WASTEWATER REUSE: A SUSTAINABLE WATER RESOURCE IN THE MIDDLE EAST AND AFRICA

Valentina LAZAROVA

Technology and Research Centre (CIRSEE), Suez Lyonnaise des Eaux,
38, rue du Président Wilson, 78230 Le Pecq, France

ABSTRACT

Municipal wastewater reuse, reclamation and recycling are essential to the development of sound water and environment management policies. In arid and semi-arid regions, wastewater reuse is a vital component of their development ensuring alternative water resource, sustainability, reduction of the environmental pollution and health protection. The purpose of this paper is to provide an overview of the role of wastewater reuse in the development of new integrated resource management strategy in arid regions and to analyse the costs and benefits of wastewater reclamation in comparison with other alternative solutions. The emphasis is made on the technical-economic evaluation of the reclaimed water for several typical treatment schemes needed to produce water quality in accordance with the different reuse applications (agricultural and landscape irrigation, potable and industrial uses).

Key words: Middle East, Africa, wastewater reuse, integrated resource management, cost evaluation, reclamation technologies.

TABLE OF CONTENTS

INTRODUCTION

Water, the white gold of our planet, is our most precious heritage. Like the air, the sun and the earth, water is an essential element for life, and is present everywhere: from the smallest of our body cells, to every activity of our daily life. Yet unfortunately, water is no longer the pure, inexhaustible and ever available resource which was exploited and venerated by our forefathers. Water is endangered by its uneven distribution in time and space as well as by the growing pollution of natural resources and their « savage » exploitation. On the eve of the 21st century, water management has become a global issue.

Despite improvements in the efficiency of water use in many developed countries, the demand for fresh water has continued to climb as the world's population and economic activity have expanded. According to some recent projections, in 2025 two thirds of the world's population will be under conditions of moderate to high water stress and about half of the population will face real constraints in their water supply. The situation of water stress is particularly critical in the Middle East and North Africa, an arid region which accounts for about 5% of the world's population, but only 1% of the fresh water. Almost all fresh and renewable waters such as rivers, streams, lakes and groundwater, which are termed « conventional water », have already been exploited in Saudi Arabia, the Arab Emirates, Oman, Qatar, Kuwait, Bahrain, Yemen, Jordan, Israel, Palestinian Autonomy and Libya or will be fully developed in several other countries of the Middle East and North Africa by the next few years. It is important to stress that in the countries in Arabian peninsula, only a few part of water demand is covered by renewable surface or groundwater. Depletion of non-renewable resources (fossil groundwater in deep aquifers) has taken place at an accelerated rate in order to meet the rapidly rising demand, especially in the agricultural sector. Figure 1 illustrates this trend comparing the distribution of water supply and demand in Saudi Arabia for 1990 and 2010 (Al-Ibrahim, 1990). Sea water desalination and wastewater reuse become important alternative resources.

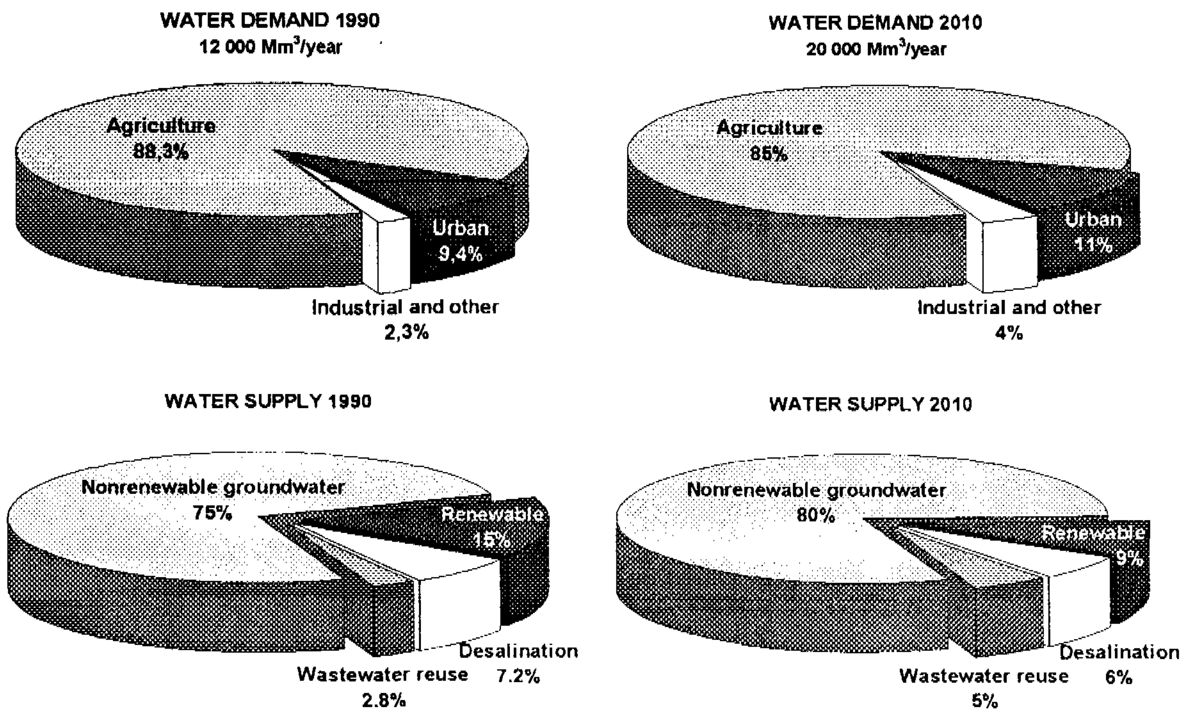

Fig. 1 Distribution of water demand and supply in Saudi Arabia (adapted from Al-Ibrahim, 1990)

In a recent report on the environmental problems of the Middle East and North Africa, the World Bank strongly recommends the soon implementation of comprehensive water demand management policies: (1) raise water prices to ensure complete cost recovery and even impose marginal cost of next resources in order to enhance water conservation, (2) recycle and reuse solid and liquid wastes, (3) eliminate subsidies on fertilisers and pesticides in order to slow down the potential pollution of resources and (4) promote the introduction of the private sector into the water industry and utilities.

The main objective of this paper is to demonstrate the role of wastewater reuse for the development and implementation of a comprehensive integrated water management strategy in the arid regions of the Middle East and Africa, in order to face water stress, ensure alternative resource and sustainable development of the arid and semi-arid regions.

BACKGROUND

Population growth, urbanisation and industrial development are the main factors which increase the water shortage by perpetually pushing up demand. One approach widely used to evaluate the water availability is the **water stress index**, measured as the annual renewable water resources per capita that are available to meet needs for domestic, industrial and agricultural use. On the basis of past experiences of moderately developed countries in arid zones, renewable freshwater resources of 1,000 m^3/capita/year have been proposed as a benchmark below which most countries are likely to experience ***chronic water scarcity*** on a scale sufficient to impede development and harm human health (World Resources). According to some experts, below 500 m^3/capita/year, the countries experience ***absolute water stress*** (Falkenmark and Widstrand, 1992).

