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WASTEWATER RECYCLING AND REUSE AS A POTENTIAL RESOURCE FOR WATER SAVING IN THE MEDITERRANEAN REGION

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INTRODUCTION

Given current demographic trends and future growth projections, as much as 60% of the global population may suffer water scarcity by the year 2025. The water-use efficiency techniques used with conventional resources have been improved. However, water-scarce countries will have to rely more on the use of non-conventional water resources to partly alleviate water scarcity. Such water resources are harnessed for agricultural and other uses through specialized processes such as desalination of seawater and highly brackish water; harvest of rainwater; collection, treatment, and use of wastewater; capture and reuse of agricultural drainage water; extraction of groundwater containing a variety of salts. Appropriate strategies for managing soil, water and crops may also beneededwhenthese resources areusedfor irrigation.

Marginal-quality water resources

Marginal-quality waters consist of: (1) wastewater generated by domestic, commercial and industrial uses; (2) drainage water generated by irrigated agriculture and surface runoff that has passed through the soil profile and entered the drainage system; (3) groundwater from different sources, such as underlying saline formations, seawater intrusion in coastal areas, recharge of agricultural drainage, storm water runoff from urban areas, and/or infiltration from wastewaterirrigated areas. Marginal-quality waters contain one or more impurities at levels higher than in freshwater, including salts, metals, metalloids, residual drugs, organic compounds, endocrine-disrupting compounds, and the active residues of personal care products and/or pathogens. These constituents may have undesirable effects on soils, crops, water bodies, or human and animal health.

Wastewater from domestic, municipal, and industrial activities

Population growth coupled with the provision of goods and services that allow higher living standards have increased the demand for good-quality water to provide for the needs of the domestic, municipal, and industrial sectors in water-scarce countries. Consequently, greater amounts of wastewater are being generated. After treatment, and in conjunction with suitable management practices, this could be reused for a variety of purposes. Urban wastewater consist of a combination of some or all of the domestic effluent produced (black water and grey water), water produced by commercial establishments and institutions (including hospitals), industrial effluent and storm water which has not infiltrated the soil, as well as other forms of urban runoff (Van der Hoek, 2004).

Estimates of the extent to which wastewater is used for agriculture worldwide reveal that at least 2 _ 106 ha are irrigated with treated, diluted, partly treated or untreated wastewater (Jimenez and Asano, 2004). The use of untreated wastewater is intense in areas where there is no or little access to other sources of irrigationwater. Fewdatabases are available that describe the extent to which wastewater is used for agriculture at thenationalor regional levels (MinhasandSamra, 2003; Van der Hoek, 2004). Owing to the variable quantities of water available for human consumption in water-scarce countries, estimates of the per capita generation of wastewater vary, ranging from 30 to 90m3 yr_1. The volumes of wastewater generatedinsomecountries of Central and WestAsiaand North Africa (CWANA) are presented in Table 3. A significant part of the wastewater generated in these countries is used to supplement the freshwater needs of a variety of crops.

Table 3 – Volume of wastewater generated annually in some countries of Central and West Asia and North Africa

Country	Reporting year	Wastewater volume ($\times 10^6\ m^3\ yr^{-1}$)
Algeria	2004	600
Bahrain	1990	45
Egypt	1998	10012
Iran	2001	3075
Jordan	2004	76
Kuwait	1994	119
Kyrgyzstan	1995	380
Lebanon	1990	165
Libya	1999	546
Morocco	2002	650
Oman	2000	78
Saudi Arabia	2000	730
Syria	2002	825
Tunisia	2001	240
Turkey	1995	2400
United Arab Emirates	2000	881
Uzbekistan	2004	170
Yemen	2000	74

Except for Algeria, Jordan and Uzbekistan; data derived from the wastewater databases of the Food and Agriculture Organization, available at http://www.fao.org/landandwater/aglw/waterquality/waterusedb.jsp.

The rate at which populations are increasing means that wastewater treatment and its sustainable use is an issue that requires more attention and investment. Most developing countries have not been able to build wastewater treatment plants on a large enough scale and, in many cases, they were unable to develop sewer systems fast enough to meet the needs of their growing urban populations. As a result, in several countries, particularly in Sub-Saharan Africa (SSA), the sanitation infrastructure in major cities has been outpaced by population increases, making the collection and management of urban wastewater ineffective. In many large cities (for example, Accra in Ghana), only a small part of the wastewater produced (_10%) is collected in piped sewerage systems for treatment (Drechsel et al., 2002). Owing to the 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, the Food and Agriculture organization of the United Nations (FAO), and the United Nations Development Programme (UNDP), among others. There is now more scope in the water and environment sector to develop and implement wastewater treatment technologies that: (1) need low levels of capital investment for construction, operation and maintenance; (2) maximize the separation and recovery of by-products (such as nutrients) from polluted substances; (3) are compatible with the intended reuse option in that they yield a product of an appropriate quality in adequate quantities; (4) can be applied at both very small and very large scales; (5) are accepted by farming communities and the local population. Bearing in mind that treated wastewater could be used for agricultural, environmental, recreational and industrial purposes, it is important to realize that such wastewater must be adequately treated and used appropriately. This is important for several reasons:

