF	1331	65	1,649	209	1,023	34.00	95.1	87.3	96.7	2,195	3,198
	Madaba	L	1382	282	5,107	784	1,657	239.00	79.6	84.6	85.6	3,970	25,201
	Mafraq	L	566	198	1,358	525	424	249.00	65.0	61.3	41.3	711	28,840
	Ramtha	L	1194	239	2,285	540	964	361.00	80.0	76.4	62.6	2,076	2,000
	Tafila	TF	942	35	1,538	138	700	47.00	96.3	91.0	93.3	772	1,272
Tunisia	Kalaat El Andalos	L	601	87	1,213	330	495	130.00	85.5	72.8	73.7	195	3,500
	Rades	L	354	96	720	381	196	184.00	72.9	47.1	6.1	331	3,000
	SE1 Hammamet	AS	264	17	586	70	280	15.00	93.6	88.1	94.6	901	41,000
	Hammamet Sud	AS	416	24	1,096	90	435	24.00	94.2	91.8	94.5	2,130	23,000
	SE3 Nabeul	AS	187	19	452	92	148	23.00	89.8	79.6	84.5	391	290,000
	Grombalia	AS	423	14	868	76	336	13.00	96.7	91.2	96.1	885	920,000
	Beja	AS	1358	43	2,628	267	574	42.00	96.8	89.8	92.7	9,602	43,000
	Mejdez El Bab	AS	598	27	1,140	75	537	21.00	95.5	93.4	96.1	533	28,000
	Menzel Borguiba	AS	338	11	772	61	220	11.00	96.7	92.1	95.0	1,316	15,000
	Sidi Bou Ali	L	343	49	1,082	302	322	58.00	85.7	72.1	82.0	113	na
	Monastir el Ghadir	TF	345	16	1,074	77	333	17.00	95.4	92.8	94.9	866	na
	Wardanin	AS	495	15	1,491	77	550	20.00	97.0	94.8	96.4	509	na
	Sahline	AS	319	9	863	52	257	8.00	97.2	94.0	96.9	930	410,000
	Houmt Essouk	L	406	68	767	193	266	51.00	83.3	74.8	80.8	586	3,000
	Lella Meriam	L	388	97	659	197	206	56.00	75.0	70.1	72.8	232	170,000

AS: activated sludge; L: lagoon; TF: trickling filter; * RBC: rotating biological contactor (not in service).

C.4: Operational costs (OPEX) of the surveyed WWTPs

Country	WWTP	Treatment system	Number of personnel	Number of personnel per 1,000 m^3	Energy (KWh/y)	Energy cost (US$/y)	Salaries (US$/y)	Cost of spare parts and others (US$/y)	Annual OPEX (US$)
Jordan	Abu Nuseir	AS	23	16.3	790,882	38,414	70,457	14,539	123,410
	Aqaba	L	27	3.1	279,412	13,571	47,143	12,000	72,714
	Baq'a	TF	28	2.7	1,764,706	85,714	110,000	42,857	238,571
	Fuheis	AS	27	26.5	588,235	28,571	77,143	11,586	117,300
	Jerash	AS	27	16.8	692,853	33,653	70,000	23,247	126,900
	Karak	TF	21	18.3	65,794	3,196	64,286	14,286	81,767
	Kufranja	TF	28	16.1	388,235	18,857	73,314	26,186	118,357
	Madaba	L	19	5.3	240,412	11,677	48,426	21,029	81,131
	Mafraq	L	15	7.8	221,118	10,740	73,326	13,643	97,709
	Ramtha	L	12	5.5	193,735	9,410	38,423	18,831	66,664
	Tafila	TF	23	27.0	268,353	13,034	69,540	23,666	106,240
Tunisia	Kalaat El Andalos	L	6	15.8	83,160	7,819	13,262	581	21,663
	Rades	L	4	3.1	9,645	699	10,450	4,908	16,057
	SE1 Hammamet	AS	13	3.6	573,736	29,546	25,831	62,037	76,951
	Hammamet Sud	AS	13	2.4	1,063,437	57,262	41,639	8,400	107,301
	SE3 Nabeul	AS	11	4.7	359,130	19,522	50,048	30,196	201,217
	Grombalia	AS	7	3.2	304,379	15,725	22,545	4,937	43,206
	Beja	AS	10	1.4	2,254,130	123,240	37,818	67,403	228,461
	Mejdez El Bab	AS	6	6.4	407,560	20,646	13,044	9,732	43,421
	Menzel Borguiba	AS	11	2.7	1,254,944	71,179	32,745	10,345	114,269
	Sidi Bou Ali	L	6	15.6	24,315	1,406	18,408	4,368	24,181
	Monastir el Ghadir	TF	13	4.9	145,826	7,627	53,301	20,357	81,285
	Wardanin	AS	6	5.7	279,776	14,604	19,917	1,677	36,199
	Sahline	AS	5	1.7	286,250	15,698	22,434	2,262	40,394
	Houmt Essouk	L	5	2.9	395,243	20,492	31,719	1,669	53,880
	Lella Meriam	L	4	5.0	124,118	6,730	11,288	671	18,690