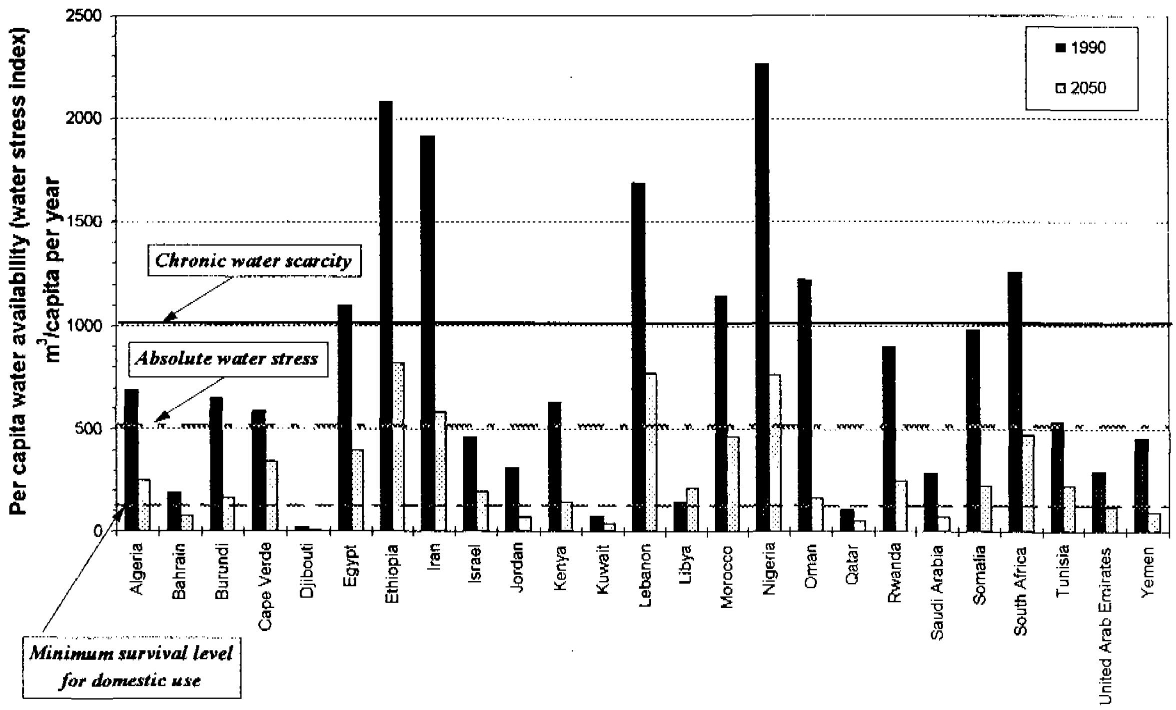

Fig. 2 Projected annual renewable resources per capita per year (water stress index) for 2050 compared with 1990 for countries with water shortage in the Middle East and Africa (adapted from World Resources 1996-1997)

Population Action International has projected future water stress index for 149 countries, showing that one third of them will be under water stress by 2050. Africa and parts of western Asia appear particularly vulnerable to increasing water scarcity (Fig. 2). In addition, numerous nations with adequate water resources have arid regions where drought and restricted water supply are common (northwestern China, western and southern India, large parts of Pakistan and Mexico, the western coasts of the USA and South America, Mediterranean region).

Figure 2 shows that a number of Middle Eastern countries are already well below the absolute water stress of 500 m^3/capita/year and will attend by 2050 the minimum survival level of 100 m^3/capita/year for domestic and commercial use. These data also suggest that many countries will have to manage water resources far more efficiently than they do now if they are to meet their future needs. Nevertheless, such projection must be interpreted cautiously, since that depends on the actual situation. Israel, for example, supports its increasing population, industrial growth and intensive irrigation with less than 500 m^3/cap/year with efficient management of its wastewater, 70% of which are reused for irrigation after appropriate treatment. A high standard of living is maintained with domestic, urban and industrial consumption of about 100-125 m^3/cap/year by water metering, effective pricing and control and public education on water conservation. Even so, Israel's present water use may not be sustainable, since it overdraws water from aquifers and depends on the West Bank for 25% of its supply.

INTEGRATED MANAGEMENT OF WATER RESOURCES

The integrated management of water resources, in terms of long term water planning, comprises three main elements: water supply and demand management, environmental protection and sustainable development, viewed in terms of their interactions and conveyed by economic, social and ecological criteria. The notion of sustainable development, in particular as it relates to ensuring adequate water supply, encompasses several requirements including economic development on the basis of existing natural resources but without degradation of the environmental systems. Every aspect of resources is taken into account, including quality (more stringent standards, better targeted to different uses), quantity (restrictions in some sectors), interactions between different types of resources (rivers, lakes, underground water), better management of the anthropogenic water cycle and administrative and legal control mechanisms. The main aim of this new policy is to ensure a dynamic balance between the needs which stem from human activities and the needs of nature, whilst averting a conflict of interest between the different users and developing the use of waste products.

This approach leads to the creation of closed and decentralised loops favouring the development of alternative solutions suited to local constraints, and responding to present and future needs (Fig. 3). Supplying the anthropogenic water cycle with alternate water resources, such as water reclamation or desalination amounts to accelerating the natural water cycle through advanced technical solutions.

The development of such an integrated water management strategy in countries with water shortage includes an analysis of the technical, economic, institutional and environmental aspects of the following alternative solutions: (1) development of any undeveloped water supply solutions, including desalination of brackish or sea water, (2) wastewater treatment and reuse, (3) inter-basin transfer, (4) improvement of irrigation system efficiency, (5) minimisation of water leakage and proper charges for water and (6) import of water from neighbouring countries.

