Wastewater treatment and reuse as a potential water resource for irrigation

Choukr-Allah R., Hamdy A.

in

Hamdy A. (ed.).
The use of non conventional water resources

Bari : CIHEAM / EU DG Research
Options Méditerranéennes : Série A. Séminaires Méditerranéens; n. 66

2005
pages 101-124

WASTEWATER TREATMENT AND REUSE AS A POTENTIAL WATER RESOURCE FOR IRRIGATION

R.Choukr-Allah* and A. Hamdy**
* I.A.V Hassan II, Salinity and plant nutrition laboratory BP 773, Agadir, Morocco
E-mail: ch.redouane@wanadoo.net.ma

** Mediterranean Agronomic Institute of Bari (CIHEAM-IAMB), Via Ceglie 9, Valenzano (BA), Italy
E-mail: hamdy@iamb.it

SUMMARY - Water resources scarcity, accessibility, and environmental degradation are the major challenges facing most of the Mediterranean region and especially the southern and eastern Mediterranean countries. An increasing number of countries are now approaching full utilization of their surface and ground freshwater and that most of the economically viable development of these resources has been already implemented.Treated and re-used sewage water is becoming a common source for additional water in some water scarce regions and many countries have included wastewater re-use in their water planning. Policies have been formulated but few have had the capacity to implement them in their water management practices in terms of actions to deal with water pollution control and waste disposal. In arid and semi-arid countries, particularly the developing ones, the full utilization and re-use of sewage water is still far from our final goal, i.e. to be used as a water source, in spite of the vital role it could play in reducing the high pressure imposed on the limited available freshwater. Health and environmental problems are the major obstacles restricting the sustainable and safe re-use and recycle of wastewaters which require concerted efforts supported by regional and international organizations, if real change and beneficial results are to be realized in the near future.

Key words: wastewaters re-use, water management, water saving, irrigation.

INTRODUCTION

Agriculture is the largest single user of water with about 75% of freshwater being currently used for irrigation (Prathapar, 2000). In some cases, it draws as much as 90% of the total water (Allan, 2001).

With increasing pressure on freshwater resources in water-deficit regions, there is a need to conserve and use available freshwater supplies more efficiently because future increases in agricultural production will have to rely heavily on existing water resources. Thus, there is a great potential for improving water-use efficiency in agriculture, particularly in those areas where need is the greatest (Oweis *et al.,* 2000; Wallace, 2000; Hatfield *et al*., 2001). In addition, non-conventional water sources, particularly treated wastewaters represent complementary supply sources that may be substantial in regions affected by extreme scarcity of renewable water resources.

Expansion of urban population and increased coverage of domestic water supplies and sewage network will give rise to greater quantities of municipal wastewater which can become a new water source, particularly for irrigation. The water recycling and re-use provide a unique and a viable opportunity to increase traditional water supply. Water reuse can help to close the loop between water supply and wastewater disposal. The successful development of this reliable water resource depends upon close examination and synthesis of elements from infrastructure and facilities planning, wastewater treatment plant sitting, treatment process reliability, economic and financial analysis, water utility management, and public acceptance.

Consequently, the re-use of municipal wastewater will require more complex management practices and stringent monitoring procedures than when good-quality water is used. Treatment and re-use of sewage waters is becoming a common source for additional water in some water scarce regions. Re-use of sewage waters, when properly managed, has the benefit of reducing environmental degradation.

For many of those arid and semi-arid countries, re-use of wastewater may contribute more future water availability than any other technological means of increasing water supplies. Treated wastewater can be used effectively for irrigation, industrial purposes and groundwater recharge and for protection against salt intrusion in groundwater aquifers. Furthermore, the wastewater treatment and possible use of sewage effluents is a health and environmental necessity to the civil society, especially in urban areas. Therefore, for those countries, the use of appropriate technologies for the development of alternative sources of water is, probably, the single most adequate approach for solving the problem of water shortage, together with the improvements in efficiency of water use and adequate control to reduce water consumption. Our water management policy should be fundamentally directed to support that "no higher quality, unless there is a surplus of it, should be used for a purpose that can tolerate a lower grade". This is what we are challenging for and we have to find the key-recommendations and solutions for action.

APPROPRIATE TECHNOLOGIES

The term «appropriate technology» has been described as a subjective judgment depending on the observer's viewpoint. The primary reason for confusion is the inexact definition of the term. The definition chosen here is that of a technology which is affordable to and operable by the user which reliably provides the degree of purification needed for the wastewater's end use. Note that this definition includes the following key requirements:

- Affordable: both in capital and operation and maintenance (O&M) costs
- Operable: within an affordable O&M cost the user can operate the system with locally available labor and infrastructure
- Reliable: the system can meet effluent quality requirements prescribed by the empowered regulatory agency

Classification of the urban wastewater quality in developing countries

A classification of the urban wastewater quality in Morocco has been carried out for ONEP (1998). The results of this study provide a precise idea about the quality of wastewaters in Morocco, of the evolution of ratios and the restitution rates, on the basis of agglomeration size (Table 1).

Table 1. Classification of wastewaters in Morocco

Parameters	Small Villages (less than 20,000 inhabitant)	Average Cities (Between 20.000 and 100,000 inhabitant)	Large cities (more than 100,000 inhabitant)	National average
BOD_5 (mg/l)	400	350	300	350
COD (mg/l)	1000	950	850	900
TSS (mg/l)	500	400	300	400
Restitution rates (%)	50	75	80	65
Supply x restitution rate(l/inhab)	40	70	80	60

Source: ONEP-GTZ (1998)

The bigger the city is, the more the concentration of polluting elements explained in terms of BOD_5, COD, and MES decreases. In fact, big cities use a more important quantity of water, which leads to a more considerable dilution of wastewaters.

Low cost technologies

The treatment systems which meet the appropriate technology definition for rural application must be chosen based on the needs of the intended use. If surface water discharge is contemplated, there are a number of different systems which may be both affordable and reliable in meeting these standards. In the U.S. surface water discharge requirements start at «Secondary treatment» (BOD_5 and TSS of 30 mg/l) and get more stringent, usually in terms of these two parameters and nutrients (N&P). Sometimes the requirements are seasonal, and sometimes they consider facility size, but they are usually based on the water quality of the receiving water body.

Presently there are a limited number of appropriate treatment processes for small communities which should be considered. These include stabilization ponds or lagoons, slow sand filters, land treatment systems, and constructed wetlands. All of these fit the operability criteria discussed above, and to varying degrees, are affordable to build and reliable in their treatment performance. In order to illustrate the viability of these systems, the following example is provided. In this example, a small sewered community collects its wastewater at the treatment site, and the effluent will be required to meet WHO standards for unrestricted agricultural irrigation.

INFILTRATION PERCOLATION TECHNIQUES

The infiltration percolation technique constitutes an efficient and low technology way to ensure an acceptable disinfection level of wastewaters (Lance et al., 1976 and 1980; Lefever, 1988; Schmitt, 1989; Brissaud et al., 1991). Infiltration percolation consists in infiltrating sewage into calibrated and homogeneous sand beds. This natural filtration process allows removal of suspended solids (SS), chemical oxygen demand (COD), oxidizable nitrogen (NTK) and microorganism.

ARTIFICIAL OR CONSTRUCTED WETLANDS

Artificial or constructed wetlands are increasingly viewed as a viable tertiary treatment alternative for municipal wastewater. In recent years, there have been several major works published on these systems (EPA, 1988; Hammer, 1989; Reed *et al*., 1995). A limited number of previous studies have examined the reduction in indicator bacteria by constructed wetlands (Reed *et al*., 1985).

In the multi-species wetlands, decreases in total nitrogen were particularly in evidence during the summer months (July and August) with lower rates of removal during the fall and early winter. BOD5 concentrations were decreased to the tertiary standard during all the months of this study.

The duckweed system, BOD5 was reduced to a lesser extent and total nitrogen actually increased during some of the study months. Overall decreases were noted in both the duckweed and multi-species systems for total coliforms, fecal coliforms, Giardia, Cryptosporidium and enteric viruses. A higher rate of removal of parasites occurred in the aquatic duckweed system. The multi-species system provided a greater rate of removal for the indicator bacteria. No significant removal of coliphages was observed from the duckweed system. The degree of removal of microorganism in the duckweed pond appeared to be related to their size, with greater removal of the largest organism (i.e., parasites). This suggests that removal is related to the settling of the organism in the pond. Longer retention times could potentially increase the removal of the parasites and viruses.

STABILISATION PONDS

Wastewater stabilization ponds (WSP) are man made large shallow basins enclosed by concrete or earthen embankments in which raw Or Settled sewage is treated by exploiting natural processes, mainly the power of the sum through photosynthesis of algae to produce the oxygen necessary for the bacteria that promote purification. Since the natural process does not need electromechanical equipment, the purification system is not exposed to damage and operational interference is therefore minimal.

The removal efficiency depends on the following factors:

- The absence of toxic and inhibitory substances

- The consistency of volumetric and surface loading

- The temperature of the water (preferably more than 15 C) - Adequate Mixing

- Adequate sludge depth to enhance the performance of the anaerobic bacteria at the bottom of the pond.