C.5: Standardization of capital costs (CAPEX) of the surveyed WWTPs

Country	WWTP	*Treatment system*	*CAPEX equipment (JD and TD)* (1)	*CAPEX construction + land (JD and TD)* (2)	*Cost Index ratio for equipment w.r.t 2000* (3)	*Cost Index ratio for construction w.r.t 2000* (4)	*Standardized CAPEX for equipment (JD and TD)* (5) = (1)*(3)	*Standardized CAPEX for construction (JD and TD)* (6) = (2)*(4)	*Total CAPEX (JD and TD)* (7) = (5)+(6)	*Total CAPEX (US$)* (8) = 0.7*JD = 1.4* TD	*Annual CAPEX (US$)* (9) = (8)/life period	*Annual OPEX (US$)* (10)	*Annual TOTEX (US$)* (11) = (9)+(10)
Jordan	Abu Nuseir	AS	685,362	1,028,043	1.37	1.49	938,946	1,531,784	2,470,730	3,529,614	176,481	123,410	299,891
	Aqaba	L	224,127	1,270,053	1.36	1.45	304,813	1,841,577	2,146,390	3,066,271	102,209	72,714	174,923
	Baq'a	TF	2,909,712	4,364,568	1.02	1.04	2,967,906	4,539,151	7,507,057	10,724,367	536,218	238,571	774,789
	Fuheis	AS	2,750,000	2,250,000	1.1	1.2	3,025,000	2,700,000	5,725,000	8,178,571	408,929	117,300	526,229
	Jerash	AS	1,113,000	2,067,000	1.4	1.5	1,558,200	3,100,500	4,658,700	6,655,286	332,764	126,900	459,664
	Karak	TF	207,500	622,500	1.32	1.35	273,900	840,375	1,114,275	1,591,821	79,591	81,767	161,358
	Kufranja	TF	266,555	621,962	1.3	1.36	346,522	845,868	1,192,390	1,703,414	85,171	118,357	203,528
	Madaba	L	63,000	567,000	1.3	1.36	81,900	771,120	853,020	1,218,600	40,620	81,131	121,751
	Mafraq	L	132,761	752,312	1.32	1.35	175,244	1,015,621	1,190,866	1,701,237	56,708	97,709	154,417
	Ramtha	L	105,000	595,000	1.36	1.45	142,800	862,750	1,005,550	1,436,500	47,883	66,664	114,548
	Tafila	TF	261,300	609,700	1.32	1.35	344,916	823,095	1,168,011	1,668,587	83,429	106,240	189,669
Tunisia	Kalaat El Andalos	L	414,800	622,200	1.1	1.12	456,280	696,864	1,153,144	823,674	27,456	21,663	49,119
	Rades	L	13,050	73,950	2.1	2.3	27,405	170,085	197,490	141,064	4,702	16,057	20,759
	SE1 Hammamet	AS	196,000	294,000	1.85	1.8	362,600	529,200	891,800	637,000	31,850	76,951	108,801
	Hammamet Sud	AS	4,400,000	3,600,000	1.1	1.12	4,840,000	4,032,000	8,872,000	6,337,143	316,857	107,301	424,158
	SE3 Nabeul	AS	126,000	234,000	1.9	1.9	239,400	444,600	684,000	488,571	24,429	201,217	225,645
	Grombalia	AS	589,200	883,800	1.2	1.2	707,040	1,060,560	1,767,600	1,262,571	63,129	43,206	106,335
	Beja	AS	3,105,000	3,795,000	1.1	1.12	3,415,500	4,250,400	7,665,900	5,475,643	273,782	228,461	502,243
	Mejdez El Bab	AS	4,485,000	2,415,000	1.1	1.12	4,933,500	2,704,800	7,638,300	5,455,929	272,796	43,421	316,218
	Menzel Borguiba	AS	3,093,500	3,093,500	1.05	1.07	3,248,175	3,310,045	6,558,220	4,684,443	234,222	114,269	348,491
	Sidi Bou Ali	L	270,000	1,080,000	1.08	1.07	291,600	1,155,600	1,447,200	1,033,714	34,457	24,181	58,638
	Monastir el Ghadir	TF	122,500	227,500	3	3	367,500	682,500	1,050,000	750,000	37,500	81,285	118,785
	Wardanin	AS	327,000	763,000	1.2	1.2	392,400	915,600	1,308,000	934,286	46,714	36,199	82,913
	Sahline	AS	731,500	731,500	1.2	1.2	877,800	877,800	1,755,600	1,254,000	62,700	40,394	103,094
	Houmt Essouk	L	168,200	1,513,800	1.5	1.6	252,300	2,422,080	2,674,380	1,910,271	63,676	53,880	117,556
	Lella Meriam	L	13,500	76,500	1.77	1.8	23,895	137,700	161,595	115,425	3,848	18,690	22,537

C.6: Unit cost of wastewater treatment

Country	WWTP	OPEX (US$/m^3)	CAPEX (US$/m^3)	OPEX (US$/PE/y)	CAPEX (US$/PE/y)	TOTEX (US$/m^3)	TOTEX (US$/PE/y)	Built up area (ha)	Built up area (m^2/PE)	Personnel per 1,000 PE	KWh/y	KWh/PE/y	Spare parts and others (US$/PE/y)
Jordan	Abu Nuseir	0.240	0.343	8.54	12.21	0.582	20.75	0.75	0.52	1.59	790,882	44.99	1.01
	Aqaba	0.023	0.032	1.50	2.10	0.055	3.60	11.00	2.26	0.56	279,412	5.75	0.25
	Baq'a	0.064	0.143	1.20	2.69	0.206	3.89	5.00	0.25	0.14	1,764,706	8.87	0.22
	Fuheis	0.315	1.099	8.39	29.24	1.415	37.63	0.50	0.36	1.93	588,235	42.06	0.83
	Jerash	0.217	0.569	3.99	10.47	0.786	14.46	1.25	0.39	0.85	692,853	21.80	0.73
	Karak	0.195	0.190	5.69	5.53	0.386	11.22	0.80	0.56	1.46	65,794	4.58	0.99
	Kufranja	0.187	0.135	3.49	2.51	0.322	6.01	2.70	0.80	0.83	388,235	11.46	0.77
	Madaba	0.062	0.031	1.15	0.57	0.092	1.72	10.00	1.41	0.27	240,412	3.40	0.30
	Mafraq	0.138	0.080	5.54	3.21	0.219	8.75	6.00	3.40	0.85	221,118	12.53	0.77
	Ramtha	0.084	0.060	2.10	1.51	0.144	3.60	6.50	2.04	0.38	193,735	6.09	0.59
	Tafila	0.342	0.269	15.18	11.92	0.611	27.10	0.50	0.71	3.29	175,200	25.03	3.38
Tunisia	Kalaat El Andalos	0.157	0.198	2.00	2.53	0.355	4.53	2.50	2.31	0.55	83,160	7.67	0.05
	Rades	0.034	0.010	1.25	0.37	0.044	1.62	3.50	2.73	0.31	9,645	0.75	0.38
	SE1 Hammamet	0.046	0.019	4.79	1.98	0.065	6.77	1.00	0.44	0.57	573,736	25.05	2.71
	Hammamet Sud	0.054	0.160	3.82	11.28	0.214	15.10	0.75	0.27	0.46	850,350	30.27	0.30
	SE3 Nabeul	0.061	0.007	2.00	0.24	0.068	2.24	0.90	0.73	0.89	359,130	29.10	2.45
	Grombalia	0.055	0.080	2.34	3.42	0.135	5.75	1.10	0.60	0.38	304,379	16.47	0.27
	Beja	0.086	0.103	2.19	2.62	0.188	4.81	9.00	0.86	0.10	2,254,130	21.60	0.65
	Mejdez El Bab	0.128	0.801	2.25	14.14	0.929	16.39	1.00	0.52	0.31	407,560	21.13	0.50
	Menzel Borguiba	0.078	0.159	1.54	3.16	0.237	4.70	1.50	0.20	0.15	1,254,944	16.91	0.14
	Sidi Bou Ali	0.172	0.245	8.06	11.49	0.417	19.55	0.50	1.67	2.00	24,315	8.11	1.46
	Monastir El Ghadir	0.085	0.039	1.73	0.80	0.124	2.53	1.65	0.35	0.28	145,826	3.11	0.43
	Wardanin	0.094	0.121	2.72	3.51	0.214	6.22	0.50	0.38	0.45	279,776	21.00	0.13
	Sahline	0.037	0.057	6.20	9.62	0.094	15.82	0.85	1.30	0.77	200,300	30.73	0.35
	Houmt Essouk	0.085	0.101	2.20	2.60	0.186	4.80	6.50	2.65	0.20	395,243	16.13	0.07
	Lella Meriam	0.064	0.013	5.27	1.08	0.077	6.35	1.60	4.51	1.13	124,118	34.99	0.19

Annex D: Research questionnaires

D.1: Administrators' questionnaire

Question 1: How do you rate the influence of these factors on wastewater reuse? (Targeted 58 administrators, 14 managers of WWTPs, and 96 farmers).

No.	*Factors*	*Crucial*	*Trivial*
1	Awareness and attitude change		
2	Crop marketing and acceptance of crop consumers		
3	Crop yield and fertilizers in reclaimed wastewater		
4	Cropping restriction and agricultural profit		
5	Farmers' involvement		
6	Health risks to farmers and crop consumers		
7	Impact on irrigation equipment		
8	Impacts on quality of soil, crops, and water resources		
9	Institutional conflicting interests		
10	Land fragmentation		
11	National water availability/scarcity		
12	Opinion of reference groups and concern for criticism		
13	Pricing of freshwater and reclaimed wastewater		
14	Psychological aversion		
15	Quality standards and regulations		
16	Religious prohibition		
17	Securing users for the reclaimed wastewater		
18	Storage, conveyance, and reliability of supplies		
19	Unavoidable use of freshwater		
20	Wastewater treatment approach		
21	Water availability/accessibility at irrigation scheme level		
22	Others, specify and rate		

Question 2: Which of the following factors has major influence on wastewater treatment? (Targeted 58 administrators and 14 managers of WWTPs. It did not target farmers).