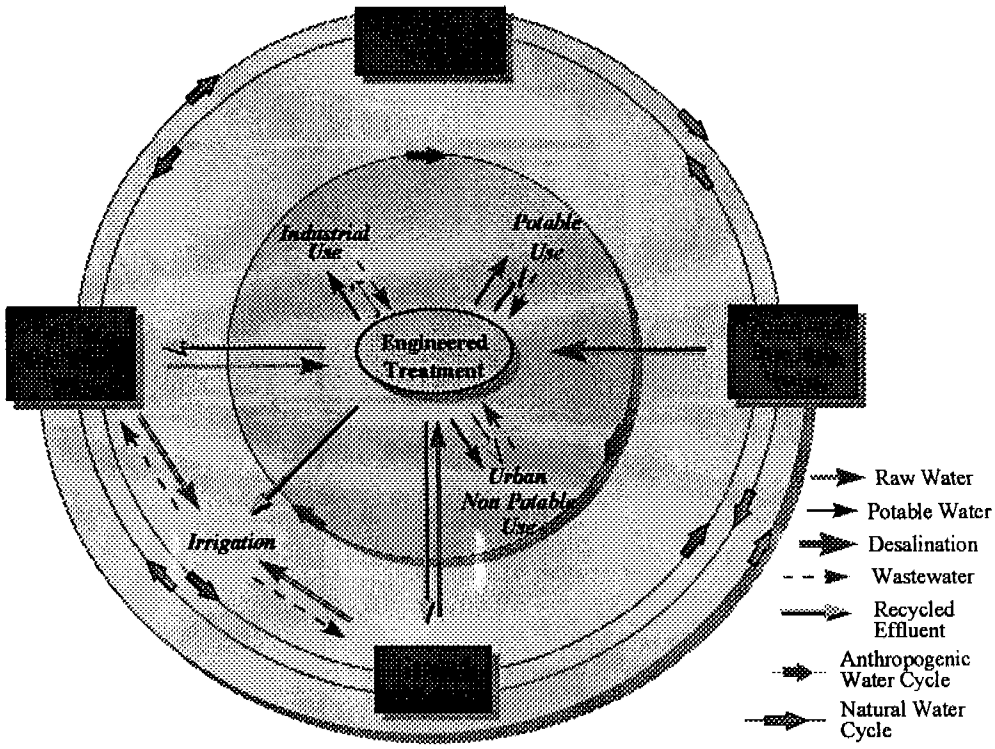

Fig. 3 Integrated water management with wastewater reuse and desalination as alternative water resources

Improving the efficiency of water use and reducing waste and losses are the most affordable solutions to face water scarcity. Conservation of water becomes essential through pricing reforms, wastewater treatment technologies and wastewater reuse, especially for non-potable purposes.

For a number of countries in the Middle East and North Africa, where current fresh water reserves are or will be in the near future at the limit of the survival level (the minimum amount needed for domestic, urban and industrial use), recycled wastewater is the only significant low cost alternative resource for agricultural, industrial and urban non-potable purposes. A higher investment—about US$300-500—is needed for the sewerage network (Arlosoroff, 1996). However, in such countries with dense population, wastewater collection and treatment is essential to protect public health and prevent environmental pollution. Thus, the additional cost for wastewater reuse for irrigation, for example, represents only a small fraction—about 30% of the total cost for wastewater treatment and disposal. Moreover, the multiple other benefits of wastewater reuse and recycling are recognised in a number of countries and included in their water master plans and national policies.

ROLE OF WASTEWATER REUSE

Depending on local conditions and consumers' requirements in terms of quality, two major types of reuse have been developed and practiced throughout the world (Table 1): (1) potable uses, which can be direct, following high levels of treatment, or indirect, after passing through the natural environment and (2) non-potable uses in agriculture (irrigation), industry and urban settlements.

Agriculture accounts for the largest share of water consumption, with up to 70-98% of global demand. In some arid and semi-arid countries, wastewater reuse provides the greatest share of irrigation water (Israel, Jordan, Tunisia). Urban non-potable reuse (irrigation of green areas, waterfalls, fountains, road cleaning, car wash, toilet flushing and fire-fighting) is developing rapidly and is becoming a key element in the integrated water management policies in high density urban areas. This application begins to be well developed in numerous countries in the Middle East. Indirect potable water production from wastewater is carried out on a large scale in the United States, UK and South Africa. The only existing example of direct potable water production is the Windhoek plant in Namibia: 15% of wastewater diluted with natural resource water, with the aim of reaching 25% by the year 2000. There has never been any report of a negative impact of this type of water on human health.

Table 1: Categories of water reuse: implementation and management characteristics

Application		Requirements	Driving factors
Potable wastewater reuse	Indirect potable	• Health effect studies • High water quality (pathogens) • Advanced treatment • Blending with drinking water	• Water shortage and drought • Water independence • Groundwater replenishment • Population growth • Regulatory pressure
	Direct potable		• Water stress • No other alternative (Windhoek) • Public support (Denver)
Non potable wastewater reuse	Agricultural irrigation *- food crops* *- non food crops* *- aquaculture*	• Agronomic value • Impact on soils • Water quality (pathogens, salinity) • Secondary treatment and disinfection	• Water shortage and drought • Alternative to effluent disposal • Cost savings • Fertilising value
	Recreational uses *- fishing, boating, swimming*	• Water quality (pathogens)	• Water shortage and drought • Enhancement of the environment
	Industrial uses *- cooling and boiler water* *- process water*	• Water quality (pathogens, salinity) • Advanced treatment	• Water price • Water independence
	Urban uses *- unrestricted landscape irrigation (parks, schools)* *- restricted irrigation (golfs, cemeteries, residential)* *- fire protection* *- in-building uses*	• Water quality (pathogens) • Dual distribution systems • Tertiary treatment and disinfection	• Water shortage and drought • Population growth • Public authority reuse policy • Stringent discharge standards • Enhancement of the environment

Wastewater reuse and recycling offers a great water resource potential for arid and semi-arid countries, in particular to ensure additional water for industry, agriculture and urban non-potable reuse. For example, under optimal conditions, a city with 1,000,000 population and water consumption of 125 m^3/cap/year can collect, treat and reuse 80% of that amount for irrigation of up to 20,000 ha of agricultural areas (Shuval, 1994).

In Africa, wastewater reclamation projects are being conducted in water deficient areas for agricultural irrigation. Examples of this expansion are found in Egypt (El-Gohary *et al*, 1989), Tunisia (Bahri and Brissaud, 1995), Morocco (Benchekroun and Bouchama, 1991), South Africa (Korf *et al.*, 1996), Namibia (Haarhoff and Van der Merwe, 1995), and Zimbabwe (Marks and Lock, 1988).

The existing wastewater reuse experience in the Middle East is also successful: 20,000, 26,000, 55,000, 67,000 and 115,000 m^3/d are reused for agriculture and landscape irrigation in Taif, Dubai, Jubail, Doha and Abu Dhabi, respectively with chlorinated tertiary effluent (Al-A'ama and Nakhla, 1995; Banks, 1991). Water quality of the disinfected tertiary effluent is relatively high from 100 MPN/100 mL in Dubai to 2.2 MPN/100 mL in Taif and Jubail. An important step to reuse wastewater effluent has been made in Riyadh, the capital of Saudi Arabia, where 200,000 m^3/d of treated sewage water is used to irrigate 175 farms with an area of 1,200 ha (Al-Ibrahim, 1990). A dual water pipeline has been suggested for Taif to meet growing demands by the year 2020 (Ukayli and Husain, 1988).

Mohorjy (1989) defines the role of wastewater reuse in Middle Eastern countries as resourcefuls, economical, serviceable, feasible, convenient, suitable, dependable and acceptable. However, despite the undoubted advantages and benefits, wastewater reuse is only on an earlier stage of development in the Middle East and Africa. The total volume of reclaimed water in the Middle East in 1992 is estimated at 453 million m^3 or less than 30% of the volume of desalinated water (Abdulrazzak, 1995). Currently, wastewater reuse represents only 14% of the domestic water demand and should be increased to 50-70% of the total wastewater volume. Moreover, implementation of water reuse programs can alleviate existing pollution problems in the coastal areas and in shallow aquifers.