Expected BOD_5 removal for different detention times in anaerobic ponds have been given by Mara (1976), as shown in Table 2

Table 2. BOD Removal in anaerobic ponds loaded at 250 kg BOD_5 per m^3 per day

Retention time, Days	BOD5 removal, Percent
1.5	50
2.5	60
5.0	70

EFFICIENCY OF DIFFERENT TECHNOLOGY OPTIONS

In summarizing the options for a small community the choice of treatment for ultimate reuse will hinge on the following:

- Reuse Requirements - If the reused wastewater is to be used for vegetables, citrus or other crops to be eaten raw, the options employing stabilization ponds and intermittent filters can be used, or a recirculation alter may be substituted with subsurface drip irrigation only. This last restriction may be lifted if it can be proven that the RSF effluent is free of nematode eggs, or if disinfection of the effluent is employed.

- Land Availability - If sufficient land is available the other limitations stated above and below will control the options evaluated. If land availability is limited by economies or terrain or surrounding development, one of the filter options should be chosen.

- Operational Capability - If a sufficiently skilled management program with electricity is available, all options are possible. If, as is often the case, only unskilled labor is locally available, only the pond-wetland or anaerobic lagoon-intermittent filter options are viable.

Table 3. Comparison of the two passive alternative technologies

	Lagoon Wetland	Anaerobic Lagoon-ISP
Land requirement, m^2	13,000	2,000
Energy KWH/d	0	0
Capital cost, US$	200,000	150,000
	250,000	200,000
O&M cost, US$/yr.	5,000-7,000	7,000-10,000
Effluent Quality		
BOD5 (in=200), mg/l	10	5
TSS (in=100), mg/l	10	5
TN (in=50), mg/l	10-35	35-40

TP (in=10) mg/l	7-8	7-9
FC (in=l0^{6}), per 100 ml	10^2-10^3	10^1-10^2
Virus (in=10^3), per L	10^1-10^2	0-10
Parasite Ova (in=10^3), per L	0-10	0

Concerning the treatment of wastewaters, Table 4 sums up the results of the treatment results of some experimental treatment plants in Morocco.

Table 4. Treatment performance (in reduction percentage)

Plant	Ouarzazate		Ben Sergao	Drarga	Ben Slimane	Marrakech	Bouznika
Processing System	Lagoon	High Output Lagoon	Filtration - percolation		Aerated Lagoon	facultative Lagoon	Lagoon
Period of Stay (Days)	25	21.9	-	-	30 – 40	30	-
BOD_5 (mg/l)	81.7	65.3	98	98.5	78	97	75
COD (mg/l)	72	65.4	92	96	79	76	71
TTS (mg/l)	28	-	100	96.6	-	69	76
NTK (mg/l)	31.5	48	85	96.8	75	71	14
Ptot (mg/l)	48.5	54	36	95.9	41	85	-
CF /100ml	99.9	99.9	99.9	99.9	100	99.4	99.9
O. Helminthes/L	100	100	100	100	100	100	100

Source: ONEP-FAO (2001)

Finally, when the viable options which pass the above tests are evaluated against each other, experience in the U.S. bas shown that they are very similar in present worth cost, so local availability or cost of components, climatic and social conditions, and support infrastructure may be the deciding factor between them. For example, the lack of suitable sand or substitute media locally will significantly increase the cost of the filter options. Very close proximity of housing to the treatment site May make odor concerns a key issue, and add costs to certain options to control odors. Therefore, engineering decisions of which method of treatment or sitting of the facility may be skewed to suit local needs. However, in all cases the appropriate technology options presented herein are significantly more sustainable than the use of sophisticated urban wastewater treatment technologies such as activated sludge with tertiary treatment for small communities of North Africa.

ECONOMIC AND FINANCIAL ASPECTS

The financing of the projects concerning the construction of a treatment plant constitutes the main handicap for the realization of these projects. The majority of the projects of wastewater treatment are financed by communes through state credits. Other plants have been built by way of experiment, within the framework of partnership including water reuse and municipalities. The financial contribution of international organizations also helps in the construction of small plants in some cities and small communes of Morocco. Although the communes have proved to be willing to work, the initiation of treatment plant depends first on the establishment of a sewerage network. The cost of financing the latter makes future treatment plants seem illusory.

The investment costs of wastewaters, treatment plant varies considerably according to the adopted technology, the treatment process, and the specificities of the site, the pollutant load, and final disposal of treated wastewaters. For the treated wastewaters directed to reuse, the standards of health and environment protection impose a high quality requirement of the final effluent. Still, it is possible to compare the costs of investment of different projects and the reuse of wastewaters in Morocco per equivalent inhabitant.

Table 5. Costs of different processing plants of wastewaters in Morocco

Plant	Investment cost (millions of dirham)	Functioning cost (dirham / year)	Cost per inhabitant / year (dirham)	Cost / m^3 (dirham)
Ouarzazate	5	108.500	643	1,43
Ben Sergao	5	307.500	250	1,12
Benslimane	96,44	935.000	1.928	1,45
Drarga	20,3	260.000	1.000	1,70

Until now, there is no model for cost estimation of wastewater treatment in the Moroccan context. As mentioned above, these costs vary according to a number of factors. However, leading experiences have shown that the cost of technologies appropriate for Morocco such as lagoon and filtration-percolation vary between 1,12 and 1,70 Dirham per m^3 of treated waters (1 Euro= 10 Dirham).

In the case of Drarga and Benslimane, the treated wastewaters are sold. In Benslimane, the treated wastewaters are sold to the golf course for 2Dh/m^3 while the initial tariff for farmers in Drarga is 0, 50 Dh/m^3. For mere comparison, the agricultural wastewaters distributed by the offices of Agricultural Development are sold for an average tariff of 0.5 Dirhams/m^3, while the price for potable water varies between 2 and 8 Dirhams/m^3. It is worth noting that in many places, farmers resort directly to underground waters and solely pay the fees of pumping. In some regions where the level of the ground water has witnessed a considerable decrease, especially in Souss Massa, the pumping cost have become very expensive and may raise up to 1.5 Dirhams per m^3.

The increase in the price of water has always been subjected to resistance. Nonetheless, due to the scarcity of resources and repetitive droughts, more and more farmers accept the principle of a more rational resource management, especially through a more adequate price setting policy. In the regions with more severe water scarcity, farmers are ready to pay the cost of water, provided they have a perennial source.

Within the framework of the law on water 10-95, the deduction charges are stipulated and the use of raw wastewaters are banned. It is therefore expected that once the application decrees of the law will be enforced, the demand for treated wastewaters, in addition to the willingness to pay for this water, will increase significantly.

The treated wastewaters contain fertilizing elements and allow the farmer to save fertilizes inputs. The Table 10 is based on the performances obtained in Ouarzazate and Ben Sergao projects.

Table 6. Economic gain from treated wastewaters irrigation.

Cultivation	Net gain of water (Dh / year/inhab)	Benefit in fertilizers (Dh / year/inhab.)	Total benefit (Dh / year/inhab)
Tender Wheat	750	1.492	2.242
Unground corn	1.588	3.614	5.202
Fodder corn	1.568	3.572	5.140
Clover (Berseem)	774	1.539	2.313

Courgette	677	1.545	2.222
Marrow	611	1.216	1.827
Tomato	1.553	3.542	5.095
Potato	940	2.140	3.080

(1) Calculated on the basis of pumping water of Sous Massa (0.7 dh/m^3) and of the selling price of treated wastewaters (0.5 dh/m^3).

(2) Calculated on the basis of the total value of fertilizing elements in treated wastewaters.

WASTEWATER REUSE

Owing to the variable availability of water in water scarce countries for human consumption, there are different estimates on per capita generation of wastewater, which may range from 30 to 90 m^3 on an annual basis. Therefore, population of one million would generate wastewater in the range of 30×10^6 m^3 to 90×10^6 m^3. Considering average use of such water at 10000 m^3 ha^{-1} yr^{-1} would mean irrigation of about 3000-9000 ha. In order to supplement the freshwater needs, a large part of wastewater generated in these countries is reused to grow a variety of crops. The total area irrigated with untreated, partly treated, adequately treated, or diluted wastewater is estimated at 20×10^6 ha in 50 countries, somewhat below 10% of total irrigated area in developing countries.

Although all water is recycled through the global hydrologic cycle, adequate local treatment of wastewater and its reuse are crucial for several reasons: (1) The discharge of untreated wastewater into surface water is becoming difficult in the presence of government policies and regulations in several countries to protect the quality of receiving water used for different purposes and to avoid contamination of downstream water. (2) Being a significant water resource, treated wastewater may be used as a reliable source of irrigation of crops in urban and peri-urban areas, urban parks, playgrounds, sports fields, school yards, golf courses, commercial nurseries, and road plantings. Other uses may be industrial (cooling, boiling, and processing), environmental (wetlands, wildlife refuges, riparian habitats, urban lakes and ponds), and non-potable (fire fighting, air conditioning, dust control, and toilet flushing). It may also be used for aquaculture and groundwater recharge, which has received considerable attention in recent years. (3) Preservation of existing scarce sources of good-quality water for drinking and other household matters. (4) Consequent to reuse of treated wastewater as an irrigation source, a decrease in the demand for freshwater to be used for irrigation. (5) In case of appropriate treatment and management, treated wastewater presents a source of several nutrients essential for plant growth. This is a direct benefit to the farmer because of no or little investment on a significant farm input dealing with fertilizer purchase and application. (6) The benefits of reusing treated wastewater must also be considered against the cost of not doing so at the human health, economic, and environmental levels.