No.	*Factors*	*Yes*	*No*
1	Over-reliance on foreign expertise		
2	High cost of treatment		
3	Inappropriateness of the selected treatment systems		
4	Institutional deficiencies		
5	Lack of local skills for design and construction		
6	Lack of local skills for O&M		
7	Low local funding and over-reliance on grants and loans		
8	Poor cost recovery		
9	Poor involvement of the private sector		
10	Stringency of the quality standards and low demand for the treated effluent		

Remarks:

D.2: List of data on wastewater treatment plants

Country: Location: Date: / /

No.	Questions	Answer
1	Position of person interviewed: 1- Plant manager 2- Site engineer 3- O&M laborer 4- Ministry engineer 5- Ministry official 6- Other, specify	
2	Qualification of person interviewed: 1- PhD 2- MSc 3- BA 4- Diploma 5- Secondary school 6- Other, specify	
3	How long is the experience of the person interviewed?	
4	Qualification and training of the plant manager: 1- PhD 2- MSc 3- BA 4- Diploma 5- Secondary school 6- Other, specify	
5	How long is the experience of the plant manager's?	
6	What is the scientific background of the plant manager? 1- Civil engineering 2- Chemical engineering 3- Mechanical engineering 4- Electrical engineering 5- Sanitary engineering 6- Chemistry 7- Biology 8- Economy 9- Business administration 10- Accountancy 11- Other, specify	
7	Who owns the WWTP?	
8	Who is operating and maintaining the WWTP?	
9	Which sewerage projects are connected to this WWTP?	
10	What is the total population served by this WWTP?	
11	What is the population density (c/ha)?	
12	What is the average water consumption (l/c/day)?	
13	Does the WWTP treat industrial wastewater? 1- Yes 0- No	
14	Does the WWTP receive wastewater from unsewered communities by tankers 1- Yes 0- No	
15	What is the highest level (msl) in the project area?	
16	What is the lowest level (msl) in the project area?	
17	What is the depth of the groundwater table in the project area?	
18	What is the soil type in project area? 1- Rock 2- Soil 3- Other, specify	
19	What is the total built-up land area of the WWTP (ha)?	
20	What is the total land area of the WWTP (ha)?	
21	What is the price of land in the project area (US$/m^2)?	
22	What is the price of similar land but away from WWTPs?	
23	What is the area of agricultural land in project area (ha)?	
24	What treatment process is used? Answer 1- Yes, 0- No 1- Extended aeration - Activated sludge 2- Trickling filter 3- Anaerobic ponds 4- Facultative ponds 5- Maturation ponds 6- Oxidation ditch 7- Aerated lagoons 8- RBC 9- Manual screening 10- Mechanical screening 11- Manual grit chamber 12- Mechanical grit chamber 13- Primary sedimentation 14- Secondary sedimentation 15- Chemical odor control	

	16- Disinfection 17- Thickening 18- Sludge stabilization 19- Mechanical sludge dryers 20- Sludge drying beds 21- Other, specify	
25	How far is the WWTP from the residential area served (Km)?	
26	Who proposed the project? Answer 1- Yes, 0- No 1- Private foreign 2- Donor agency 3- Government 4- Municipality 5- Private local 6- Other, specify	
27	Which of the following participated in the planning of the WWTP? 1- Yes, 0- No 1- Foreign engineers 2- Government engineers 3- Municipality engineers 4- Private consultancy engineers 5- Foreign sociologists 6- Government sociologists 7- Municipality sociologists 8- Private consultancy sociologists 9- Foreign economists 10- Government economists 11- Municipality economists 12- Private economists 13- Community leaders 14- Foreign agronomists 15- Local agronomists 16- Politicians 17- Others, specify	
28	Which of the following participated in the design of the WWTP? 1- Yes, 0- No 1- Foreign engineers 2- Government engineers 3- Municipality engineers 4- Private consultancy engineers 5- Foreign sociologists 6- Government sociologists 7- Municipality sociologists 8- Private consultancy sociologists 9- Foreign economists 10- Government economists 11- Municipality economists 12- Private economists 13- Community leaders 14- Foreign agronomists 15- Local agronomists 16- Politicians 17- Others, specify	
29	Who constructed the project? Answer 1- Yes, 0- No 1- Government contractor 2- Municipality 3- Local contractor 4- Foreign contractor 5- Communities 6- Others, specify	
30	When was the project construction first started?	
31	When was the project construction completed?	
32	How was the CAPEX funded?	
33	How is the OPEX recovered?	
34	At what price is the treated effluent sold or given to farmers?	
35	What is the price of fresh water for irrigation?	
36	Are the farmers allowed to drill their own ground water wells? 1- Yes 0- No	
37	What is the unit cost of treated effluent per cubic meter at reuse point?	
38	How is the unit cost of treated effluent calculated?	
39	Who pays for the treatment of wastewater?	
40	Who pays for the transport of the treated wastewater from the WWTP to the agricultural area?	
41	Who pays for distribution of the treated wastewater in the agricultural land?	
42	What problems were faced through out the planning, construction and operation of this WWTP? Answer 1- Yes, 0- No 1- Design problems 2- Under-loading 3- Overloading 4- Lack of skilled design engineers 5- Lack of skilled O&M engineers 6- Lack of skilled O&M labor 7- High CAPEX and lack of fund 8- Odor problems 9- Mosquitoes problems 10- Social and religious obstacles, 11- Others, specify	

43	Has any awareness program preceded the project implementation? 1- Yes 0- No	
44	Was the following considered during the planning and design of the project? 1- Yes, 0- No 1- Acceptance 2- Affordability 3- Willingness of households to connect to the sewerage system 4- Willingness of households to pay for sewerage 5- Willingness of households to pay for treatment 6-Willingness of farmers to pay for treated wastewater 7- Willingness of farmers to pay for transport and distribution 8- Willingness of people to buy/consume reuse crops 9- Other, specify	
45	What is the followed incentives system to attract and encourage workers in the project? Answer 1- Yes, 0- No 1- High salaries 2- Subsidies 3- Availability of safety measures 4- Awareness programs 5- No incentives 6- Others, specify	
46	What is the followed incentives system to encourage farmers to reuse treated wastewater? Answer 1- Yes, 0- No 1- Providing good water quality 2- Providing water at low price 3- Early involvement of farmers 4- Fertilizers saving 5- Reliability of water supply 6- Enforcement 7- Awareness programs 8- Allowance of unrestricted irrigation 9- Financial subsidies 10- Availability of markets for reuse crops 11- Availability of regulations against use of fresh water in irrigation 12- Availability of farmers' association 13- Others, specify	
47	When was the project last rehabilitated?	
48	What is the number of engineers in the project?	
49	What is the number of O&M laborers in the project?	
50	What is the number of accountants in the project?	
51	What is the number of drivers in the project?	
52	What is the number of sweepers in the project?	
53	What is the number of lab technicians in the project?	
54	What is the number of guards in the project?	
55	What is the total number of personnel in the project?	
56	How much excess or shortage in the manpower you have in the project? Answer 1- Managers 2- Engineers 3- O&M laborers 4- Accountants 5- Drivers 6- Sweepers 7- Lab technicians 8- Guards 9- Others, specify	
57	How many vehicles the project employs?	
58	What is the opinion of the society about job of persons working with wastewater? 1- High level job 2- Medium level job 3- Low level job 4- Normal job 5- Shameful job 6- Others, specify	
59	What safety measures at the WWTP you have? Answer 1- Yes, 0- No 1- Protecting clothes 2- Masks 3- First aid unit 4- Caution signs 5- Awareness programs 6- Fences 7- Others, specify	
60	Do you have a quality monitoring system in the WWTP? 1- Yes 0- No	