1. The discharge of untreated wastewater into surface water bodies affects the quality of both the water it enters and thewater further downstream.

2. Treated wastewater could be used to provide a reliable source of irrigation water in urban and peri-urban areas, providing water for parks, play and sports grounds, and roadside greenery. Its other uses may be environmental (providing water for wetlands, wildlife refuges, riparian habitats, urban lakes and ponds), or industrial (used in cooling, boiling, and the processing of materials). It could also be used as a source of non-potable water to provide for many needs (fire fighting, air conditioning, dust control, and toilet flushing). It may also be used for aquaculture and groundwater recharge, a

use, which has received considerable attention in recent years as it needs proper legislation and periodic monitoring of the aquifer quality.

3. The treatment of wastewater before discharging it into surface water bodies helps to safeguard existing (scarce) sources of good-quality drinking water and protects the environment.

4. Using treated wastewater for irrigation decreases the demand for freshwater in agriculture.

5. If it is treated and managed appropriately, treated wastewater can be used to provide several nutrients essential for plant growth. This directly benefits farmers because they have to make little or no investment in fertilizer (a significant farm input) or its application. The benefits of using treated wastewater must also be considered against the human health, economic, and environmental costs of not using it. For example, treating and using wastewater would reduce the discharge of untreated wastewater into the environment (so reducing water pollution and the contamination of drinking water supplies), and would improve the socioeconomic situation of farmers, and thus their health and that of their families.

Table 4 – Guidelines for microbiological qualities of treated wastewater for irrigation[a]

Category	Wastewater reuse conditions	Exposed group of communities	Irrigation method	Intestinal nematodes[b] (arithmetic mean; no. per 1000 mL)[c]	Faecal coliforms (geometric mean; no. per 100 mL)[d]
A	Unrestricted irrigation (all crops, including vegetable and salad crops eaten uncooked, sports fields, public parks[e])	Workers, consumers, public	Any	≤ 0.1[f]	$\leq 10^3$
B	Restricted irrigation (cereal crops, industrial crops, fodder crops, pastures, and trees[g])	B1 workers, children > 15 years, nearby communities	Spray or Sprinkler	≤ 1	$\leq 10^5$
		B2 same as B1	Flood or furrow	≤ 1	$\leq 10^3$
		B3 workers, children of all ages, nearby communities	Any	≤ 0.1	$\leq 10^3$
C	Localized irrigation (crops in category B, but without exposure of workers and communities)	None	Trickle or drip	Not applicable	Not applicable

Modified from Blumenthal et al. (2000) and Carr et al. (2004).
[a] In specific situations, these guidelines may be modified according to local epidemiological, socio-cultural, and hydrogeological factors.
[b] *Ascaris* and *Trichuris* species and hookworms. The guideline values are also intended to protect against risks from parasitic protozoa.
[c] During the irrigation period, routine monitoring is not required if wastewater is treated in waste stabilization ponds (WSP) or wastewater storage and treatment reservoirs (WSTR).
[d] During the irrigation period, the faecal coliform counts should preferably be done weekly, but at least monthly.
[e] Local epidemiological factors may require a more stringent standard for public lawns, especially hotel lawns in tourist areas. A guideline of ≤ 200 faecal coliforms $100\ mL^{-1}$ is appropriate for the lawns.
[f] This guideline value can be increased to ≤ 1 if conditions are hot and dry and surface irrigation is not used, or if wastewater treatment is supplemented with anti-helminthic chemotherapy campaigns in areas of wastewater use.
[g] In the case of fruit trees, irrigation should stop 2 weeks before fruit is picked, and no fruit should be picked up from the ground. In addition, sprinkler irrigation should not be used.