Owing to gradual addition of contaminants into freshwater bodies and the awareness of their possible impacts, wastewater treatment is now receiving greater attention from the governments of several water scarce countries and organizations such as World Bank. Keeping in view the foreseeable scenario of reusing treated wastewater for agricultural, environmental, recreational and industrial purposes, there is a greater scope in the water and environment sector to develop and implement wastewater treatment technologies that (1) need low capital investment on construction, operation and maintenance, (2) maximize the recovery of by-products such as nutrients from the pollution substances, (3) show compatibility with the intended reuse option in terms of appropriate quality and adequate quantity, (4) could be applied from very small to very large scale, and (5) have acceptance from the farming community and local population.

Untreated wastewater is being used by poor farmers in an unregulated manner in many developing countries to irrigate a variety of crops. Most cities of these countries have large number of open and covered channels that are interconnected and distributed within and around urban premises. In general, these channels carry a mixture of wastewater generated by domestic, municipal, and industrial activities. The farmers divert this untreated wastewater for irrigation as and when needed. They prefer to grow high-value vegetables as a market-ready product to generate greater income (Qadir *et al*., 2000). In most cases, there is no check on the part of administrators on such use of wastewater. Rather they regard this farming practice as a viable option for wastewater disposal. The farmers consider untreated wastewater as a source of irrigation, which involves less cost than other sources of irrigation water such as groundwater pumping (Van der Hoek *et al*., 2002). Other benefits to the farmers include no or little investment on fertilizer purchase and application, and greater crop production than freshwater irrigation. Therefore, farmers take health risks and use untreated wastewater when they find an opportunity for additional benefits such as greater income generation, improved nutrition, and education for children (Ensink *et al*., 2002; Matsuno *et al*., 2004). The use of untreated wastewater is intense in areas where there is a lack or little access to other sources of irrigation water. Most farmers are not fully aware of the health and environmental implications of using untreated wastewater for irrigation.

In Morocco, the use of raw wastewaters is a current and old practice. Raw wastewaters are used where they have most value in general. These practices are resorted to on the periphery of some big cities where agricultural lands are located downstream of effluent discharge, and also in small areas around the treatment networks. Climatic constraints push farmers to irrigate cultivations in places where water resources are available.

In recent years, the reuse of wastewaters has also developed around some suburbs recently provided with a treatment network. A total of 7000 ha is directly irrigated with raw wastewater discharged by towns, i.e. about 70 million m^3 of wastewater is used every year in agriculture with no application of health control (WHO standards for example). Many crops are irrigated in this manner (fodder, market gardening, major crops, arboriculture…).

The irrigation of market garden crops with raw wastewaters is forbidden in Morocco, but this ban is not respected. This makes the consumer of agricultural products and the farmer face risks of bacteria or parasite disease.

Table 7. Main areas of raw wastewater reuse in Morocco

Area	Surface (ha)	crops
Marrakech	2000	Cereals, fruit threes
Meknes	1400	Cereals, fruit threes
Oujda	1175	Cereals, fruit threes
Fès	800	Fruit threes
El Jadida	800	Fodder
Khouribga	360	Cereals,
Agadir	310	Fruit threes, soybean, floriculture
Béni-Mellal	225	Cereals, Cotton, beetroot
Ben guérir	95	Fodder, fruit threes
Tétouan	70	Fodder
Total	7235	

Source: CSEC (1994)

In general, the volume of wastewaters reused does not represent more than 0.5% of the water used in agriculture.

This situation tends to occur in all agglomerations that are provided with a treatment system or where wastewaters are discharged. Following an investigation carried out by SNAI (1998), a total of 70 areas where raw wastewaters are used and found in the country. This practice is not free of dangerous consequences for human health and for the environment. For example:

- Spread of water borne diseases (more than 4000 cases of Typhoid and more than 200 case of malaria have been noted in 1994, some cholera sources in the Sbou basin).

- Difficulty and high cost of treatment potable water.
- Many sections of water courses in the country contain low quantities of dissolved oxygen, and even a total deficit in oxygen when discharges are significant, and which causes massive fish mortality, and;
- Many barrage waters are atrophic, as a consequence of the significant phosphorus and nitrogen levels in the waste discharges.

There are several negative impacts of continued and uncontrolled applications of untreated wastewater as an irrigation source, which include: (1) Groundwater contamination through movement of high concentrations of a wide range of chemical pollutants (Ensink *et al*., 2002), particularly in case wastewater contains untreated industrial effluent. Nitrate (NO_3^-) and heavy metals reaching groundwater have the potential to impact human health under conditions of groundwater pumping for direct human consumption, although limited information is available on this aspect (Cooper, 1991). Accumulation of pathogens has also been found in groundwater immediately below the wastewater-irrigated fields. (2) Gradual build-up of deleterious ions such as sodium (Na^+) and a range of metals and metalloids in soil solution and on the cation exchange sites. The concentrations of potentially harmful metals and metalloids may reach to levels that may become phytotoxic to a wide range of species, and in certain cases toxicity may occur in soil faunae and florae, higher animals, and humans (Qadir *et al*., 2004). Accumulation of excess Na^+ in the soil has the potential to cause numerous adverse phenomena, such as changes in exchangeable and soil solution ions and soil pH, destabilization of soil structure, deterioration of soil hydraulic properties, and increased susceptibility to crusting, runoff, erosion and aeration, and osmotic and specific ion effects on plants (Sumner, 1993; Qadir and Schubert, 2002). (3) Accumulation of potentially toxic substances in crops and vegetables that ultimately enter the food chain, impacting human health. There are chances of greater accumulation of metals such as cadmium (Cd) in leafy vegetables than non-leafy species (Qadir *et al*., 2000). Excessive exposure to this metal has been associated with illnesses in human beings including gastroenteritis, renal tubular dysfunction, hypertension, cardiovascular disease, pulmonary emphysema, cancer, and osteoporosis (Wagner, 1993). There are numerous illnesses associated with ingestion of excessive levels of other metals and metalloids. Similarly, pathogens may enter and accumulate in the food chain. In most cases, industrial pollution inducing a variety of metals and metalloids could cause greater and long lasting impacts on human health than pathogenic organisms. (4) Extended contact of farmers with untreated wastewater may expose them and their families to health risks such as parasitic worms, and viruses, and bacteria that have the ability to cause diseases. Studies conducted on farmers using untreated wastewater for irrigation have shown higher prevalence of diarrhea through hookworm and roundworm infections than those farmers using freshwater for irrigation. Hookworm infections occur when larvae, added to the soil through wastewater, penetrate through the skin of farmers working barefoot. In addition, nail problems—koilonychia in the form of spoon-shaped nails—have a more occurrence in wastewater-irrigated farmers (Van der Hoek *et al*., 2002).

Owing to the environmental implications and health risks, the use of untreated wastewater for irrigation cannot be encouraged. However, the poor farmers of many developing countries are expected to continue using untreated wastewater as long as it is accessible, and alternate disposal options are not available. With little allocation of funds for wastewater treatment and disposal, it is extremely difficult for these countries to enforce a ban on agricultural use of untreated wastewater, which supports a large number of livelihoods. In addition, an immediate ban would mean disposal of untreated wastewater into freshwater bodies leading to an increase in pollution of surface-water with negative impacts on downstream water quality and health of its users. In this way, most environmental and health problems will move to downstream areas, which already suffer from water quality problems in many irrigation projects. Therefore, the use of untreated wastewater can only be avoided in case of providing adequate funding for construction and efficient operation of treatment plants. However, the present scenario suggests that economies of most developing countries do not afford to build such treatment plants. Keeping in view these challenges, the studies carried out by researchers at the International Water Management Institute (IWMI) have proposed a number of policy options to maximize the benefits and minimize the risks involved with agricultural use of untreated wastewater (Scott *et al*., 2000; Ensink *et al*., 2002; Van der Hoek *et al*., 2002; Matsuno *et al*., 2004). These policy options include: (1) use of appropriate irrigation techniques and selection of suitable crops that are less likely to transmit contaminants and pathogens to consumers, (2) use of protective measures such as boots and gloves to control exposure of farm workers from pathogens,

(3) implementation of medical care program through the use of preventive therapy such as anti-helminthic drugs, (4) appropriate post-harvest management of vegetables through washing and improved storage, (5) conjunctive use of wastewater and freshwater to dilute the risks and greater benefits through supply of nutrients(Choukr-Allah, 1996a, 1996b) on a larger area, (6) upstream wastewater management and appropriate low-cost treatment, (7) education and awareness among farmers, consumers, and government organizations, and (8) implementation of monitoring programs for key environmental, health, and food safety parameters. While considering the situation that unconditional restriction on wastewater use is not possible in many developing, the World Health Organization has made a commitment to take into account the realities faced by these countries when reviewing its guidelines for wastewater use in agriculture (IWMI, 2003).