61	Where are the chemical parameters tested? 1- Onsite laboratory 2- Central governmental lab 3- Other specify	
62	Where are the microbiological parameters tested? 1- Onsite laboratory 2- Central governmental laboratory 3- Other specify	
63	How are the results kept? Answer 1- Yes, 0- No 1- Manual 2- Computer 3- Not kept 4- Both manual and computer 5- Other, specify	
64	How many PCs do you have in the WWTP?	
65	How many of the personnel use the PC?	
66	What do you do with the treated effluent?	
67	What percentage of treated effluent is reused?	
68	What disinfection system is used in the WWTP? 1- Chlorination 2- Maturation ponds 3- Ozonation 4- UV 5- None 6- Others, specify	
69	What guidelines for effluent quality you apply? 1- National 2- WHO 3- EC 4- Others,	
70	What considerations were taken in determining the required effluent quality? Answer 1- Yes, 0- No 1- Restricted irrigation guidelines 2- Unrestricted irrigation guidelines 3- Groundwater protection 4- Surface water protection 5- Protection of ecosystem 6- Responsiveness to farmers' demand 7- Other, specify	
71	What is your opinion on the performance of the existing treatment technology? Answer 1- Yes, 0- No 1- Simple and easy for O&M 2- Simple but difficult for O&M 3- Sophisticated but the available skills can handle the O&M 4- Sophisticated and the available skills cannot handle the O&M 5- Other, specify	
72	What is the quantity of the sludge produced?	
73	What is done with the produced sludge? 1- Yes, 0- No 1. Processed and dumped on-site 2. Processed on-site and dumped off-site 3. Transported unprocessed to another WWTP 4. Transported by trucks to a dumping site 5. Dumped unprocessed on-site 6. Others, specify	
74	How much does the sludge disposal cost?	
75	How is the treated effluent transported to the disposal/reuse point? 1- Pumped through pipelines 2- By gravity through pipelines 3- Open channels 4- Other, specify	
76	* What agricultural crops are irrigated with fresh water in the reuse area?	
77	* What agricultural crops are irrigated with treated wastewater of this WWTP?	
78	* How much is the annual saving in fertilizers achieved due to reuse?	
79	* What was the area of land cultivated before project construction?	
80	* What is the area of land cultivated after project construction?	

81: Characteristics of influent and effluent:

Parameter	*Dry season*		*Rainy season*		*Remarks*
	Influent	*Effluent*	*Influent*	*Effluent*	
pH					
T (°C)					
Design plant capacity (m^3/day)					
Operational capacity (m^3/day)					
Hydraulic loading rate					
Organic loading rate (Kg BOD/m^3.day)					
TSS (mg/l)					
TDS					
BOD_5 (mg/l)					
COD (mg/l)					
Nitrate (mg/l)					
Ammonia (mg/l)					
TKN (mg/l)					
Chloride (mg/l)					
Phosphorus (mg/l)					
FC (MPN/100 ml)					

82: Capital Expenses (CAPEX).

Component	*Number of units*	*Life period (years)*	*Cost*

83: Operational Expenses (OPEX).

No.	*Item*	*Quantity per year*	*Cost (US$/year)*	*Remarks*
1	Managers			
2	Engineers			
3	Workers			
4	Drivers			
5	Guards			
6	Sweepers			
7	Energy/electricity			
8	Energy/fuel			
9	Chemicals and chlorine			
10	Spare parts and fittings			
11	Sludge disposal			
12	Telephones/fax			
13	Water			
14	Laboratory testing			
15	Pesticides			
16	Others			

Other observations and remarks

D.3: Farmers' questionnaire

Country: Scheme: Farm No. Date: / /

No.	*Question*	*Answer*
1	Age	
2	Area of irrigated land (ha)	
3	Major source of irrigation water? 1- Fresh groundwater 2- Fresh surface water 3- Fresh surface water blended with treated wastewater 4- Treated wastewater	
4	Number of persons from farmer's family working in the farm	
5	Number of non-family persons working in the farm	
6	Annual value of non family labor	
7	Annual value of family labor	
8	Since how many years you are using this water?	
9	Water consumption of the farm (m^3/Donum) or (m^3/year)	
10	Annual expenditure of water for irrigation?	
11	Water price	
12	Irrigation period (months)	
13	How is irrigation water measured? 1- Water meter 2- Estimation based on land area 3- Estimations based on supply hours 4- Water meter exists but not accredited and other method is used	
14	Do you use a pump?	
15	How much does the pump cost?	
16	What is the life period of the pump?	
17	What are the annual operational costs of the pump?	
18	Do you use extra piping and/or storage to transport water to the farm?	
19	If answered Q18 yes, how much does it cost?	
20	Type irrigation system used inside your farm? 1- Furrow 2- Sprinklers 3- Drip 4- Flooding	
21	Annual expenditure on fertilizers and pesticides?	
22	Annual expenditure on pesticides and land preparations?	
23	Annual expenditure on seeds and nursery?	
24	What crops you irrigate with this water?	
25	What is done with the agricultural harvest? 1- Sold in the market 2- Sold in the market and onsite 3- Personal use only 4- Sold in the market and personal use 5- Others, specify	
26	Annual income of your farm?	
27	Are you member of farmers' association?	
28	Are concerned about the water quality?	
29	How do you consider farmers' involvement in decision-making? 1- Necessary 2- Unnecessary 3- No answer	
30	Do you have irregular supply of water during peak season?	
31	Do you use freshwater for distribution of pesticides?	
32	Do you have problems concerning quality of crops?	
33	Do you have problems concerning soil?	
34	Do you have problems concerning the irrigation system?	
35	Do you have problems concerning occupational health?	
36	Do you have problems concerning price of water?	
37	Do you have problems concerning marketing your harvest?	
38	Do you accept to use treated wastewater for restricted irrigation?	