Finally, the analysis of the role of wastewater reuse in the integrated water management shows that reclaimed water could be an attractive, competitive and viable alternative water resource for all arid and semi-arid countries:

- for developing countries—the main objective is health and environmental protection—the poverty is a root cause of much environmental degradation, because the very poor have no options to degrading their own environment in their quest for survival and they also suffer the most as a result of this degradation;
- for developed countries—wastewater reuse enables to avoid substantial loss of investments for water desalination, as well as for wastewater treatment needed in all cases for social and environmental reasons.

Key factors for the successful development of wastewater reuse

Six key factors with gradual importance contribute to the success of a water reuse project: economic, financial, regulatory, psychological, organisational and technical factors (Fig. 4).

The economic, financial and psychological factors depend on two main groups of parameters: (1) the internal motivation of the local water agencies and authorities to rapidly establish a meaningful economic analysis and a rigorous financial plan and to gain public acceptance and (2) external non-controlled parameters such as slow and heavy institutional decision-making process, politicians' subjectivity, stakeholders' personality.

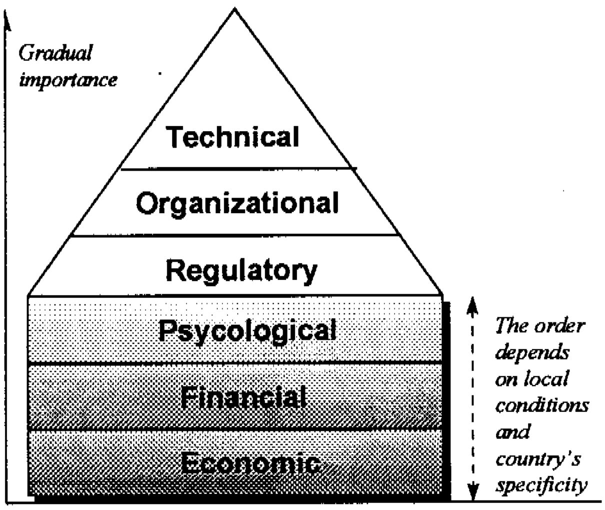

Fig. 4 Influence of the main key factors for the successful development of wastewater reuse

The psychological factor is essential for initiating, implementing and sustaining a long term wastewater reuse program. Surveys on the public's attitude toward various wastewater reuse projects indicate that the public acceptance tends to increase with income and education. The reuse for potable purposes receives the greatest opposition even in developed countries. Public education is an important factor for success in both developed and developing countries. Abdel Rahman (1994) underlines that taboos, local habits and customs make Islamic people very skeptical about reusing wastewater. In the same time, inadvertent or unintended reuse of raw wastewater are not uncommon.

The regulatory factor is not so much important as some projects are running in states where no specific water reuse regulations were established. In those cases, regulation is made on a case-by-case basis, using other states' references and drinking water standards. However, the development and enforcement of wastewater reuse standards is an essential step for the development and social acceptance of wastewater reuse. These reuse standards must be adapted to the country's administrative infrastructure and respond to its water conservation strategy.

The organisational factor governs the implementation time and quality of a project, not its success or failure. In the case of complex administrative organisation, the development of wastewater reclamation could be refrained by conflictual interest between organisations such as the department of environment and the department of agriculture or between local and national governments. Therefore an administrative reorganisation may be necessary to guarantee the development of wastewater reuse into a general water management scheme. Examples of such changes are taking place in Tunisia, Morocco and Egypt (Jankel and Williamson, 1996).

The technical factor is the least important as today available technologies make it possible to reach any water quality required by users and regulatory compliance. Various extensive and intensive technologies can been applied, depending on local conditions, plant size and water quality standards (Lazarova *et al.*, 1998). However, the choice of the most appropriate technologies plays a key role for the reliable operation of the reclamation plants and the guarantee of water quality at lower O&M costs.

Contribution of the private sector: Lyonnaise des Eaux experience

Over recent years, an important trend in developed and emerging countries is the privatisation and opening of the water supply and sewerage services to market forces. Many less developed countries are also keen to promote private sector involvement in the water sector. The main advantage is to cut public sector deficits, promote investments and ensure a better water resources management.

The international group Suez Lyonnaise des Eaux serves over 70 millions inhabitants in all continents with various contracts, from limited O&M services to total privatisation of the water sector. Wastewater reuse is becoming a new service developed to better satisfy client's and customer's requirements in the regions with chronic water deficits and stress. In order to better guarantee water quality requirements for the different reuse applications, the Lyonnaise des Eaux group is developing various technical tools: (1) extensive technologies (ponds, infiltration-percolation, wetlands), well adapted to the climatic condition of tropical and sub-tropical regions, as well as (2) intensive technologies (filtration, physico-chemical treatments, membranes) and advanced disinfection processes (chlorination, UV irradiation, ozonation), which are more compact et guarantee better water quality (Lazarova *et al.*, 1998, Renaud *et al.*, 1997). Their implementation ensures better public health and environmental protection and leads to new urban applications.

The actual trend in private operation is the choice of the most adapted technologies to the given local conditions. In Casablanca (Morocco) for example, LYDEC (Lyonnaise des Eaux of Casablanca) is thinking of the integration of wastewater reuse into the middle and long term master plans. Agricultural and landscape irrigation are the main reuse applications. In order to guarantee the WHO standards of <1000 faecal coliforms/100mL et <1 helminth egg/L, various extensive (lagooning, high rate ponds) and intensive processes (activated sludge, trickling filters, disinfection) have been evaluated.

Significant problems of drought for many consecutive years in Spain showed the importance of wastewater reuse as alternative resource for irrigation, ensuring the sustainable development of Catalonia, Andalousia and the islands of Canary's and Balears. The group AGBAR, for example, operates over 200 WWTP with wastewater reuse and design capacity from 200 to 40,000 m^3/d (Llagostera and Prat, 1997). Important R&D efforts have been made on the choice of appropriate treatment technologies: from tertiary treatment by infiltration-percolation and disinfection in Catalonia and Balears, to membrane processes in Canarian islands (project DEREA).

In countries where the existing water reuse standards are very stringent (Australia, the USA, the Middle East), secondary and tertiary treatment is required followed by final disinfection. Such an example is the wastewater reuse facility in Taif, Saudi Arabia, designed and constructed by Degrémont company (67 000 m^3/d, 270 000 p.e.), where the treated effluent is used for agricultural and landscape irrigation after advanced treatment by coagulation/flocculation, multimedia filtration, activated carbon filtration and chlorination.