The precaution to be taken in reusing treated wastewater

Any project with the aim to treat and reuse wastewaters should have the main objectives directed to:

- Study the effects of using treated wastewaters on land, cultivations, and irrigation systems;
- Define the health criteria required for the use of treated wastewaters.
- Identify the most appropriate techniques for maximum exploitation rising treated wastewaters and the residual sludge.
- Study the efficiency of the wastewater treatment system per basin
- Follow the effects of reuse process on the environment and especially on the quality of underground waters.
- Reinforce national capacities in reusing treated wastewaters for agricultural purposes
- Exploit the results in extending the use of treated wastewaters at the national and regional level.
- Produce dimension standards for future plants
- Calculate the direct or indirect costs that come within a financial and economic analysis.
- Reduce the nuisance impacts on the environment generated by the raw wastewaters, and;
- Conserve the underground water resources.

POTENTIAL OF SAVING BY USING TREATED WASTEWATER

Wastewater treatment provides opportunities to increase the use of wastewater in agriculture (Choukr-Allah, 2004, GWP8Med, 2000). The percentage of population served with water supply and sanitation varies from one country to another. The table 1 below indicate that the annual water use in domestic and industrial sectors could reach 83 BMC. Assuming 80% of wastewater will be collected and treated, the annual collected wastewater could reach 66.7 BMC. The existing wastewater reuse is estimated at 0.75 BMC in the Mediterranean countries (FAO, 1997). The potential treated wastewater for reuse can therefore be estimated at 66 BMC/year in the Mediterranean region. Based on the water demand of year 2025, and assuming that this water could be satisfied, the saving using treated wastewater could reach 70 BMC / year. The cost to achieve this saving is estimated to 55 billions euros which include the need to fill the gap in water supply and sanitation coverage for 25 million people without access to water and to treat the wastewater effluents.

Table 1. Annual domestic and industrial water use and potential treated wastewater for reuse

	Potential Total Irrigation Savings	Potential Total Domestic Savings	Potential Total industrial Savings	Potential Treated Wastewater for use	Total Potential Water Savings
	M m3/year	M m3/year	M m3/year	M m3/year	M m3/year
Syria	1,360.0	174.1	3.5	135.9	1,673.5
Lebanon	95.0	99.7	1.9	286.3	482.9
Jordan	73.8	71.0	0.4	89.7	234.9
Egypt	4,773.0	1,079.4	55.5	5,108.1	11,016.0
Libya	400.2	161.9	1.2	248.0	811.2
Tunisia	270.6	91..5	1.2	201.1	564.3
Algeria	270.0	368.3	8.4	1,138.6	1,785.4
Morocco	1,016.1	186.5	4.1	553.9	1,760.6
Albania	99.4	129.3	0.0	221.4	450.1
Croatia	0.0	121.7	4.8	506.9	633.3
Cyprus	15.6	16.1	0.1	20.1	51.8
France	488.0	1,947.9	371.1	26,776.5	29,583.5
Greece	569.4	359.0	2.6	779.2	1,710.3
Italy	2,537.6	2,136.9	197.5	16,135.3	21,007.4
Malta	0.7	15.5	0.0	25.3	41.4
Spain	2,415.4	1,472.1	79.9	7,567.3	11,534.7
Turkey	2591.5	1,818.8	48.8	6,173.9	10,633.0
Total	16,976	10,250	781	65,968	93,974

WASTEWATER AS AN ADDITIONAL WATER RESOURCE

Benefits

There are several benefits of treated wastewater reuse. First, it preserves the high quality, expensive fresh water for the highest value purposes–primarily for drinking. The cost of secondary-level treatment for domestic wastewater in MENA, an average of $US 0.5/m3, is the cheaper, in most cases much cheaper, than developing new supplies in the region (WB, 2000). Second, collecting and treating wastewater protects existing sources of valuable fresh water, the environment in general, and public health. In fact, wastewater treatment and reuse (WWTR), not only protects valuable fresh water resources, but it can supplement them, through aquifer recharge. If the true, enormous, benefits of environmental and public health protection were correctly factored into economic analyses, wastewater collection, treatment and reuse would be one of the highest priorities for scarce public and development funds. Third, if managed properly, treated wastewater can sometimes be a superior source for agriculture, than some fresh water sources. It is a constant water source, and nitrogen and phosphorus in the wastewater may result in higher yields than freshwater irrigation, without additional fertilizer application (Papadopoulos, 2000). Research projects in Tunisia have demonstrated that treated effluent had superior non-microbiological chemical characteristics than groundwater, for irrigation. Mainly, the treated wastewater has lower salinity levels (WB, 2000, pg.8).

Case-Studies

Countries in the region which practice wastewater treatment and reuse include Spain, France, Cyprus, Malta, Tunisia, Israel, Italy, Greece, Portugal, and Egypt. However, only Israel, Cyprus and Tunisia, and to a certain extent, Jordan, already practice wastewater treatment and reuse as an integral component of their water management and environmental protection strategies.

In Tunisia, treated effluent with a total flow of 250 m3/d is used to irrigate about 4500 ha of orchards (citrus, grapes, olives, peaches, pears, apples, and pomegranate), fodder, cotton, cereals, golf courses and lawns (Abu-Zeid, 1998).The agricultural sector is the main user of treated wastewater. Mobilisation of treated wastewater, and transfer or discharge are an integral part of the national hydraulic equipment program and are the responsibility of the State, like all related projects. The advantage of this water resource is that it is always available and can meet pressing needs for irrigation water. Indeed use of wastewater saved citrus fruit when the resources dried up (over-exploited groundwater) in the regions of Soukra (600 inhabitants) and Oued Souhil (360 inhabitants) since 1960 and contributed among other things to the improvement of strategic crop production (fodder and cereals) in new areas.

Technical and economic criteria enabled the irrigation of more than 6600 ha mobilising 30% of discharged effluent. The average effective utilisation rate of treated wastewater is 20%. The volume consumed differs greatly from one area to another, according to climatic conditions (11 to 21 Million m^3 per year.) At present, treated wastewater is an available source of water for farmers, but on the one hand, it is not suitable for crops that are economically profitable, and on the other hand it poses some health risks. The best levels of utilisation are found in arboriculture areas, in areas with a tradition of irrigation and in semi arid areas.

With a projected volume of 215 million m^3 by the year 2006, the utilisation potential of this water will be about 20,000 hectares that is 5% of the areas that can be irrigated, if we assume intensive inter-seasonal storage and a massive introduction of water saving systems that would increase the mobilisation rate to 45%. It is expected that additional treatment of treated wastewater will improve the rate of use in irrigated areas (ONAS 2001).

Agricultural reuse however will not see marked improvement, unless restrictions are lifted on pilot wastewater treatment plants with complementary treatment processes. This can only be decided when the stations are functioning with acceptable reliability. This will take a few years of experience. Nonetheless, in all cases, and regardless of the treatment method, technical and organizational measures should be introduced in order to systematically warn those managing the reuse of any breakdowns that may occur in the wastewater treatment plants and to avoid the flow of treated wastewater into the distribution network.

In Jordan, Treated wastewater generated at nineteen existing wastewater treatment plants is an important water resources component. About 72 MCM per year (2000) of treated wastewater are effectively discharged into the watercourses or used for irrigation, 76% is generated from the biggest waste stabilization pond Al-Samra treatment plant serving a population of 2 million (approximately 70% the total served population) in 2000. By the year 2020, when the population is projected to be about 9.9 million, about 240 MCM per year of wastewater are expected to be generated. All of the treated wastewater collected from the As-Samra wastewater treated plant is blended with fresh water from the King Talal reservoir and used for unrestricted irrigation downstream in the Jordan Valley.

In Israel reuse up to 1982 amounted to about 25% of the wastewater generated. Since that time several large projects lead to a large increase in water reuse. In 1987 some 230 reclaimed water projects produced about 0.27×10^6 m^3/day of reclaimed water from a population of over 4 million people (Argarnan, 1989). About 92% of the wastewater was collected by municipal sewers and of this 72% was reused for irrigation 42%) or groundwater recharge (30%). Reuse constitutes approximately 10 % of the water in Israel but by 2010 it is projected that reuse will account about 20%, with about 33% of the total water resource allocated to agricultural irrigation. This practice is generally recognized at the moment as an economically feasible strategy for developing a crucial water source for irrigation replacing freshwater to be reallocated for urban/domestic use, while also having public health advantages. About eighty percent of Israel's treated wastewater is reused in irrigation.