	1- Accept 2- Reject 3- Uncertain	
39	Do you accept to use treated wastewater for unrestricted irrigation? 1- Accept 2- Reject 3- Uncertain	
40	If you reject or uncertain in Q 38 or 39, what are the reasons? 1. Availability or accessibility to freshwater 2. Concern for health impacts 3. Concern for marketing of crops 4. Distrusted water quality 5. Religious prohibition 6. Concern for public criticism 7. Psychological aversion 8. Others, specify	
41	If cropping is unrestricted, do you accept to irrigate with treated wastewater, If the price is free?	
42	If cropping is unrestricted, do you accept to irrigate with treated wastewater, If the price is 0.05 US$/m^3?	
43	If cropping is unrestricted, do you accept to irrigate with treated wastewater, If the price is 0.10 US$/m^3?	
44	If cropping is unrestricted, do you accept to irrigate with treated wastewater, If the price is 0.15 US$/m^3?	
45	If cropping is unrestricted, do you accept to irrigate with treated wastewater, If the price is 0.20 US$/m^3?	
46	If cropping is unrestricted, do you accept to irrigate with treated wastewater, If the price 0.25 US$/m^3?	
47	If fresh water would not be available anymore, and unrestricted irrigation is allowed, do you accept to pay for treated wastewater any price?	
48	Which of the following can influence your opinions? 1. Regulations and enforcement 2. Availability or shortage of freshwater 3. Water price and farming profit 4. Cropping restriction or freedom 5. Opinion of relatives 6. Opinion of friends 7. Opinion of community leaders; Hamolah Sheikh (Clan leader) 8. Farmers involvement in the planning and decision- making 9. Potential fertilizers saving 10. Reports, brochures, and studies 11. Advice by specialists 12. Media (TV, radio, newspapers, etc.) 13. Others, specify	

Remarks:

D.4: Households' questionnaire

Household No.: Country: Location: Date: / /

No.	*Questions*	*Answer*
1	Family size?	
2	Monthly income of your household?	
3	Monthly water consumption of your household?	
4	Expenditure on water supply?	
5	1- What type of toilet you have? 1- Pour flush 2- Cistern flush 3- Both	
6	Type of sanitation system used: 1- Cesspit 2- Sewerage 3- Others, specify	
7	Expenditure on sanitary plumbing inside the house?	
8	What is your monthly expenditure on sanitation?	
9	How do you value your expenditure on sanitation? 1- Low 2- Reasonable 3- High	
10	Do you accept to pay for increased sanitation tariffs? 1-Yes 0- No	
11	Have you been involved in the planning of the public sewerage system? 1- Yes 0- No	
12	How do you consider community involvement in the planning of the sewerage system? 1-Necessary 2- Unnecessary 3- No answer	
13	What is your opinion on the job of people working in the sanitation sector? 1- Normal job 2- Low level job 3- Shameful job	
14	What is your opinion on the current sanitation service? 1- Very good 2- Good 3- Poor 4- Very poor	
15	Do you consider agricultural irrigation with treated wastewater? 1-Necessary 2- Unnecessary 3- No answer	
16	Do you accept to buy/consume crops irrigated with raw sewage? 1- Accept 2- Reject	
17	Reasons for rejection to use crops irrigated with raw sewage? 1- Concern for health impacts 2- Availability of freshwater crops 3- Affordable prices of freshwater crops 4- Psychological aversion 5- Religious prohibition 6- Concern for public criticism 7- Others, specify	
18	Do you accept to buy/consume crops irrigated with treated wastewater if approved? 1- Accept 2- Reject	
19	Reasons for rejection to use crops irrigated with treated wastewater? 1- Concern for health impacts 2- Availability of freshwater crops 3- Affordable prices of freshwater crops 4- Psychological aversion 5- Religious prohibition 6- Concern for public criticism 7- Others, specify	
20	Which of the following may influence your opinions? 1- Regulations and enforcement 2- Specialists 3- Media (TV, Newspapers, radio) 4- Public involvement 5- Community leaders 6- Opinion of relatives 7- Opinion of friends 8- Reports, studies, and brochures 9- Others, specify	

Remarks:

Annex E: Agronomics of reclaimed wastewater and freshwater for restricted and unrestricted irrigation

Parameters	*Treated wastewater (n = 51)*				*Blended water (n = 10)*				*Surface water (n = 20)*				*Groundwater (n = 15)*			
	Min.	*Max.*	*Mean*	*STD*	*Min.*	*Max.*	*Mean*	*STD*	*Min.*	*Max.*	*Mean*	*STD*	*Min.*	*Max.*	*Mean*	*STD*
Fruit trees (Citrus, peaches, apples, pears, grenades, and olives)	0	1	0.55	0.50	0	0	0.00	0.00	0	1	0.05	0.22	0	1	0.40	0.51
Vegetables (tomatoes, cucumbers, squash, potatoes, cabbages, etc.)	0	0	0.00	0.00	1	1	1.00	0.00	0	1	0.95	0.22	0	1	0.60	0.51
Fodder crops (alfalfa, sorghum, berseem, and cereals)	0	1	0.45	0.50	0	0	0.00	0.00	0	0	0.00	0.00	0	0	0.00	0.00
Furrow irrigation system	0	1	0.55	0.50	0	1	0.50	0.53	0	1	0.50	0.51	0	1	0.67	0.49
Sprinklers irrigation system	0	1	0.25	0.44	0	1	0.40	0.52	0	1	0.40	0.50	0	1	0.40	0.51
Drip irrigation system	0	1	0.27	0.45	1	1	1.00	0.00	0	1	0.75	0.44	0	1	0.87	0.35
Flooding irrigation system	0	1	0.33	0.48	0	0	0.00	0.00	0	1	0.05	0.22	0	0	0.00	0.00
Water meter is used	0	1	0.39	0.49	0	0	0.00	0.00	0	1	0.25	0.44	0	1	0.87	0.35
Water is estimated	0	1	0.63	0.49	1	1	1.00	0.00	0	1	0.75	0.44	0	1	0.13	0.35
Area of irrigated land (Donum*)	4	1,000	79.0	165.5	15	90	45.0	22.9	6	100	22.3	22.7	12	250	80.7	80.3
Number of unpaid labor from family members per Donum	0.0	1.4	0.31	0.31	0.1	0.4	0.19	0.12	0.1	1.0	0.43	0.29	0.0	0.5	0.17	0.16
Number of paid labor from non-family members per Donum	0.0	0.3	0.040	0.053	0.0	0.1	0.035	0.031	0.0	0.2	0.045	0.057	0.0	0.2	0.065	0.056
Water consumption (m^3/Donum/season)	230	1,250	700	222	500	1,071	684	169	500	1,250	721	188	625	1,429	871	215
Water price (US$ cent/m^3)**	0.13	5.71	1.41	0.73	3.33	8.57	6.08	2.03	5.00	26.19	10.02	4.74	0.97	57.14	29.35	24.68
Irrigation period (months)	4	9	6.59	0.90	6	7	6.80	0.42	5	8	6.70	0.66	6	9	7.53	0.74
Fertilizers consumption (US$/Donum/season)	0	179	51.2	48.1	119	429	227.2	90.2	36	476	216.9	114.8	71	714	277.4	167.0
Fertilizers consumption (US$/$m^3$ of water used)	0	0.29	0.078	0.081	0.190	0.54	0.336	0.110	0.07	0.71	0.306	0.164	0.10	0.86	0.330	0.216
Expenditure on pesticides, and land preparation (US$/Donum/season)	6	171	51.2	41.5	119	357	228.5	77.1	36	286	123.6	64.7	55	397	167.7	85.0
Expenditure on pesticides, and land preparation (US$/$m^3$ of water used)	0.01	0.29	0.08	0.07	0.19	0.54	0.34	0.11	0.06	0.43	0.18	0.10	0.06	0.43	0.20	0.10
Gross income (US$/Donum/season)	48	1,250	376	273	556	1,714	1,043	419	357	1,905	917	372	429	1,786	1,129	444
Gross income (US$/$m^3$ of water used)	0.07	2.14	0.58	0.48	1.000	2.14	1.51	0.47	0.57	2.86	1.31	0.55	0.65	2.14	1.34	0.56
Total expenses including family labor (US$/Donum/season)***	28	987	337	222	469	1,211	787	239	199	1,881	1,000	467	273	1,905	986	564
Total expenses including family labor (US$/$m^3$ of water used)	0.07	1.65	0.50	0.34	0.592	1.63	1.18	0.33	0.40	3.17	1.42	0.71	0.26	2.63	1.17	0.72
Total expenses excluding family labor (US$/Donum/season)	21	367	145.7	84.1	355	800	565.6	133.1	165	829	529.7	196.7	251	1,476	806.0	412.4
Total expenses excluding family labor (US$/$m^3$ of water used)	0.03	0.59	0.22	0.13	0.52	1.05	0.84	0.16	0.33	1.24	0.75	0.26	0.23	1.71	0.94	0.49
Net profit including the unpaid labor (US$/Donum/season)	-357	943	39.4	214.3	-106	693	255.0	256.7	-871	695	-82.6	375.1	-304	507	143.7	223.6
Net profit including the unpaid labor (US$/$m^3$of water used)	-0.57	1.26	0.08	0.34	-0.19	0.65	0.33	0.31	-1.74	1.04	-0.11	0.60	-0.49	0.74	0.17	0.29
Net profit excluding the unpaid labor (US$/Donum/season)	8.1	1,086	230.3	229.3	33.3	914	476.9	311.9	157.1	1,076	387.8	226.6	57.1	619	323.1	184.9
Net profit excluding the unpaid labor (US$/$m^3$of water used)	0.02	1.66	0.36	0.40	0.06	1.20	0.67	0.39	0.21	1.61	0.57	0.35	0.05	0.79	0.39	0.23