The wastewater reuse facility in West Basin, California (final capacity of 270,000 m^3/d), operated by United Water Services, subsidiary of Suez Lyonnaise des Eaux, is developing a large wastewater reuse program on the basis of advanced treatment and various reuse applications and services: (1) 70 % of the effluent is reused for landscape irrigation (parks, golfs, cemeteries, schools) after a Title 22 treatment, (2) a part of the Title 22 effluent is used for cooling in the petroleum industry after additional nitrogen removal trough biofiltration by Biofor or as boiler water after advanced membrane treatment by MF/RO, (3) another part of the secondary effluent is also treated by RO after lime or MF pre-treatment and is reused for aquifer recharge to avoid salt intrusion. Moreover, a dual distribution system is developed for the Title 22 effluent. After extension, this facility will be one of the largest reuse plants not only in California, but also in the USA.

The first indirect potable reuse project in Europe named Water 2000, is implemented in 1997 at Essex, UK by the private company Essex&Suffolk Water, subsidiary of Suez Lyonnaise des Eaux. Over 35,000 m^3/d of tertiary effluent is blended with surface water (maximum dilution rate reached is 37 %) and used for replendishment of the Hanninglield drinking water reservoir. A strict water quality control has been implemented including the monitoring of viruses and oestrogens, as well as numerous studies of the impact of reuse on the environment (estuary ecosystem) and public health.

Concerning urban water reuse applications, South Africa and Australia are the countries with the most stringent standards requiring drinking water quality and zero viruses, respectively. In this case, the treatment chains are similar to those applied for potable reuse. In order to face such stringent requirements, Lyonnaise des Eaux developed a new hybrid process, the Membrane BioReactor (MBR)®, evaluated in Australia (Cronula and Malabar) as a compact technology very well adapted for such stringent requirements. This technology was chosen for one of the first industrial applications of the in-building grey water recycling in Europe in a building with 65 apartments in Annecy, France.

In order to better satisfy the wastewater reuse requirements, the Technology and Research Centre (CIRSEE) of the Lyonnaise des Eaux is initiating and running numerous R&D projects on the water quality, including the application of high-tech methods for monitoring of organic micropollutants and pathogens, optimisation of treatment processes by means of both pilot plant studies and applications of advanced numerical modelling, as well as trough the coordination of an European project on the role of wastewater reuse in the integrated water resource management.

Economic evaluation of wastewater reuse projects

The economic analysis focuses on the value of the resources invested in a project to construct and operate it, measured in monetary terms and computed in the present value. A meaningful economic analysis depends on the reliability of the preliminary market assessment. Indeed, the identification of the potential clients, assessment of their needs, required water quality and their distance from the site of reclaimed water production govern the costs and benefits of a project.

The economic analysis should consider only the future flow of resources invested in or derived from a project. Therefore the water price should not be confused with the water cost as debt service on past investments is not included in an economic analysis (Asano and Mills, 1990). Only the marginal cost of wastewater reclamation (additional treatment, storage and distribution) must be included without the cost of wastewater collection and treatment. The final purpose is to evaluate the global economic viability of the water reuse project compared to other alternative solutions.

Theoretically, a meaningful economic analysis is composed of two phases: (1) micro-economic approach: the ***cost-effectiveness methodology*** is used for the choice of the alternative and (2) macro-economic approach: when the choice is made, the ***cost-benefit method*** should be applied to evaluate all positive impacts of wastewater reuse.

An important aspect of the economic analysis is that it should take into consideration all costs and benefits associated with the alternatives under consideration, placing all alternatives on equal footing for comparison. However, when comparing alternatives that cause complex social and environmental effects, the technique of cost-benefits calculations is hard to use. The investments and expenditures really do not fit the cost/benefit framework because the outcomes often cannot be measured in monetary values. Only a micro-economic approach is actually used to choose the alternative and assess its economic viability. The environmental benefits and the positive impact on public health are not included in this analysis but are used as marketing arguments to attract potential clients.

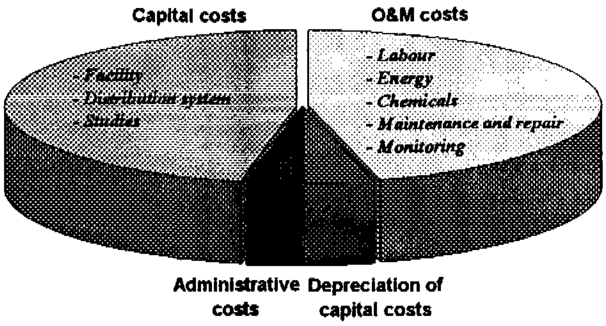

Fig. 5 Composition of reclaimed water costs

Figure 5 illustrates the composition of the total cost of water reuse. The costs of the collection of the secondary effluent, additional treatment and storage, distribution system and all connections are included. The distribution of capital and O&M costs varies from one project to another and depends on the type of the applied treatment processes. These costs are also highly influenced by local constraints: price of the building site, distance between the production site and the consumers, need to install a dual distribution system or retrofitting (Aussoleil, 1983). The latter two constraints are important as in many projects, the main capital investment concerns the distribution system.

Richards *et al.* (1993) analysed the effect of the plant capacity on capital cost for conventional secondary treatment (activated sludge) and different post-treatments (Fig. 6). The capital costs for tertiary filtration and disinfection or even for full Title 22 treatment (coagulation - flocculation, filtration and disinfection) did not exceed 30-40% of the investment for secondary treatment. Significantly higher expenses are needed for activated carbon filters (GAC) and reverse osmosis (RO).

On the basis of the experience of the USA (Fig. 7), the life cycle cost for the treatment of raw wastewater to produce reclaimed water suitable for unrestricted irrigation varies from 0.43 to 1.10 US$/m^3. The part of the O&M costs compared with the capital amortisation in the total cost depends on the treatment technology and is higher for the high-tech processes of GAC and RO compared to secondary treatment with or without tertiary filtration and disinfection. Significant economies of scale may be achieved for large reclamation facilities: the life cycle cost could be halved when the plant capacity increases from 4,000 to 20,000 m^3/d or from 50,000 to 200,000 m^3/d.

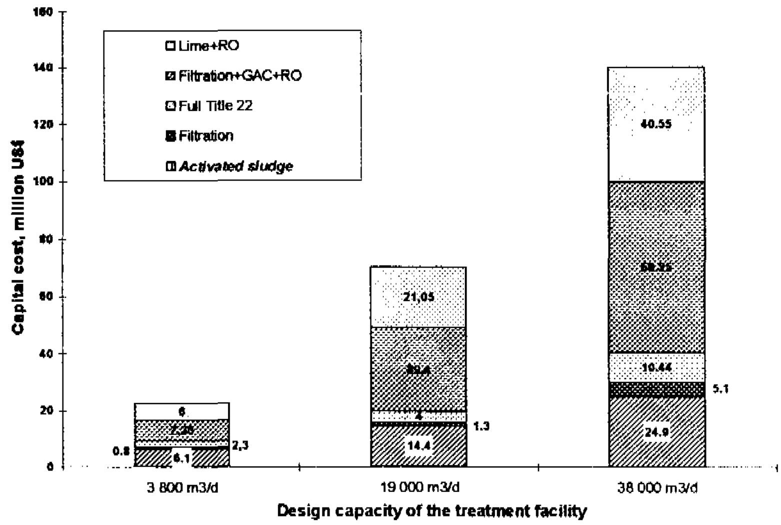

Fig. 6 Estimated Capital Costs for Reclamation Treatment Facilities in 1996 US$ (adapted from Richard et *al.*, 1993)