Based on different parameters, various guidelines (Ayers and Westcot, 1985; WHO, 1989; Blumenthal et al., 2000; Carr *et* al., 2004; WHO, 2006) are available for wastewater use in agriculture (Tables 4 and 5). However, in many developing countries these guidelines are not followed and most farmers use untreated wastewater in an unplanned manner to irrigate a variety of crops. Most cities in these countries have networks of open and covered interconnected channels located within and around urban premises. In general, these channels carry a mixture of wastewater generated by domestic, municipal, and industrial activities. The farmers divert untreated wastewater from these channels to provide irrigation water as and when it is needed. Although farmers irrigate a range of crops with wastewater, they often prefer to grow high-value vegetables as a market-ready product, which will generate a higher income (Qadir *et al.*, 2000).

In some cases, the authorities implementing government regulations periodically expel these farmers from their fields (Keraita and Drechsel, 2004) or uproot wastewater-irrigated vegetables.
In other cases, however, the administrators do not make any efforts to check the use of wastewater in this way. Rather they regard this farming practice as a viable option for wastewater disposal. The

farmers consider such untreated wastewater to be a reliable source of irrigation, which involves less cost than other sources of irrigation water such as groundwater pumping (Van der Hoek *et al.*, 2002).

Table 5 – Recommended maximum concentrations (RMCs) of selected metals and metalloids in irrigation water[a]

Element	RMC (mg L^{-1})	Remarks
Aluminum	5.00	Can cause non-productivity in acid soils (pH < 5.5), but more alkaline soils at pH > 7.0 will precipitate the ion and eliminate any toxicity
Arsenic	0.10	Toxicity to plants varies widely, ranging from 12 mg L^{-1} for Sudan grass to less than 0.05 mg L^{-1} for rice
Beryllium	0.10	Toxicity to plants varies widely, ranging from 5 mg L^{-1} for kale to 0.5 mg L^{-1} for bush beans
Cadmium	0.01	Toxic at concentrations as low as 0.1 mg L^{-1} in nutrient solution for beans, beets and turnips. Conservative limits recommended
Chromium	0.10	Not generally recognized as an essential plant growth element. Conservative limits recommended
Cobalt	0.05	Toxic to tomato plants at 0.1 mg L^{-1} in nutrient solution. It tends to be inactivated by neutral and alkaline soils
Copper	0.20	Toxic to a number of plants at 0.1–1.0 mg L^{-1} in nutrient solution
Iron	5.00	Non-toxic to plants in aerated soils, but can contribute to soil acidification and loss of availability of phosphorus and molybdenum
Lithium	2.50	Tolerated by most crops up to 5 mg L^{-1}. Mobile in soil. Toxic to citrus at low concentrations with recommended limit of <0.075 mg L^{-1}
Manganese	0.20	Toxic to a number of crops at a few-tenths to a few mg L^{-1} in acidic soils
Molybdenum	0.01	Non-toxic to plants at normal concentrations in soil and water. Can be toxic to livestock if forage is grown in soils with high concentrations of available molybdenum.
Nickel	0.20	Toxic to a number of plants at 0.5 to 1.0 mg L^{-1}; reduced toxicity at neutral or alkaline pH
Lead	5.00	Can inhibit plant cell growth at very high concentrations
Selenium	0.02	Toxic to plants at low concentrations and toxic to livestock if forage is grown in soils with relatively high levels of selenium
Zinc	2.00	Toxic to many plants at widely varying concentrations; reduced toxicity at pH ≥ 6.0 and in fine textured or organic soils

Modified from Ayers and Westcot (1985).

[a] The maximum concentration is based on a water application rate, which is consistent with good irrigation practices (10,000 $m^3 ha^{-1} yr^{-1}$). If the water application rate greatly exceeds this, the maximum concentrations should be adjusted downward accordingly. No adjustment should be made for application rates less than 10,000 $m^3 ha^{-1} yr^{-1}$. The values given are for water used on a long-term basis at one site.

Other benefits to the farmers include the fact that farmers have to invest nothing, or very little, in fertilizer purchase and application, while benefiting from greater levels of crop production than are obtained via freshwater irrigation. In addition, they enjoy higher incomes as a result of cultivating and marketing high-value crops. These benefits help the farmers to ensure that their families receive better levels of nutrition and that their children benefit from better educational opportunities. For all these reasons, farmers take health risks and use untreated wastewater when the opportunity presents itself (Ensink *et al.,* 2002; Matsuno *et al*., 2004).