* Donum = 1,000 m^2 = 0.1 ha; the value of land is not included in the analysis; One US$ = 0.7 JD = 1.4 TD (exchange rates of 2001).

** The water price includes the additional costs of pumping where applicable.

*** The total expenses include: (1) water, (2) labor, (3) fertilizers, (4) pesticides and land preparations, and (5) energy where pumps are used.

Samenvatting

Hoofdstuk 1 introduceert de probleemstelling, doelstelling, en aanpak van het onderzoek. Als gevolg van de chronische waterschaarste wordt het belang van afvalwater als onconventionele bron van water door alle landen in de MENA (Midden Oosten en Noord Afrika) regio erkend. In deze landen worden echter nog steeds grote hoeveelheden afvalwater, die wel ingezameld worden, zonder behandeling in oppervlaktewater of zee geloosd. Bovendien wordt ook het grootste deel van het afvalwater dat gezuiverd is, ongebruikt geloosd. Er bestaat dus nog een groot potentieel voor nuttig hergebruik. Het doel van het onderzoek is de opties tot stimulering en de knelpunten op het gebied van techniek, regelgeving, instituties, financiering and socio-culturele aspecten, te analyseren, die behandeling en hergebruik van afvalwater voor irrigatie in de landbouw beïnvloeden. Het onderzoek is gericht op de ervaringen in Jordanië en Tunesië. Tijdens het onderzoek is veldwerk verricht in Jordanië (2000) en Tunesië (2001) om gegevens te verzamelen over afvalwaterbehandeling, irrigatie met gebruik van het behandelde afvalwater, en het vermarkten en de vraag naar de verbouwde gewassen. In de twee landen zijn gegevens verzameld van 72 beheerders, 31 afvalwaterzuiveringsinrichtingen (awzi's), 104 boeren en hun bedrijven, 326 huishoudens en 3 marktplaatsen.

Hoofdstuk 2 reikt een conceptueel kader aan voor de analyse en worden de systeem-types voor afvalwaterbehandeling en het mogelijk hergebruik van afvalwater beschreven. Herwonnen afvalwater is een product waarvan de markt (i) een aanbodzijde heeft, waarin afvalwaterproductie, inzameling en behandeling plaatsvinden, (ii) een vraagzijde voor het gebruik van behandeld afvalwater, en (iii) een marktcontrolemechanisme en monitoring die gebaseerd zijn op de prijzen, regelgeving en het institutionele kader. Uit het onderzoek blijkt dat de markt voor afvalwater in de MENA regio in onbalans is. Om deze markt in balans te brengen, dienen de hoeveelheden ingezameld, behandeld en hergebruikt afvalwater te worden gemaximaliseerd. De inzamelingsratios zijn in de meeste landen hoog. De redenen hiervoor, die liggen in verstedelijking, en gezondheids- en milieudoeleinden, vallen buiten het kader van dit onderzoek. Om de discrepantie tussen de vraag- en aanbodzijde van de markt voor hergebruik van afvalwater te verkleinen, dient een groter deel van het afvalwater behandeld en hergebruikt te worden. De huidige indices die gebruikt worden om nationale prestaties inzake afvalwaterhergebruik te kwantificeren, zijn gebaseerd op het hergebruikte afvalwater-deel van stedelijke awzi's; ook wordt hergebruik in rurale gebieden buiten beschouwing gelaten. In het onderzoek zijn verschillende indices vergeleken, waarop een nieuwe index, de Afvalwater Hergebruik Index (Wastewater Reuse Index, *WRI*) is geïntroduceerd. De WRI kwantificeert de hoeveelheden afvalwater die worden hergebruikt als percentage van de totale afvalwaterproductie, urbaan en ruraal. Deze index maakt het beleidsmakers mogelijk om de discrepantie tussen prestaties in afvalwaterhergebruik op verschillende plaatsen en momenten te kwantificeren

In **Hoofdstuk 3** wordt de achtergrond in Jordanië en Tunesië beschreven waarhet onderzoek is uitgevoerd. Beide landen zijn pioniers op het gebied van afvalwaterbehandeling en hergebruik. **Jordanië**, gesitueerd in het hart van de MENA regio, heeft een bevolking van ongeveer 5 miljoen, over 89.556 km^2. Circa 71% van het totale waterverbruik is bestemd voor irrigatie. De totale productie van huishoudelijk afvalwater is ongeveer 241 miljoen m^3/jaar, waarvan 239 miljoen m^3 ingezameld wordt via riolering (51%) en on-site systemen

(49%). In de 17 awzi's wordt jaarlijks circa 80 miljoen m^3 afvalwater behandeld, waarvan 67 miljoen m^3 wordt hergebruikt (situatie 2000). Direct hergebruik van het secundair behandelde effluent is beperkt tot enkele boerenbedrijven in de omgeving van de bestaande awzi's. In de meeste gevallen vindt (indirect) hergebruik plaats na menging van het secundair behandelde afvalwater met water uit wadis en stuwmeren. Dit water wordt benedenstrooms in de Jordaanvallei toegepast in onbeperkte irrigatie; dit wil zeggen dat het water mag worden gebruikt voor alle gewassen, inclusief rauw te consumeren gewassen. Het Ministerie voor Water en Irrigatie (MWI) is de organizatie verantwoordelijk voor drinkwater, afvalwaterinzameling, -behandeling en -hergebruik. Andere instituten, zoals de Ministeries van Gezondheid, Landbouw en Industrie, het Normalisatie Instituut, enz., zijn echter ook betrokken bij het beleid en de regelgeving inzake afvalwater. **Tunesië**, dat in het hart van Noord Afrika ligt, heeft een bevolking van ongeveer 9,5 miljoen, over 164.418 km^2. Circa 80% van het totale watergebruik is bestemd voor irrigatie. De totale productie van huishoudelijk afvalwater is ongeveer 395 miljoen m^3 per jaar, waarvan 316 miljoen m^3/jaar ingezameld wordt via riolering (40%) en on-site systemen (60%). In de 61 awzi's wordt jaarlijke circa 148 miljoen m^3 behandeld, waarvan 50 miljoen m^3 wordt hergebruikt (situatie 2001). Direct hergebruik van het secundair behandelde effluent komt voor in vele irrigatiegebieden die voor dit doel zijn ingericht. Indirect hergebruik wordt deels toegepast door menging met zoet water in stuwmeren en in diepe grondwaterlagen, die niet voor direct gebruik als drinkwater geschikt zijn. In Tunesië is de Nationale Afvalwater en Sanitatie Dienst (Office National de l'Assainissement (ONAS)), een sub-organisatie van het Ministerie van Milieu en Landgebruik, de organizatie die belast is met beleid, regelgeving en uitvoering inzake afvalwaterinzameling en -behandeling. Hergebruik valt onder de verantwoordelijkheid van het Ministerie van Landbouw. Andere organizaties, zoals de Ministeries van Gezondheid, Industrie, Binnenlandse Zaken, enz., zijn ook betrokken bij beleid en regelgeving inzake afvalwater.