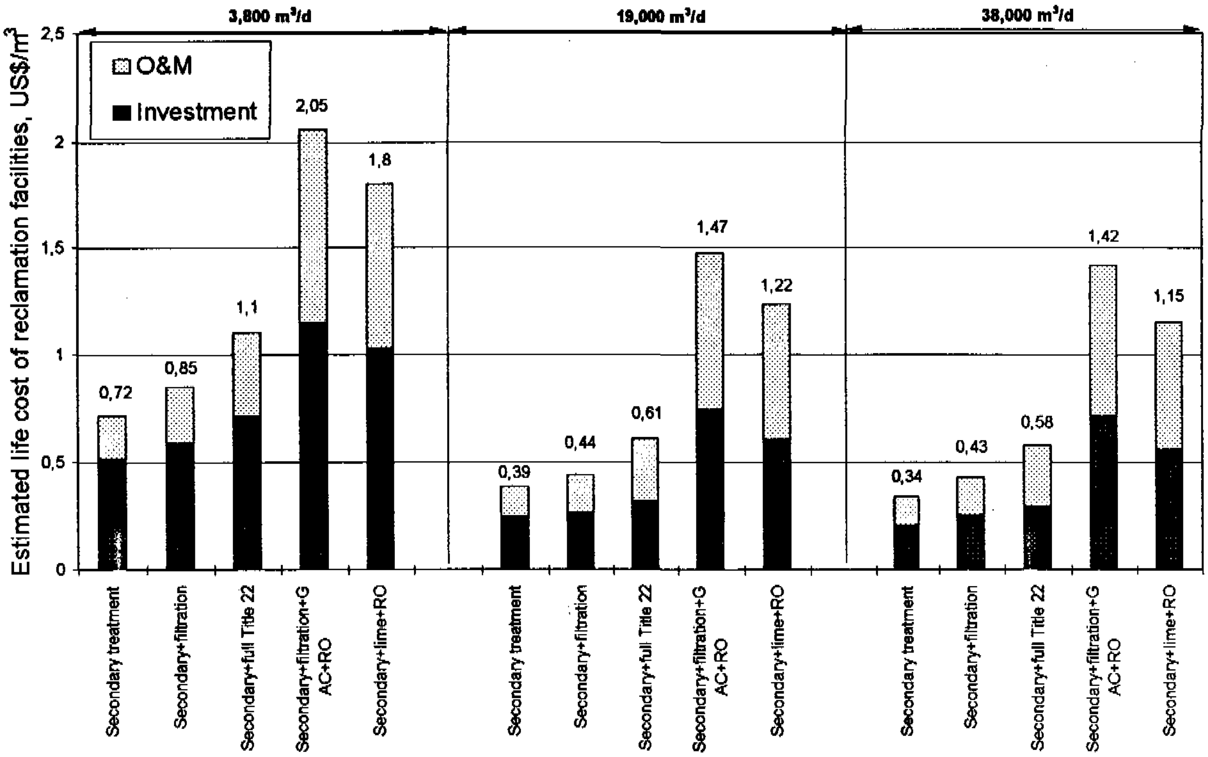

Fig. 7 Estimated operation and maintenance costs for reclamation treatment facilities in 1996 US$ (Richard *et al.*, 1993): capital costs are amortised for 20 years at a return rate of 10%

It is important to stress that the unit cost of reclaimed waste water depend not only on the plant size and the treatment chain, but also on wastewater composition, water quality requirements and other local conditions (energy costs, labour, etc.).

Distribution system cost is an important part of reclaimed wastewater cost and can reach 70% of the overall costs depending on site specific conditions. New systems need lower expense compared with the retrofitting of existing networks. Values from 0.06 US$/m^3 in Jubail, Saudi Artabia (Al-A'ama and Nakhla, 1995) to 0.14 and 0.36 US$/m^3 in the Dan Region and Jerusalem, Israel respectively (Shelef, 1991), have been reported.

Comparison with other alternatives

Most of the countries of the Arabian peninsula (Saudi Arabia, Kuwait, Bahrain, Qatar) rely heavily on large-scale desalination plants to satisfy from over 50% to 95% (Kuwait) of the urban water demand with overall combined capacity of 1,863 billion m^3 in 1990 (Abdulrazzak, 1995). A large number of small desalination plants make desalination an expensive alternative. Moreover, the high salinity of the Red Sea leads to higher desalination costs: from 2.5 to 10 US$/m^3 (Abdulrazzak and Khan, 1990) compared with the reported costs in the USA in the range of 1 to 2.6 US$/m^3. Arlosoroff (1996) reported lower values for the reverse osmosis cost in Israel in the range of 0.7 to 1.1 US$/m^3. Even if the cost of desalination has shown a clear trend towards decreasing for the last few years, direct comparison of this data remains difficult because of the lack of data as to whether the cost of transportation is included or not, and also because the reported costs are not revised for inflation.

Various water import schemes from Turkey, Pakistan, Lebanon and Iran have been proposed for some Middle Eastern countries, but have been viewed with skepticism due to the costs and political liability (Abdulrazzak and Khan, 1990; Abdulrazzak, 1995).