Despite all efforts in practice and research however, the associated health and environmental risks and the implications of the increase in the quantities of wastewater effluents in the human environment are not fully understood. Furthermore, the inclusion of sewage effluents as part of "water irrigation rights" and the associated institutional and pricing adjustments need to be analyzed as well as the modifications in the agricultural production systems. Extensive engineering and academic research is being conducted in an attempt to elaborate the consequences and effects of large scale and expanded use of treated effluents of varying degree of quality on the human and natural environment, in general, and the soil/water/crop relationship, in particular. Subsurface trickle irrigation in large field scale was tried and no yield benefits or deficits were found as compared to surface trickle irrigation. However the E.coli pathogens in the surface soil was the same as background samples suggesting a safer method of irrigation though not always the maximum yields are obtained.

In Cyprus wastewater generated from the main cities is collected and following tertiary treatment is used for irrigation. It is expected that the irrigated agriculture will be expended by 8-10% and an equivalent amount of water will be conserved for other sectors (Papadopoulos. 1995)

In Italy, in the areas near the treatment plants of the towns Castiglione, Cesena, Cesenatico, Cervia and Gatteo an intensive programme of reuse of treated wastewaters has been carried out. Wastewater irrigation now covers an area of over 4000 ha and very interesting results both in terms of the effects on the soil and on the irrigated crops are shown. The first survey of Italian treatment plants estimated the total treated effluent flow at 2 400 Mm3 /yr of usable water. This gives an estimate of the potential resource available for reuse.

The reuse of treated wastewater in Spain is already a reality in several regions of the country for four main applications: golf course irrigation, agriculture irrigation, groundwater recharge and river flow augmentation. In Tenerife, the treated water reused in irrigation amount to 17 00 m^3/day. These waters are stored in two reservoirs of a capacity of 250 00 m^3 and 50 000 m^3 respectively in San Lorenzo and Sen Isidro. The main crops irrigated are banana, vineyards, tomatoes, and cut flowers.

In Portugal, treated wastewater is a valuable potential resource for irrigation and should soon reach 580 Mm3 /yr, which is approximately twice as much as today. Even without storage, this amount could be enough to cover about 10% of the water needs for irrigation in a dry year. Roughly, between 35 000 and 100 000 ha, depending on storage capacity could be irrigated with recycled water.

In Morocco, the reuse of raw wastewaters has become a current and old practice. They are reused in agriculture in several parts the country. These practices are mainly localized to the periphery of some big continental cities where agricultural lands are locate in the downstream of effluent discharge, and also in small parts around the wastes of the treatment networks. The climatic constraints had pushed farmers to irrigate their crops with raw wastewater when water resources are not available.

During the last years, the reuse of wastewaters has also developed around some suburbs recently provided with a treatment network. A total of 7000 ha (Choukr-Allah, 2004) is directly irrigated with raw wastewaters discharged by towns, i.e. about 70 million m^3 of wastewater is used every year in agriculture with no application of the sanitary precaution (HWO standards for example). This second use concerns a diversity of cultivation types (fodder, cereals, fruit threes…).

The irrigation of vegetable crops with raw wastewaters is forbidden in Morocco, but this banning is not respected, which makes the consumer of agricultural products and the farmer face risks of bacteria or parasite contaminations. In general, the volume of wastewaters that have been recycled does not represent more than 0.5% of the water used in Agriculture.

This situation tends to be generalized in all the suburbs that are provided with a treatment system where wastewaters are discharged. Following an investigation carried out within the framework of NSLC (1998), a total of 70 areas using wastewaters are spread out in the territory. This practice is not free of dangerous consequences on human health and on environment. For example:

(i) Spread of water diseases (more than 4000 cases of Typhoid and more than 200 case of malaria have been noted in 1994, some cholera sources in the Sebou basin).

(ii) Difficulty and high cost of processing, and for the production potable water.

(iii) Many section of water courses in the country present a largely weak quantity of dissolved oxygen, and even a deficit in oxygen when these discharges are important, which causes massive fish mortality, and;

(iv) Many dam volumes present marks of eutrophication, as a consequence of the important phosphor and nitrogen wastes.

Since early nineties, many multidisciplinary projects concerning the treatment and reuse of wastewater in irrigation have been launched in Morocco. The aim was to answer the major agronomic, health, and environmental concerns. The results of these researches have made the local collectivities and the regional agriculture services benefit from reliable data necessary to conceive and to size the treatment plants of wastewaters adapted to the local contexts and to disseminate the best practices for reusing treated wastewaters in agriculture.

In Egypt an ambitious programme is running for municipal wastewater treatment that will provide by the year 2010 nearly 3 billions m^3/yr of treated wastewater as an additional water source to be used in agriculture (Abu-Zeid, 1992).

Most nations in the region are already importing virtual water, in the form of food, and will likely have to increase specific imports, such as cereal crops. Despite this, many countries wish to increase fresh water supplies to domestic, and industrial usages, and at the same time, expand irrigated agriculture. For example, Tunisia wishes to increase the area of irrigated agriculture by at least 30,000 hectares (ha), and Egypt, by 880,000 ha. How can these seemingly contradictory objectives be reconciled? The answer is water demand management more efficient water use within all sectors. One specific component is to increasingly reuse domestic wastewater, for industry, for some municipal purposes, such as flushing toilets and irrigating green spaces, but above all, for agriculture, to offset the fresh water being taken out of this sector.

WASTEWATER REUSE CONSIDERATIONS

Wastewater reuse applications

In the planning and implementation of wastewater reclamation and reuse, the reuse application (see Table 2) will usually govern the wastewater treatment needed, and the degree of reliability required for the treatment processes and operations. Because wastewater reclamation entails the provision of a continuous supply of water of consistent quality, the reliability of the existing or proposed treatment processes and operations must be evaluated in the planning stage (Tchobanoglous and Burton, 1991). Specific reuse categories and treatment technologies that may be applicable will depend on the location and type of wastewater management employed (e.g., centralized versus decentralized, as discussed subsequently). Worldwide, the most common use of reclaimed wastewater has been for agricultural irrigation. Recently, groundwater recharge and potable reuse have received considerable attention in the United States. The re-purification project in San Diego, CA, in which it is proposed to blend re-purified wastewater with local runoff and imported water in a local water supply storage reservoir, is an example of such a project (Montgomery and Lowry, 1994.)

Table 2. Categories of municipal wastewater reuse and potential issues/constraints

Wastewater reuse categories	Issues/constraints
Agricultural irrigation	(1) Surface and groundwater Pollution if not managed properly, (2) Marketability of crops and public acceptance, (3) effect of water quality, particularly salts, on soils and crops, (4) public health concerns related to pathogens (bacteria, viruses, and parasites), (5) use for control of area including buffer zone, (6) may result in high user costs.
Crop irrigation	
Commercial nurseries	
Landscape irrigation	
Parks	
School yards	
Freeway medians	
Golf courses	
Cemeteries	
Greenbelts	
Residential	
Industrial recycling and reuse	(1) Constituents in reclaimed wastewater related to scaling, corrosion, biological growth, and fouling, (2) public health concerns, particularly aerosol transmission of pathogens in
Cooling water	

Boiler feed Process water Heavy construction	cooling water.
Groundwater recharge Groundwater replenishment Salt water intrusion control Subsidence control	(1) Organic chemicals in reclaimed wastewater and their toxicological effects, (2) total dissolved solids, nitrates, and pathogens in reclaimed wastewater.
Recreational/environmental uses Lakes and ponds Marsh enhancement Stream-flow increase Fisheries Snowmaking	(1) Health concerns of bacteria and viruses, (2) eutrophication due to nitrogen (N) and phosphorus (P) in receiving water, (3) toxicity to aquatic life.
Non-potable urban uses Fire protection Air conditioning Toilet flushing	(1) Public health concerns on pathogens transmitted by aerosols, (2) effects of water quality on scaling, corrosion, biological growth, and fouling, (3) cross-connection.
Potable reuse Blending in water supply Pipe to pipe water supply	(1) Constituents in reclaimed wastewater, especially trace reservoir organic chemicals and their toxicological effects, (2) aesthetics and public acceptance, (3) health concerns about pathogen transmission, particularly viruses

Source: Tchobnoglous and Burton, 1991

Wastewater quality and health issues

Irrigating with untreated wastewater poses serious public health risks, as sewage is a major source of excreted pathogens - the bacteria, viruses, protozoa- and the helminths (worms) that cause gastro-intestinal infections in human beings.

Wastewater may also contain highly poisonous chemical toxins from industrial sources as well as hazardous material from hospital waste. Relevant groups of chemical contaminants are heavy metals, hormone active substances (HAS) and antibiotics. The risks associated with these substances may, in the long run, turn out to constitute a greater threat to public health and be more difficult to deal with than the risks from excreted pathogens. Unregulated and continuous irrigation with sewage water may also lead to problems such as soil structure deterioration (soil clogging), salinization and phytotoxicity.

These risks are not limited to ‘official’ wastewater but often also apply to rivers and other open water sources, as indicated by figures gathered by Westcott: 45% of 110 rivers tested carried faecal coliforms levels higher than the WHO standard for unrestricted irrigation (FAO, unpublished, cited in Birley).