Hoofdstuk 4 analyseert de Jordaanse en Tunesische ervaringen met afvalwaterbehandeling. De meest gebruikte systemen voor afvalwaterbehandeling zijn actief-slib systemen in verschillende varianten, oxidatiebedden en oxidatievijvers. Voor 26 awzi's zijn het functioneren, en de situatie waarin ze functioneren, onderzocht. De effluentkwaliteit, de zuiveringskosten (kapitaals- en beheerslasten) en het landgebruik zijn gebruikt als indicatoren voor het evalueren van de technologische prestaties. Ook de situatiekenmerken voor afvalwaterbehandeling zijn onderzocht. Hieronder vallen (i) regelgevend kader en institutionele capaciteit, (ii) financiële ruimte en (iii) technische capaciteit. De belangrijkste conclusie is dat afvalwaterbehandeling in Jordanië en Tunesië niet wordt belemmerd door de zuiveringstechnologie zelf (de hardware), maar door de situationele kenmerken die nodig zijn voor het doeltreffend functioneren van de technologie (de software). De prestaties van de awzi's variëren aanzienlijk van de ene tot de andere awzi; zelfs tussen inrichtingen in één land die binnen hetzelfde type vallen en waarin dezelfde processen worden toegepast, komen aanzienlijke verschillen voor. De actief-slibsystemen en oxidatiebedden zijn in het algemeen superieur in termen van effluentkwaliteit, landgebruik en populariteit, ten koste van meer apparatuur, reserveonderdelen en energieverbruik. Actief-slib systemen zijn het duurst, gevolgd door oxidatiebedden. Hoewel oxidatievijvers in principe het goedkoopst zijn, brengen de benodigde aanpassingen van de natuurlijke lagunesystemen de kosten voor beheer en onderhoud op een vergelijkbaar niveau als de actief slib- en oxidatiebedsystemen. Oxidatievijvers blijken minder aanbevelenswaardig, behalve in gevallen waar land beschikbaar is voor een redelijke prijs, en wanneer de huidige percepties over oxidatievijvers positiever worden.

Hoofdstuk 5 analyseert de potentiële drijfveren en belemmeringen die het hergebruik van afvalwater kunnen stimuleren of ontmoedigen. De onderliggende, fundamentele drijvende krachten voor afvalwaterhergebruik kunnen zo beter worden begrijpen. Een aantal geselecteerde irrigatiegebieden werd onderzocht en methodische interviews met stakeholders werden gehouden als onderdeel van het veldonderzoek. De geselecteerde stakeholders waren overheidsfunctionarissen, operationele staf, boeren en burgers (huishoudens). De drijfveren en belemmeringen op regelgevings- en socio-cultureel gebied blijken van groot belang in de besluitvorming van zowel de boeren – die het behandelde afvalwater moeten kopen en een bepaalde agronomische benadering moeten toepassen – als het publiek – dat moet beslissen of het producten wil kopen die verbouwd zijn met gebruik van (behandeld) afvalwater. Deze drijfveren hebben meer invloed op de *WRI* dan de technische overwegingen. De meest prominente drijfveren zijn aan de ene kant (i) landelijke waterschaarste en een grote vraag naar additionele waterbronnen, (ii) de bredere maatschappelijke erkenning van afvalwater als een non-conventionele bron, (iii) de door de bestaande awzi's geproduceerde substantiële hoeveelheden secundair behandeld effluent die geschikt zijn voor beperkte irrigatie, (iv) de perceptie van respectievelijk boeren en consumenten die positief lijkt te zijn met betrekking tot de acceptatie van hergebruik van afvalwater en consumptie van hiermee verbouwde gewassen; (v) de bestaande vermarktingsystemen voor landbouwgewassen die het publiek niet toelaten onderscheid te maken tussen gewassen geïrrigeerd met behandeld afvalwater en gewassen die geïrrigeerd zijn met water van een andere bron; en (vi) de positieve attitude van de Islam ten opzichte van hergebruik van afvalwater. De belemmeringen aan de andere kant zijn (i) de conventionele doelstelling in het nationale beleid van afvalwaterbeheer met de daaraan gekoppelde "lozings"filosofie -- awzi's zijn gewoonlijk ontworpen en gebouwd voor de bescherming van de volksgezondheid en het milieu, terwijl hergebruik vaak pas wordt overwogen nadat de inrichting reeds in gebruik is genomen, (ii) de toegang tot grond- en oppervlaktewater van goede kwaliteit tegen te lage tarieven, hetgeen een competitie ontwikkelt voor het behandeld afvalwater, (iii) de bestaande zeer restrictieve normen en richtlijnen die het gebruik van behandeld afvalwater slechts toestaan voor beperkte irrigatie, en dus de vermarktingsopties van de boeren beperken, (iv) het onvoldoende functioneren van de instituties, veroorzaakt door het grote aantal betrokken organizaties waartussen onvoldoende coördinatie en samenwerking bestaat en waar het behartigen van de eigen belangen prioriteit heeft, (v) onvoldoende opslagcapaciteit voor het behandelde effluent, waardoor de aanvoer naar het boerenbedrijf onbetrouwbaar wordt, (vi) onvoldoende bewustzijn en educatie van de boeren en het publiek met betrekking tot de kosten en baten van hergebruik van afvalwater, (vii) over-afhankelijkheid van donorfinanciering ten gevolge van beperkte beschikbaarheid van lokale fondsen, en slechte inkomsten-generatie, en (viii) de psychologische aversie die sommige boeren en consumenten tegen hergebruik van afvalwater hebben, en de vrees voor kritiek vanuit de maatschappij op dit punt.