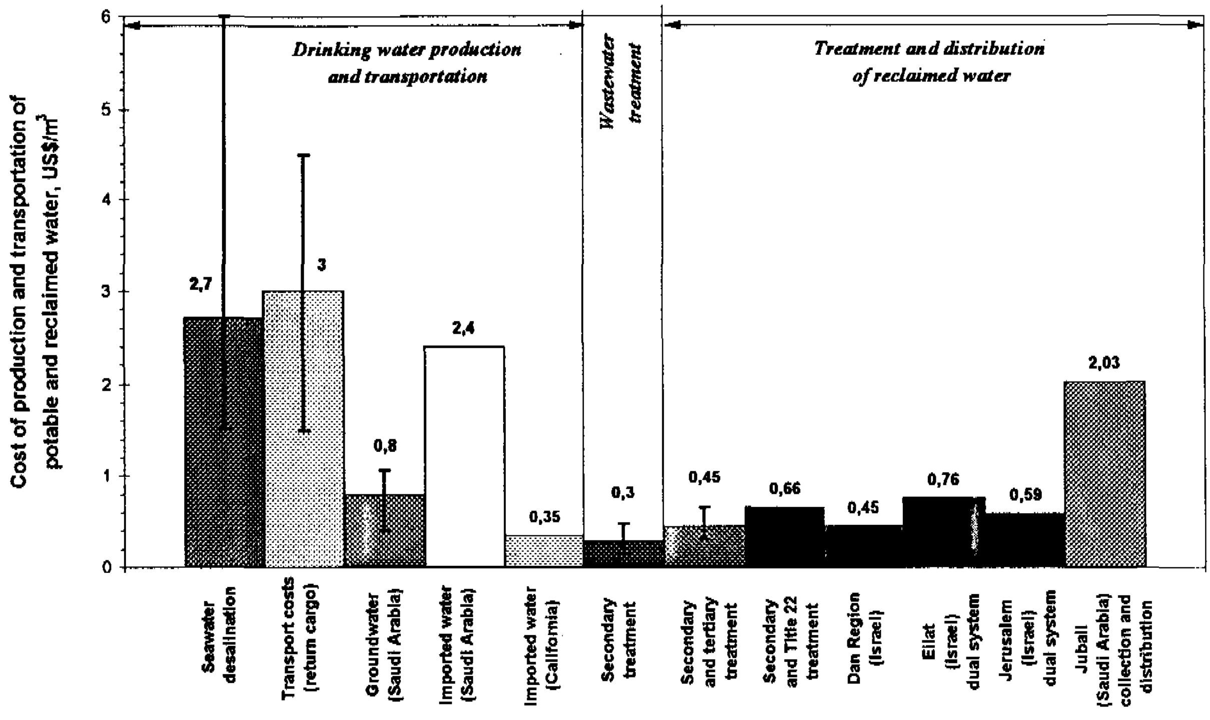

Fig. 8 Comparison of estimated costs of various alternative water supplies

Figure 8 tentatively compares the cost of reclaimed water with other alternative resources. The costs of production and transportation of drinking water are given for Saudi Arabia (Abdulrazzak and Khan, 1990) without correction for inflation. In view of the high real cost of potable water in the Middle East without state's subsidies, 20 US$/m^3 in Qatar, for example (Ahmad, 1988), sea water desalination remains a viable solution. However, reclaimed water, even after intensive treatment up to the stringent Title 22 standard, appears as the lower cost alternative. The additional post-treatment and distribution lead to 50-100% increase in the costs required for the secondary treatment.

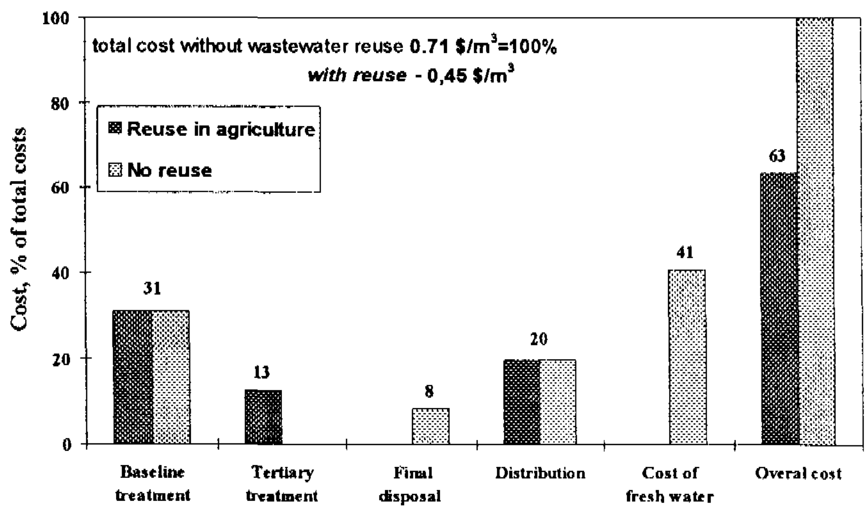

Fig. 9 Comparison of total cost of water supply in the Dan region, Israel with and without wastewater reuse (adapted from Shelef, 1991)

The potential economic value of wastewater reuse is well illustrated by Shelef (1991) by comparing the cost of water supply with and without reclaimed wastewater for different projects in Israel (Fig. 9). In the Dan region, wastewater reclamation enables the saving of 37% of the cost needed for water supply, including intensive agricultural irrigation. The additional cost of tertiary treatment is outbalanced by the high cost of fresh water and sea outfall for wastewater discharge.

Wastewater reuse benefits

The benefits of wastewater reuse projects are usually fragmented among a number of agencies, authorities and the public, which do not necessarily bear its cost. Such disparity of interests is quite common in areas where the responsibility for water supply is distinctly separate from the authority to manage wastewater. By contrast, in agencies where the entire water cycle is managed under the same administrative entity, water reuse gains ready acceptance because its diverse benefits are all appreciated. However, when responsibilities are not consolidated, the challenge is to bring the stakeholders together to identify the benefits, add them up and assign their costs fairly to all beneficiaries (Sheikh *et al.*, 1998).

A water reuse project generates monetary and non-monetary benefits. As a result, water reuse projects are often underevaluated when compared to other projects and significant opportunities for beneficial reuse are lost (Sheikh *et al.*, 1998). The non-monetary benefits consist in an improvement in the environment and the public health, reducing the discharge of nutrients in receiving water, reducing drinking water treatment cost, safeguarding recreational use and tourism.

Table 2 summarises some methods for evaluation of monetary benefits. To estimate, for example, the agricultural benefits of recycled water, a resource economist would consider the market value of the crops grown, and the costs of all inputs to their cultivation. Some statistical methods can then be used to isolate the value attributable to recycled water, which may be significantly higher than the current or future cost of water. A similar approach can be used to measure the value of industrial uses in the marketplace. The benefit of recycled water to residential water users, who do not produce a market value, can be determined as a function of their willingness to pay for water. The evaluation of the consent is based on surveys of a representative sample of the users. According to a recent study by the California Urban Water agencies, monthly willingness to pay higher residential water bills to avoid shortages ranged from $11.60 and $16.90 (Sheikh *et al.*, 1998).

Table 2. Wastewater reuse benefits with monetary value and methods for their estimation

Benefits	Estimation methods
• sale of reclaimed water	
• reliable water supply	• engineering approach: equal to the cost of existing water supply sources • economic approach: real value of the water
• effluent disposal	• equal to the « next best » alternative disposal project • equal to avoided costs
• energy conservation	• avoided cost for not pumping groundwater or imported water
• agriculture	• less use of fertilisers ⇒ money savings • higher yield crops
• local and regional economic development	

The method based on the « next best » alternative disposal project consists in identifying the best alternative for effluent disposal, other than reuse and estimating its cost. The benefit of the water reuse would then be considered equal to this cost. Resource economics uses the avoided cost model, too, but with a twist: it calculates the avoided cost of alternative effluent discharge, as well as the water supply value of the effluent. This cost may be indexed to anticipate future discharge requirements.

The typical benefits for the wastewater agency and local authorities include: (1) reduction of effluent discharge and preservation of discharge capacity, (2) elimination of certain treatment processes to meet mass limits, for nutriments, for example, (3) reduction or elimination of major sewers through construction of satellite water reclamation plants, and (4) sale of recycled water. On the basis of the USA experience, Sheikh *et al.* (1998) proposed some monetary values of wastewater reuse benefits (Table 3).