The ideal solution is to ensure full treatment of the wastewater to meet WHO guidelines prior to use, even though the appropriateness of these guidelines are still under discussion. However, in practice most cities in low income countries are not able to treat more than a modest percentage of the wastewater produced in the city, due to low financial, technical and/or managerial capacity. The rapid and unplanned growth of cities with multiple and dispersed wastewater sources makes the management more complex. In many cities a large part of the wastewater is disposed of untreated to rivers and seas, with all related environmental consequences and health risks. The perspectives regarding the increase in wastewater treatment capacity in these cities are bleak. It may safely be assumed that urban and peri-urban farmers increasingly will use wastewater for irrigation, irrespective of the municipal regulations and quality standards for irrigation water.

Only a few large cities in developing countries and newly industrializing countries have adequate sewer systems and treatment plants, which is not the case for the majority of developing countries. In any case, usually, only a small portion of the wastewater is treated and purified even when it is channeled through a sewer system. Existing sewage treatment plants rarely operate satisfactorily and, in most cases, wastewater discharges exceed legal and/or hygienically acceptable maxima.

This does not necessarily lie in the treatment plants themselves, but in the frequent lack of adequately trained technicians capable of technically operating such treatment plants.

The discharge of untreated wastewater and/or minimally treated municipal ones in water sources has resulted in a substantial economic damage and has posed serious health hazards to the inhabitants, particularly in the developing countries. In many countries, various diseases are particularly prevalent and the consequential costs for the health care system are considerable.

Considerable sums have been spent on water and wastewater treatment in both the developing and developed regions of the world to substantially reduce waterborne diseases and meet commonly accepted environmental and ecological objectives. Yet, statistics indicate that in spite of such enormous investments in water quality improvement and protection, in the less developed countries, nearly 2 billion people are suffering from the lack of clean drinking water and sanitation facilities.

This is now the case in many mega-cities where the drinking water supplies from rivers or local groundwater sources are no longer sufficient, mostly because of their poor quality.

As a matter of fact, water quality problems are certainly not restricted to urban areas. The lack of sanitation facilities and the too often associated unsafe drinking waters remain among the principal causes of disease and death, especially in rural areas. Specific measures to counteract water-related threats are often needed, but, lack of investments and inadequate local management often lower their effectiveness.

Institutional manageability

Wastewater reuse is characterised by the involvement of several departments and agencies, either governmental or private or both. In the southern part of the Mediterranean countries, few governmental agencies are adequately equipped for wastewater management. In order to plan, design, construct, operate and maintain treatment plants, appropriate technical and managerial expertise must be present. This could require the availability of a substantial number of engineers, access to a local network of research for scientific support and problem solving, access to good quality laboratories and monitoring system and experience in management and cost recovery. In addition, all technologies, included the simple ones, require devoted and experienced operators and technicians who must be generated through extensive education and training.

For adequate operation and minimization of administrative conflicts, a tight coordination should be well defined among the Ministries involved such as those of Agriculture, Health, Water Resources, Finance, Economy, Planning, Environmental Protection and Rural Development. The basic responsibilities of such inter-ministerial committees could be outlined in:

- developing a coherent national policy for wastewater use and monitoring of its implementation;
- defining the division of responsibilities between the respective Ministries and agencies involved and the arrangements for collaboration between them;
- appraising proposed re-use schemes, particularly from the point of view of public health and environmental protection;
- overseeing the promotion and enforcement of national legislation and codes of practice;
- developing a national staff development policy for the sector;

Financial considerations

The lower the financial costs, the more attractive is the technology. However, even a low cost option may not be financially sustainable because this is determined by the true availability of funds provided by the polluter. In the case of domestic sanitation, the people must be willing and able to cover at least the operation and maintenance cost of the total expenses. The ultimate goal should be full cost recovery although, initially, this may need special financing schemes, such as cross subsidization, revolving funds and phased investment programmes.

In this regard, adopting an adequate policy for the pricing of water is of fundamental importance in the sustainability of wastewater re-use systems.

The incremental cost basis, which allocates only the marginal costs associated with re-use, seems to be a fair criteria for adoption in developing countries.

Subsidizing re-use system may be necessary at the early stages of system implementation, particularly when the associated costs are very large. This would avoid any discouragement to users arising from the permitted use of the treated wastewater.

However, setting an appropriate mechanism for wastewater tariff is a very complex issue. Direct benefits of wastewater use are relatively easy to evaluate, whereas, the indirect effects are “non monetary issues” and, unfortunately, they are not taken into account when performing economic appraisals of projects involving wastewater use. However, the environmental enhancement provided by wastewater use, particularly in terms of preservation of water resources, improvement of the health status of poor populations in developing countries, the possibilities of providing a substitute for freshwater in water scarce areas, and the incentives provided for the construction of urban sewage works, are extremely relevant. They are also sufficiently important to make the cost benefit analysis purely subsidiary when taking a decision on the implementation of wastewater re-use systems, particularly in developing and rapidly industrializing countries.

Monitoring and Evaluation

Monitoring and evaluation of wastewater use programmes and projects is a very critical issue, hence, both are the fundamental bases for setting the proper wastewater use and management strategies. Ignoring monitoring evaluation parameters and/or performing monitoring not regularly and correctly could result in serious negative impacts on health, water quality and environmental and ecological sustainability.

Unfortunately, in many countries that are already using or start using treated wastewater as an additional water source, the monitoring and evaluation programme aspects are not well developed, are loose and irregular. This is mainly due to the weak institutions, the shortage of trained personnel capable of carrying the job, lack of monitoring equipment and the relatively high cost required for monitoring processes.

In the developing countries, two types of monitoring are needed: the first, process control monitoring to provide data to support the operation and optimization of the system in order to achieve successful project performance; the second, compliance monitoring to meet regulatory requirements and not to be performed by the same agency in charge of process control monitoring.

In the developing countries, to avoid failure in wastewater use and attain the desired success, the monitoring programme should be cost effective, and should provide adequate coverage of the system. Equally so, it must be reliable and timely in order to provide operators and decision making officials with correct and up-to-date information that allows the application of prompt remedial measures during critical situations.

Public awareness and participation

This is the bottleneck governing the wastewater use and its perspective progress. To achieve general acceptance of re-use schemes, it is of fundamental importance to have active public involvement from the planning phase through the full implementation process.

Some observations regarding social acceptance are pertinent. For instance, there may be deeprooted socio-cultural barriers to wastewater re-use. However, to overcome such an obstacle, major efforts are to be carried out by the responsible agencies.

Responsible agencies have an important role to play in providing the concerned public with a clear understanding of the quality of the treated wastewater and how it is to be used; confidence in the local management of the public utilities and in the application of locally accepted technology, assurance that the re-use application being considered will involve minimal health risks and minimal detrimental effects on the environment.

In this regard, the continuous exchange of information between authorities and public representatives ensures that the adoption of specific water re-use programme will fulfill real user needs and generally recognized community goals for health, safety, ecological concerns programme, cost, etc.

In this way, initial reservations are likely to be overcome over a short period. Simultaneously, some progressive users could be persuaded to re-use wastewater as supplementary source for irrigation. Their success would go a long way in persuading the initial doubters to re-use the wastewater available.

MAJOR NEEDS FOR RECYCLING AND REUSE OF WASTEWATER

Applying realistic standards and regulations

An important element in the sustainable use of wastewater is the formulation of realistic standards and regulations. However, the standards must be achievable and the regulations enforceable.

Unrealistic standards and non-enforceable regulations may do more harm than having no standards and regulations because they create an attitude of indifference towards rules and regulations in general, both among polluters and administrators. In arid and semi-arid countries where wastewater is recognized additional water source standards, guidelines and regulations in the majority of developing countries do not consider the re-use aspect as an integrated part of the treatment process; they are only intended to control and protect the quality of water bodies where the reclaimed water is discharged. In reality, in the arid regions of the Near-East, North-Africa and Southern-Europe, not all countries have developed guidelines and regulations for reclaimed water use. For those countries, standards and regulations for the re-use should be tailored to match the level of economic and administrative capacity and capability standards should cope with the local prevailing conditions and should be gradually tightened as progress is achieved in general development and in the economic and technical capability of the involved institutions and of the private sector as well.

Formulation of national policies and strategies

It is now widely recognized that wastewater re-use constitutes an important and integral component of the comprehensive water management programs of the majority of countries, more so in the water scarce ones.

This implies that these countries should have national policies and strategies relating to wastewater management in general and wastewater re-use for agriculture, in particular, in order to guide programme, projects and investments relating to wastewater collection, treatment, re-use and disposal in a sustainable manner.

This requires the establishment of a clear policy with regard to wastewater management.

This policy should be compatible with a number of related sectoral or sub-sectoral policies such as national water management and irrigation policy, national health, sanitation and sewage policy, national agricultural policy and national environmental protection policy.

Such policy should give guidance on the following issues:

- the current and future contribution of treated wastewater to the total national water budget;
- criteria required to achieve maximum benefit of wastewater-reuse for the different water sectoral uses;
- modalities for strengthening the national capacity building in this sector.