Hoofdstuk 6 beschrijft het huidige beleid voor tarifering van (zuiver) water en de opties voor het verhogen van deze tarieven om het hergebruik van afvalwater te stimuleren door het prijsverschil tussen de beide waterkwaliteiten te vergroten. Ook wordt het effect van het verhogen van het watertarief op de winstmarges in de boerenbedrijven onderzocht. Als de huidige tarieven onveranderd blijven, kan hergebruik van afvalwater commerciëel alleen aantrekkelijk zijn als het gratis, of tegen een zeer laag tarief, aan de boeren wordt verstrekt. De voordelen van een verhoudingsgewijze verhoging van de schoon-watertarieven zijn drievoudig. Ten eerste zou dit het behandeld afvalwater aantrekkelijker maken. Ten tweede zou het waterbesparing stimuleren waardoor de druk op de grondwatervoorraad vermindert. Ten derde zou het kunnen worden gebruikt als bron van inkomsten om de investeringskosten voor transport en distributie van behandeld afvalwater (deels) te dekken. De bestaande watertarieven (voor grondwater, oppervlaktewater, gemengd water en secundair behandeld water) hebben een beperkte invloed op de winstgevendheid van landbouwbedrijven, omdat deze tarieven zeer laag zijn. Een verhoging van de tarieven met US$0,05/m^3 vermindert de winst voor de boer met US$250-700/ha/jaar. Een verhoging van de tarieven met US$ 0,10/m^3 zou de hierboven genoemde reductie van de winst van de boeren verdubbelen. Een dergelijke vermindering van de winstgevendheid is cruciaal voor sommige boeren en triviaal voor anderen. Het verhogen van de tarieven met meer dan US$0,10 zou irrigatie met grond- of oppervlaktewater echter onhaalbaar maken en zou de boeren mogelijk kunnen dwingen om over te gaan op het gebruik van behandeld afvalwater als de tarieven daarvan laag blijven en als de aanvoer en de kwaliteit betrouwbaar zijn. Deze drijfveer zou echter zijn effect kunnen verliezen door het feit dat veel boeren hun eigen voorzieningen beheren om deels in hun waterbehoefte te voorzien met zowel oppervlaktewater als grondwater. Derhalve is het essentieeldat ook de energietarieven worden aangepast. In deze gevallen blijft het de vraag of het verhogen van de diesel- of elektriciteitstarieven, en het verlagen van de subsidies hierop, de meest doeltreffende manier is om te stimuleren dat minder grond- of oppervlaktewater en meer behandeld afvalwater wordt gebruikt.

Hoofdstuk 7 beschrijft de bereidheid van boeren om voor behandeld afvalwater te betalen. Er is een regressiemodel ontwikkeld om de beslissingen van de boeren te correleren met de financiële stimuli waaruit deze beslissingen voortkomen. Het model laat zien dat de watertarieven en de winstgevendheid van de landbouwbedrijven een significante invloed kunnen hebben op de bereidheid van de boeren om voor behandeld afvalwater te betalen. Circa 97% van de boeren had interesse om behandeld afvalwater te gebruiken, als dit gratis ter beschikking zou worden gesteld, als het aanbod betrouwbaar zou zijn en als het geschikt zou zijn voor obeperkte irrigatie. Deze bereidheid nam af tot 84% en 47% als de voorgestelde tarieven US$0,05/m^3, resp. US$0,10/m^3 zouden zijn. Met dergelijke tarieven kunnen de minimum kosten voor het aanbieden van secundair behandeld afvalwater nauwelijks gedekt worden. Als het water ook geschikt moet zijn voor onbeperkte irrigatie, dan brengt dit nog additionele zuiveringskosten met zich mee. Dit betekent dat ambitieuze pogingen om kosten terug te verdienen door de tarieven voor behandeld afvalwater te verhogen, mogelijk slechts deels zouden slagen aangezien de boeren nog steeds gemakkelijke en goedkope toegang hebben tot competitieve alternatieve waterbronnen.

Hoofdstuk 8 presenteert de conclusies van het onderzoek. De hoofdconclusies zijn: (i) de onbalans in de markt voor behandeld afvalwater – groot aanbod en lage vraag – wordt veroorzaakt door hoge verhoudingen van afvalwaterproductie en inzameling, gemiddelde verhoudingen voor behandeling, en lage voor gebruik van het effluent, en (ii) het in balans brengen van de markt voor behandeld afvalwater impliceert het maximaliseren van de behandelingsverhouding tot dicht bij de inzamelingsverhouding en het verhogen van de hergebruikverhouding tot dicht bij de behandelingsverhouding, (iii) een verhoogde kwaliteit en kwantiteit van behandeld afvalwater wordt bepaald door de situationele kenmerken waarin de bestaande technologieën zijn toegepast, en (iv) verhoogde verhoudingen in het gebruik van behandeld afvalwater voor irrigatie in de landbouw lijken sterker bepaald door regelgeving, tarifering van alternatieve schoon-waterbronnen, institutionele factoren en socio-culturele drijfveren en belemmeringen, dan door de technische factoren.

Biography

Maher Omar Rushdi Abu-Madi was born on 19th January 1969 in the village of Attil, 90 km north of Jerusalem, the West Bank - Palestine. In 1987 he finished his secondary education at Attil Boys School. In 1993 he was awarded a Bachelor degree in Chemical Engineering and Technology from India, Banaras Hindu University (BHU), Institute of Technology, Department of Chemical Engineering and Technology. He worked for few months with Palestine Pharmaceutical Company, Ramallah, which he left in 1994 to attend a training course entitled "Water Supply and Environmental Sanitation" at Birzeit University in cooperation with IHE-Delft. In 1996 he was awarded M.Sc degree in Sanitary Engineering from IHE-Delft, the Netherlands.

After his graduation, he accomplished a desk study on the technically and socially acceptable options in water supply and sanitation in the Eastern Mediterranean countries as a consultancy work to the International Research Center for Water and Sanitation (IRC) in The Netherlands.

Upon his return to Palestine in 1996, he was employed by an NGO called the Palestinian Hydrology Group (PHG). He worked as a water and environmental engineer, where he worked on many development projects and research issues in the field of water supply and sanitation. He enjoyed most working among communities and understanding their characteristics, capabilities, and needs. This has much facilitated his PhD research, especially the part dealing with households and farmers.

In 1999 he was nominated by Birzeit University to pursue his PhD education at UNESCO-IHE Institute for Water Education and the Technical University of Delft, under the WASCAPAL cooperation project for capacity building.

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"This is not the end,
it is not even the beginning of the end,
but it is the end of the beginning"
[W. Churchill]

As a result of chronic water scarcity, the countries of the MENA region (Middle East and Northern Africa) recognize reclaimed wastewater as a non-conventional water resource. Nonetheless, in this region, substantial amounts of the wastewater that are collected are still discharged into the sea or water courses without treatment. Moreover, most of the treated wastewater is not re-used but discharged. The objective of this research is to analyze the technological, regulatory, institutional, financial, and socio-cultural opportunities (incentives) and constraints (disincentives) that influence the adoption of wastewater treatment and reuse for agricultural irrigation in the MENA region based on the experiences of Jordan and Tunisia. A fieldwork was conducted in Jordan and Tunisia to collect data on wastewater treatment, agricultural irrigation with the reclaimed wastewater, and crop marketing and consumption. The data collection in the two countries targeted 72 administrators, 31 wastewater treatment plants, 104 farmers and their irrigated farms, 326 households, and 3 crop markets.

Though Jordan and Tunisia have made great strides in raising the proportion of re-used wastewater, their Wastewater Reuse Index (*WRI*) (which measures the actual reuse rate over the potential one) is still only 27.8 and 12.7, respectively. The lack of an integrated wastewater management and reuse policy, and the poor coordination between bureaucracies are major hurdles. Different from the expectation, farmers and customers alike are relatively well prepared to use reclaimed wastewater in irrigation, and to buy crops from these fields. However, to raise the *WRI*, the economic and marketing dimensions of reuse should be better recognized. Notably, pure freshwater should be priced higher and reflect its true scarcity, thus creating a stronger incentive for farmers to buy the reclaimed wastewater. Similarly, better crop market transparency and regulation would increase the confidence of the consumer and remove a disincentive to buy such crops.



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