Surveys and research studies carried out in different countries revealed that fields irrigated with untreated wastewater yielded more than those irrigated with freshwater (Shende, 1985; Minhas and Samra, 2004; Table 6). In addition, economic analyses based on the cost of production of different crops have shown attractive economic returns from wastewater-irrigated fields in Syria (Qadir et al., unpublished data). The analyses revealed that each US$ invested in the production process gave a return of US$ 5.31 in the case of wheat (*Triticum aestivum* L.) irrigated with wastewater and US$ 2.34 in the case of wheat irrigated by groundwater. In addition to the higher wheat yields provided by wastewater-irrigated plots, there were savings with regard to fertilizer use. In comparison with those growing groundwater-irrigated wheat, the farmers using wastewater to irrigate wheat saved US$ 95 ha_1. Similar economic return trends were obtained for faba bean (*Vicia faba* L.). However, in the case of cotton (*Gossypium hirsutum* L.), there was little difference between the returns from wastewater irrigation (US$ 5.17) and groundwater irrigation (US$ 5.23) for each US$ invested. This is because wastewater resources in the area during the long summer growing season of cotton are not sufficient to provide the crop with its needs. Therefore, the wastewater-irrigating farmers also use fertilizers and pump groundwater as and when needed. The cultivation of vegetables – which are grown on only 7% of the wastewater-irrigated area because of government restrictions –produced the highest economic returns from wastewater irrigation: US$ 7.48 for each US$ invested. This was much greater than in the case of vegetables irrigated with groundwater, where the return was US$ 3.29 per US$ investment (Qadir et al., unpublished data). Although these crop yield and economic analyses indicate that communities who use untreated or partly treated wastewater clearly benefit financially, there is a need to carry out comprehensive analyses of the potential environmental and health implications and their costs. These must be weighed against both the short- and long-term benefits of wastewater use.

Owing to the low literacy rate found amongst farmers in developing countries, limited and inappropriate information gathering and reporting, insufficient public pressure, most farmers using polluted water in low-income countries remain uninformed about the health and environmental consequences (Hussain *et al*., 2002). Moreover, farmers and authorities have insufficient knowledge about the technical and management options available for reducing the environmental and health risks associated with wastewater use. Depending upon the levels of contaminants present, the continued and uncontrolled use of untreated wastewater as an irrigation source could have a variety of implications. These include the following:

1. Groundwater contamination through the movement of high concentrations of a wide range of chemical pollutants (Ensink *et al*., 2002). This is particularly true in the case of wastewater that contains untreated industrial effluent. The pollutants reaching groundwater in this way have the potential to impact upon human health when groundwater is pumped for direct human consumption. Pathogens have also been found to accumulate in the groundwater found immediately beneath wastewater-irrigated fields (Ensink *et al*., 2002).

2. The gradual buildup, in the soil solution and on the cation exchange sites of soil particles, of ions such as Na^+ and a range of metals and metalloids which are deleterious to the soil. In this way, potentially harmful metals and metalloids may reach phytotoxic levels (Qadir et al., 2005). The accumulation of excess Na^+ in the soil can have numerous adverse effects, including changes in exchangeable and soil solution ions and soil pH, the destabilization of the soil structure, the deterioration of the soil's hydraulic properties, and an increased likelihood of crusting, runoff, erosion and aeration. It can also have osmotic effects and specific ion effects in plants (Sumner, 1993; Qadir and Schubert, 2002).

3. The accumulation of potentially toxic substances in crops and vegetables which will, ultimately, enter the food chain, so damaging human and animal health. For example, leafy vegetables irrigated with untreated wastewater containing metals and metalloids can accumulate higher levels of certain metals, such as cadmium (Cd), than non-leafy species (Qadir et al., 2000). Excessive exposure to this metal has been associated with various illnesses in people, including gastroenteritis, renal tubular dysfunction, hypertension, cardiovascular disease, pulmonary emphysema, cancer, and osteoporosis (Wagner, 1993). Numerous illnesses are also associated with the ingestion of excessive levels of other metals and metalloids. Similarly, pathogens may enter the food chain via the same pathway. However, in most cases, industrial pollutants in the form of a variety of metals and metalloids can cause greater and longer lasting health effects in people than pathogenic organisms.

4. The health risks associated with the presence of parasitic worms, and viruses and bacteria. These have the potential to cause disease in farming families exposed to untreated wastewater for extended periods. Such diseases also raise the issue of the financial consequences associated with treatment. Farmers using untreated wastewater for irrigation demonstrate a higher prevalence of hookworm and roundworm infections than farmers using freshwater for irrigation. Hookworm infections occur when larvae, added to the soil through wastewater use, penetrate the skin of farmers working barefoot (Van der Hoek *et al.,* 2002).