Such policy should be accompanied by an appropriate national strategy for wastewater reuse characterized by the following features:

- spelling out ways and means of implementing policy directives;
- defining the nature and mechanisms of inter-institutional collaboration, allocation of funds, establishment of pilot wastewater reuse demonstration sites of good management practices and phasing the implementation of wastewater programmes;
- fostering the share of responsibilities between involved ministries, agencies and authorities, and the way to link and integrate the activities among them, individually and in combination;
- identifying an economically feasible, safe and socially acceptable set of standards, regulations and codes of practices for sustainable use.

Ideally, policies of wastewater reuse and strategies for its implementation should be part of water resources planning at the national level. At the local level, individual reuse projects should be part of the overall river basin planning effort.

Institutional, Legal and Political aspects of wastewater reuse

Safe water treatment, disposal and reuse are the responsibility of different organizations such as authorities, cooperatives and communities operating under the jurisdiction of the ministries of agriculture, water resources and others. The responsibilities of these organizations must be considered and reconciled.

To tackle the range of institutional levels involved and to allocate responsibilities in both treatment and reuse stages, several actions are needed, including:

(i) A well-defined policy and strategy for the comprehensive management and reuse of treated wastewater is a precondition to success.

(ii) Many different stakeholders are involved, so roles and responsibilities (who does what) need to be clearly defined, along with mechanism to ensure the active co-ordination of the various institutions.

(iii) Inadequate legislation often hinders the effective reuse of treated wastewater. Integrated legal arrangements can be of great value, along with provisions for active enforcement of all laws and regulations, without exception.

(iv) A comprehensive plan of action for reusing treated wastewater, with clearly assigned roles, needs to be complemented by periodic reviews and follow-up. Adequate funding is essential.

(v) Capacity building is required to analyse staff needs and provide suitable training.

(vi) More participatory approaches are needed, including raising the awareness of the general public (whose cultural and religious perceptions sometimes regard treated wastewater as impure). Irrigators also need to be involved in the planning and utilisation of this resource.

(vii) More co-ordination is needed between donors and national institutions involved in wastewater reuse.

To reinforce and help consolidate improved arrangements in countries with many ministries involved, the possible formation of a « higher council » to create policy and strategies should be considered. This body could oversee implementation and obtain necessary funding.

Where many different laws complicate wastewater reuse, consideration could be given to consolidated legislation that would cover all aspects of water resources planning, management and utilisation.

Awareness raising, education, and best practices

Targeted health education is the most realistic, practical and cost effective measure to reduce health risks associated with wastewater use in agriculture. The following categories should be addressed:

- Policymakers: convince them that the use of wastewater is a reality that has to be accepted; provide them with data on the food security, income generating capacity, health and nutrients aspects of wastewater use in agriculture; show trade-offs of costs and benefits of wastewater treatment and reuse in agriculture, co-management of water provision, sanitation, treatment and reuse, and strategies for handling wastewater from the source to the users.

- Farmers: provide information through interactive learning methods on health risks associated with wastewater use, information and technical assistance on proper crop selection in relation to wastewater quality, irrigation techniques, protective clothing (boots), personal hygiene, washing crops before marketing, group organization for on field sanitation and washing facilities; preventing damage to soils and ground water.

- Consumers: Inform them on proper washing; cooking or blanching of vegetables; and sufficient cooking time for fish raised with wastewater; necessity of paying for treatment of household wastewater as they are the generators.

- Tradesman: use of clean water for freshening products (vegetables) on the market; ways for minimizing contamination risks during transport and processing.

- Local authorities: to help them understand the implications of wastewater use and the role they can play in minimizing the risks.

- The NGO’s and media may have to play a vital role in this exercise, if authorities are slow to take the lead.

Best practices should include:

- Crop selection and certification of produce (labelling);

- Variations in absorption of certain chemicals by crops, makes crop selection a suitable strategy, in the absence of market forces, which discourage crop restriction;

- Offering financial incentives i.e. labelling clean products, which will fetch higher prices, is also a possibility provided customers are willing to pay more and certification programs, which are costly processes, can be set up;

- Suitable irrigation system.

Improving irrigation practices

Irrigation techniques, which wet only the roots and not the leafy part of vegetables, were suggested as good practice for minimizing risk of contamination. Bed and furrow irrigation, drip systems and any other technique applying water close to the root systems was suggested. There is a further advantage in that there will be less infiltration into groundwater. Rotating wastewater application over fields if this is possible is another means to limit over-fertilisation and pollution of groundwater. Avoiding irrigation with wastewater in the two weeks before harvest can minimize the risk from pathogen contamination of leafy vegetables, but this necessitates a fresh water source accessible to farmers, which is rarely possible in these peri-urban situations.

CONCLUDING REMARKS AND RECOMMENDATIONS

Domestic WWTR is one tool to address the food and water insecurity facing many countries in the Mediterranean. In coming years, in most Mediterranean countries, valuable fresh water will have to be preserved solely for drinking, very high value industrial purposes, and for high value fresh vegetables and salad crops consumed raw. Where feasible, most crops in arid countries will have to be grown increasingly, and eventually solely, with treated wastewater. The economic, social and environmental benefits of such an approach are clear. To help the gradual and coherent introduction of such a policy, which protects the environment and public health, governments shall have to adapt an Integrated Water Management approach, facilitate public participation, disseminate existing knowledge, and generate new knowledge, and monitor and enforce standards.

- One of the prerequisites for any cure is an adequate information base. This includes inventorying water stocks, on one hand, and ascertaining the demand at local and regional level, in quantitative and qualitative terms within the framework of national water strategy, on the other one. Economic, social and environmental concerns must all be taken into account in accordance with the goal of sustainability.

- It is important to strengthen the capacity of national and local hydrological research institutes to improve their links to environmental research as well as to institutes in the field of economic and social science, particularly in the field of urban studies and planning. The transfer of knowledge to local government decision-makers must be improved.

- Local governments must focus their policies on treating municipal wastewater to eliminate the rapid degradation in both surface and groundwater quality. In this regard, simple methods of wastewater treatment are to be recommended as realistic solutions; equally so, governments have to operate as well to strengthen the capacity of both institutions and users.

Efforts concerning domestic sewage must center on promoting and further developing low cost, easy-to-handle and, in general, regionally developed technologies with a low degree of complexity. Special weight must be placed on minimizing the energy needs for these technologies.

- The failure of governance at local government level should be counteracted by improving the efficiency of public administration at the local level. The measures required include the building of responsibilities, combining management and financing functions, improving environmental legislation and monitoring, dismounting bureaucratic, decentralizing tasks to the lowest levels possible, increasing the transparency of government activities as well as enhancing the skills of the public administration employees.

- Enhancing and improving cooperation between local governments and the informal sector which is far below the level required. The informal sector should be exploited to a greater extent and integrated with decentralized public administration to find more rapid, appropriate and flexible solutions to the existing and raising problems. In this regard, the involvement of the NGOs has to be strengthened in the management of infrastructural institutions and the mobilization of public participation and individual responsibility within the framework of urban supply and wastewater treatment and use projects.

- Existing water charges must be changed so that they reflect scarcities and increase the reliability of supply. Most of the water tariff systems in both developed and developing countries do not reflect the economic and environmental scarcity of water. To be environmentally and economically viable, water tariff systems should ensure that the costs of collecting, treating and using water are recovered. Low income users should be able to reduce the amount they have to pay through active participation in systems of water collection, water supply and wastewater disposal and treatment.

The demand of major polluters or large consumers should be controlled using the instrument of marginal cost tariffs. Taxing consumption in this way is a financial incentive to water sustainability.

Where many different laws complicate wastewater reuse, consideration could be given to consolidated legislation that would cover all aspects of water resources planning, management and utilisation.

REFERENCES

Abu-Zeid, M. (1992). *Egypt efforts towards management of agricultural water demand*. National Water Research Center, MPWWR, Egypt.

Abu-Zeid, M. (1998). Recent Trends and Development: Reuse of Wastewater in Agriculture, *International Journal on Environmental Management and Health*, 9(2-3): .

Abbott, C.L. and Hasnip, N.J. (1997). *The safe use of marginal quality water in agriculture*. Report of Project R 6570, Overseas Development Unit, HR Wallingford, UK.

Allan, J.A. (2001). *The Middle East Water Question: Hydropolitics and the Global Economy*. I.B. Tauris & Co. Ltd., London, UK.

Ayers, R.S. and Westcot D.W. (1985). *Water Quality for Agriculture*. FAO Irrigation and Drainage Paper 29 (Rev. 1). Food and Agriculture Organization, Rome, Italy.

Ayers, R. M. and Mara, D. D. (1996). *Analysis of Wastewater for Use in Agriculture. A Laboratory Manual of Parasitological and Bacteriological Techniques*. World Health Organization, Geneva. www.who.int/entity/water_sanitation_health/wastewater/labmanual.pdf

Blumenthal, U.J., Peasey, A., Ruiz-Palacios, G. and Mara, D.D. (2000). *Guidelines for wastewater reuse in agriculture and aquaculture: Recommended revisions based on new research evidence*. WELL Study, Task No. 68 (Part 1), London School of Hygiene and Tropical Medicine, UK.