Table 3 Examples of monetary value of benefits (according to Sheik *et al.*, 1998)

Benefit	Applicability	Value (US$/$m^3$)[1]
Water supply	very common	0.24-0.89
Water supply reliability	very common	0.11-0.81
Effluent disposal	very common	0.16-1.63
Energy conservation	situational	0-0.20
Economic development	situational	no data
Environmental benefits		
Upstream watershed	*very common*	*no data*
Downstream watershed	*common*	*0.33-0.65*
Environmental restoration	*situational*	*no data*
Public health	*situational*	*no data*

[1]*The range of dollar values is derived from specific examples*

CONCLUSIONS

A number of countries in the Middle East and North/Southern Africa are faced with water stress due to limited water resources, rising demand in all sectors and lack of planning efforts. The development and implementation of comprehensive integrated water management strategy with water reuse is the only way to avoid the further increase in the imbalance between limited supplies and rapidly growing demand, as well as the significant deterioration of environment, extensive mining of groundwater reserves and increasing pollution.

For such countries where current fresh water reserves are or will be in the near future on the limit of the survival level, recycled wastewater is the only significant low cost alternative resource for agricultural, industrial and urban non-potable purposes. Only the marginal cost of wastewater reclamation (additional treatment, storage and distribution) must be considered, excluding the cost of wastewater collection and treatment. Thus, the additional cost for wastewater reuse for irrigation, for example, represents only a small fraction—about 30% of the total cost for wastewater treatment and disposal. On the basis of stringent requirements for unrestricted landscape irrigation or other urban and industrial uses, reclaimed water cost could be up to 100% of the cost of the conventional secondary treatment. However, the cost of reclaimed water remains significantly cheaper compared with other alternative solutions as desalination and water transport or importation from neighbouring countries.

Numerous benefits with non-monetary and monetary values have been reported: from the improvement in the environment and the public health to the market value of enhanced food production, water supply reliability and water and energy conservation. Recognising these benefits, several countries in North Africa are including wastewater reuse in their water master plans and national policies.

In conclusion, it is important to underline that the successful development of water reuse projects in arid and semi-arid regions in Africa and the Middle East requires new policy and legislation to promote and control wastewater reuse, new institutional set-up to provide coordination and cooperation between the concerned authorities, public education and choice of the most appropriate technologies for the given reuse applications, plant size and local conditions.

REFERENCES

Abdel Rahman H. A. (1994) Can the standards be too high? Gulf Cooperation Council countries face a regulatory dilemma in the reuse of wastewater. *WWI*, August, 12-14.

Abdulrazzak M.J. (1995) Water supplies versus demand in countries of Arabian Peninsula. *J. Water Resource Planning and Management*, **121**, (3), 227-234.

Ahmad S. (1988) Developing an oasis in arid region through water reuse. *IE (I) Journal-EN*, **68**, 50- 54.

Al-A'ama M.S. and Nakhla G.F. (1995) Wastewater reuse in Jubail, Saudi Arabia. *Wat. Res.* **29**, (6) 1579-1584.

Al-Ibrahim A.A. (1990) Water use in Saudi Arabia: problems and policy implications. *J. Water Resource Planning and Management*, **116**, (3), 375-388.

Arlosoroff S. (1996) Promoting water resource management in the Middle East. *Int. Water Irrigation Review*, 6-16.

Asano T. and Mills R.A. (1990) Planning and analysis for water reuse projects. *AWWA*, (1), 38-47.

Aussoleil M. (1983) La réutilisation des eaux usées comme élément de planification des eaux - *La technique de l'eau et de l'assainissement*, 438/439, 23-31.

Bahri, A.and Brissaud, F. (1995) Wastewater reuse in Tunisia: assessing a national policy. *Wat. Sci. Tech.*, **33**,(10-11), 87-94.

Benchekroun T. and Bouchama N. (1991) Réutilisation des eaux usées en agriculture au Maroc. *Eau et développement*, 11, 25-29.

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

El-Gohary F. A., Abo-Eela S.I.., El-Kamah H.M. (1989) Reclamation of municipal wastewater. *World Resources: a guide to the global environment 1996-97 Oxford University Press 1996*, **21,** 1, 93-99.

Falkenmark M. and Widstrand C. (1992) Population and water resources: a delicate balance. *Population Bulletin*, Population Reference Bureau.

Jankel E. and Williamson H. (1996) Institutional development in the water and wastewater sector: the Alexandria, Egypt experience. *Wat. Sci. Tech.*, **34,** 12, 141-146.

Haarhoff J. and der Merwe B.V. (1996) Twenty-five years of wastewater reclamation in Windhoek, Namibia. *Wat. Sci. Tech.*, **33**, 10-11, 25-35.

Korf A.W., Wilken J.W. and Nel N.J. (1996) Strategies and management models for metropolitan wastewater, implementation and evaluation in the East Rand, South Africa. *Proc. IAWQ 18th Biennial International Conference & Exhibition; Singapore, June 23-28, 1996*, **6**, 109-116.

Lazarova V., Levine B. and Renaud P. (1998) Wastewater reclamation in Africa : assessment of the reuse applications and available technologies. *Proc. IX^{ème} Congrès de l'Union Africaine des Distributeurs d'Eau*, Casablanca, 16-20 February, 16p.

Llagostera J. and Prat P.S. (1997) Potential for wastewater reclamation and reuse in Spanish Mediterranean catchments. *Proc. Conf. Benefical Reuse of Water and Solids*, Marbella, Spain, April, 1997, 1/17-1/28.

Marks R.F. and Lock, R.R.. (1988) Reuse technology boosts Zimbabwe's water supply. *Water Wastewater Int.*, **3**, 3, 27-33.

Mohorjy A.M. (1989) Multidisciplinary planning and managing of water reuse. *Water Resource Bulletin*, **25**, (2), 433-442.

Renaud P., Lazarova V., Levine B. and Manem J. (1997) Wastewater reuse. International Report. *21st World Congress*, Madrid, Spain, 20-26 Sept 1997.

Richard D., Crites R.W., Asano T. and Tchobanoglous G. (1993) A systematic approach to estimating wastewater reclamation costs in California. *Proc. WEF 66th annual conference*, Anaheim, California, 3-7 October, 235-246.

Sheikh B., Rosenblum E., Kasower S. and Hartling E (1998) Accounting for the benefits of water reuse. *AWWA/WEF Water Reuse Conf. Proc.*, 1-4 February, Lake Buena Vista, Florida, 211-221.

Shelef G. Wastewater reclamation and water resources management. *Wat. Sci. Tech.*, **24**, 9, 251-265 (1991).

Shuval H. (1994) The role of wastewater recycling and reuse in water resource management under conditions of scarcity. *Proc. 8th IWRA World Congress on Water Resources: Satisfying future and global water demands*, (T2-S1) 6.1-6.19.

Ukayli M.A. and Husain T. (1988) Comparative evaluation of surface water availability, wastewater reuse and desalination in Saudi Arabia. *Wat. International*, **13**, 218-225.