Brissaud,F., Restrepo-Bardon, M., Soulie, M. and Joseph, C. (1991). Infiltration percolation for reclaiming pond effluents. *Wat. Sci. Tech*., 24(9): 185-193.

Carr, R.M., Bluementhal, U.J. and Mara, D.D. (2004). *Health guidelines for the use of wastewater in agriculture:Developing realistic guidelines*. In: *Wastewater Use in Irrigated Agriculture,* Scott,C.A., Faruqui, N.I. and Raschid-Sally, L. (eds). CABI Publishing, Wallingford, UK, pp. 41-58.

Choukr-Allah, R. (1996a). *Impact de l'irrigation par des eaux usées épurées par infiltration percolation et par épuvalisation sur la production du melon* (*Cucumis melo* L.) *sous serre*. International Workshop on Sewage Treatment and Re-Use for Small Communities: Mediterranean and European Experience. November 23 - 26, 1996, Agadir, Morocco.(under Press). Mediterranean Colloquium on Protected Cultivation. October 6 - 9, 1996, Agadir, Morocco.

Choukr-Allah, R. (1996b). *Effet de la réutilisation des eaux usées épurées par infiltration percolation et par épuvalisation et de deux types de goutteurs de l'irrigation localisée (Twin Drip et goutteur linéaire) sur une culture d'oeillet (Dianthus caryophyllus cv. Scarllette) sous serre*. International Workshop on Sewage Treatment and Re-Use for Small Communities: Mediterranean and European Experience. November 23 - 26, 1996, Agadir, Morocco.

Choukr-Allah, R. (2004). *Wastewater treatment and reuse I Morocco: Situation and perspectives*. International Workshop on Non-Conventional water use. Water Saving in Mediterranean Agriculture (WASAMED) 7-10 December, 2004 Cairo, Egypt. Published by CIHEAM/IAM- Bari, Italy.

Choukr-Allah, R. and Hamdy A. (2004). Wastewater treatment and re-use in Mediterranean region as a potential resource for drought mitigation. In: *Water Management for Drought Mitigation in the Mediterranean*, Hamdy A. and Trisorio Liuzzi G. (eds.). Options Méditerranéennes, Séries B 47. CIHEAM/IAMBari, Italy, pp. 219-244.

Cooper, R.C., 1991. Public health concerns in wastewater reuse. *Water Sci. Technol*. 24(9), 55-65.

Ensink, J.H.J., van der Hoek, W., Matsuno, Y., Munir, S. and Aslam, M.R. (2002). *Use of untreated wastewater in peri-urban agriculture in Pakistan: Risks and opportunities*. Research Report 64, International Water Management Institute, Colombo, Sri Lanka.

F.A.O. (1992). *Wastewater treatment and use in agriculture*. M.B. Pescod. Irrigation and drainage paper

F.A.O. (1997). *Irrigation in the NEAR East Region in Figures*: Report No 9, Rome, Italy.

F.A.O. (1997). *Quality control of wastewater for irrigated crop production*. D.W. Westcot. Water reports 10. FAO Rome.

F.A.O. (1998). *Proceedings of the expert consultation on Re-use of low quality water for sustainable agriculture*. 15-18 Dec., 1997, Amman, Jordan.

Hamdy, A. (1996). *Saline irrigation: Assessment and management techniques*. In Halophytes and Biosaline agriculture. Choukr-Allah R., Malcom L.V. and Hamdy A. (eds). Marcel Dekker, New York, Brussel, Hong Kong, pp. 147-181.

Hamdy. A. (1999). *Sewage water: Prospects and Challenges for Use*. In: *Mediterranean water resourses: Major challenges towards the 21st Century,* Hamdy A. and Lacirignola C. (eds). CIHEAM/IAM-Bari, Italy, pp. 407-443.

Hamdy, A. (2002). *Experiences with on-site treatment systems for the reuse of domestic wastewaters.*UNESCO Conference, Paris.

International Water Management Institute (IWMI) (2003). *Confronting the realities of wastewater use in agriculture*. Water Policy Briefing 9, IWMI, Colombo, Sri Lanka.

GWP-Med (2000). *Framework For Action for the Mediterranean, Water for the 21st Country: Vision to Action.*

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

Matsuno. Y., Ensink, J.H.J., van der Hoek, W. and Simmons R.W. (2004). Assessment of the use of wastewater for irrigation: A case in Punjab, Pakistan. *Proceedings of Symposium on Wastewater Reuse and groundwater Quality, July 2003, Sapporo*, IAHS Publication 285, pp. 28-33.

Mojtahid A., Lamiri M., Choukr-Allah R., Hamdy A. and El Omari H. (2001). Best management of reducing nitrogen pollution under irrigated sweet paper with treated wastewater. *International Workshop on Wastewater Reuse Management, September 2001, Seoul, Korea*. Ragab R., Pearce G., Kim J.C., Narizi S. and Hamdy A. (eds). ICID-CIID, pp. 55-62.

MONTGOMERY/WATSON and NBS LOWRY. (1994). *Water Repurification Feasibility Study*, Report prepared for San Diego Water Authority, San Diego, CA.

Morocco Ministry of Agriculture (1996). *Assessment of the Reuse of Wastewater for Agriculture at the Treatment Station at Ben Sergao* (published in French).

Morocco National Office of Potable Water, *Annual Evaluation of the: Performance of the Wastewater Treatment Station at Ben Sergao*, 1989-present (published in French).

NSLC (1998). National schemes on liquid cleansing: Re-use of waste water. (1991). In: *Wastewater Engineering: Treatment, Disposal, reuse*, Tchobanoglous, G. and Burton, F. L. (written and revised by). 3rd ed. Metcalf & Eddy, Inc., McGraw-Hill Book Company, New York, NY.

ONAS. Office National de l'Assainissement (Ministère de l'Environnement et de l'Aménagement du Territoire). SERAH (2001). *Etude de la stratégie nationale de valorisation des eaux usées traitées.*

Oweis T., Zhang, H. and Pala, M. (2000). Water use efficiency of rainfed and irrigated bread wheat in a Mediterranean environment. *Agron. J.,* 92: 231-238.

Papadopoulos, I. (1995). *Wastewater management for Agriculture Production and Environmental Protection in NER.* FAO Regional Office for the Near East, Cairo, Egypt.

Prathapar, S.A. (2000). Water shortages in the 21st century. In: *The Food and Environment Tightrope,* Cadman H. (ed). Australian Centre for International Agricultural Research, Canberra, Australia, pp. 125-133.

Prescod, M.B. (1992). *Wastewater Treatment for Use in Agriculture*. Food and Agricultural Organization of the United Nations, Rome.

Qadir, M., Ghafoor, A. and Murtaza, G. (2000). Cadmium concentration in vegetables grown on urban soils irrigated with untreated municipal sewage. *Environ. Develop. Sustainability,* 2: 11-19.

Qadir, M. and Oster J.D. (2004). Crop and irrigation management strategies for saline-sodic soils and waters aimed at environmentally sustainable agriculture. *Science of the Total Environment,* 323: 1-19.

Qadir, M. and Schubert, S. (2002). Degradation processes and nutrient constraints in sodic soils. *Land Degrad. Develop.*, 13: 275-294.

Schmitt, A. (1989). *Modélisation de l'épuration par infiltration*. Th. Doc. Univ. Montpellier II

Scott, C.A., Faruqui, N.I., Raschid-Sally, L. (2004). *Wastewater Use in Irrigated Agriculture: Confronting the Livelihoods and Environmental Realities.* CABI Publishing, Wallingford, UK.

Sumner, M.E. (1993). Sodic soils: new perspectives. *Aust. J. Soil Res.*, 31: 683-750.

Van der Hoek, W. (2004). A framework for a global assessment of the extent of wastewater irrigation: the need for a common wastewater typology. In: *Wastewater Use in Irrigated Agriculture*, Scott,C.A., Faruqui, N.I. and Raschid-Sally, L. (eds). CABI Publishing, Wallingford, UK, pp 11-25.

Van der Hoek, W., Ul Hassan, M., Ensink, J.H.J., Feenstra, S., Rashid-Sally, L., Munir, S., Aslam, M.R., Ali, N., Hussain, R. and Matsuno, Y. (2002). *Urban wastewater: A valuable resource for agriculture*. Research Report 63, International Water Management Institute, Colombo, Sri Lanka.

Wagner, G.J. (1993). Accumulation of cadmium in crop plants and its consequences to human health. *Adv. Agron.*, 51: 173-212.

W.H.O. (1989). *Health guidelines for the use of wastewater in agriculture and acquaculture*. W.H.O. Technical report series no. 517, World Health Organization, Geneva.

W.H.O. (1990). *Legal issues in water resource allocation, wastewater use and water supply management. Report of consultation of FAO/WHO working group on legal aspects of water supply and wastewater management*. *Geneva 27 Sept*. 1990. World Health Organization, Geneva.

W.H.O. (1992). *The International drinking water and sanitation decade*. Review (as at December, 1990). W.H.O./CW5/92.12. World Health Organization, Geneva.