Bearing in mind the challenges associated with the use of wastewater for irrigation, studies carried out by the researchers at the International Water Management Institute (IWMI), Sri Lanka have proposed a number of options to maximize the benefits and minimize the risks involved in the use of untreated wastewater for agriculture (Scott *et al*., 2000; Ensink *et al.,* 2002; Van der Hoek *et a*l., 2002; IWMI, 2003; Matsuno *et al*., 2004; Scott *et al.,* 2004;). These options include: (1) the use of suitable irrigation techniques and the selection of appropriate crops that are less likely to transmit contaminants and pathogens to consumers; (2) the use of protective measures such as boots and gloves to control farm workers' exposure to pathogens; (3) the implementation of a medical care program through the use of preventive therapy such as anti-helminthic drugs; (4) the post-harvest management of vegetables, through washing and improved storage; (5) the conjunctive use of wastewater and freshwater to dilute the risks and increase the benefits by supplying nutrients to a larger area; (6) upstream wastewater management and appropriate low-cost treatment; (7) education and increased awareness among farmers, consumers, and government organizations; (8) the implementation of monitoring programs for key environmental, health, and food safety parameters.

The Hyderabad Declaration on Wastewater Use in Agriculturemade on 14 November 2002 (available at http:// www.iwmi.cgiar.org/health/wastew/hyderabad_declaration. htm) – which resulted from a workshop organized by IWMI and the International Development Research Center, Canada – stressed the need to ‘‘safeguard and strengthen livelihoods and food security, mitigate health and environmental risks and conserve water resources by confronting the realities of wastewater use in agriculture through the adoption of appropriate policies and the commitment of financial resources for policy implementation’’. The management options used should include raising public awareness, using safer irrigation methods, minimizing human exposure, restricting the types of crops irrigated with wastewater, disinfecting produce, ensuring institutional coordination, increasing land tenure, and increasing funding (Scott *et a*l., 2004). In view of the fact that it is not possible to simply ban wastewater use in many developing countries, the World Health Organization (WHO) is considering the realities faced by these countries while revising guidelines for wastewater use in agriculture (WHO, 2006).

Wastewater treatment technology

Technology, particularly in terms of performance and available wastewater treatment options, cannot be expected to find a solution to each problem. Wastewater systems are generally capital-intensive and require expensive, specialized operators. Therefore, before selecting and investing in wastewater treatment technology, an analysis of cost effectiveness needs to be made and compared with all conceivable alternatives.

The selection of technologies should be environmentally sustainable, appropriate to the local conditions, acceptable to the users, and affordable to those who have to pay for them. In developing countries, western technology can be a more expensive and less reliable way to control pollution from human domestic and industrial wastes. Simple solutions that are easily replicated, that allow further up-grading with subsequent development and that can be operated and maintained by the local community are often considered the most appropriate and cost effective. The choice of a technology will depend to the type of reuse. The selection of reuse option should be made on a rational basis. Reclaimed water is a valuable but a limited water resource; so investment costs should be proportionnnel to the value of the resource. Also, reuse site must be located as close as possible to the wastewater treatment and storage facilities.

In the developing countries usually characterized by high population density and notable shortfall in available water resources, the proper waste water technology to be adopted under the prevailing local conditions is one of the critical issues which should be well defined. Technologies available are many and well known, but any choice should rely on those not entailing excessive costs and providing the best environmental practice and option.

Indeed, the selection of the best available technology is not an easy process: it requires comparative technical assessment of the different treatment processes which have been recently and successfully applied for prolonged periods of time, at full scale. However, this is not sufficient, the selection should be carried out in view of well-established criteria comprising: average, or typical efficiency and performance of the technology; reliability of the technology; institutional manageability, financial sustainability; application in re-use scheme and regulation determinants. Furthermore, for technology selection, other parameters have to be carefully considered: wastewater characteristics, the treatment objectives as translated into desired effluent quality which is mainly related to the expected use of the receiving water-bodies.

Benefits impact

Bearing in mind that treated wastewater could be used for agricultural, recreational and industrial purposes, it is important to realize that such wastewater must be adequately treated and used appropriately. This is important for several reasons:

1. The discharge of untreated wastewater into surface water bodies affects the quality of both the water it enters and the water further downstream.

2. Treated wastewater could be used to provide a reliable source of irrigation water in urban and peri-urban areas, providing water for parks, play and sports grounds, and roadside greenery. Its other uses may be environmental (providing water for wetlands, wildlife refuges, riparian habitats, urban lakes and ponds), or industrial (used in cooling, boiling, and the processing of materials). It could also be used as a source of non-potable water to provide for many needs (fire fighting, air conditioning, dust control, and toilet flushing). It may also be used for aquaculture and groundwater recharge - a use which has received considerable attention in recent years.

3. Using treated wastewater for irrigation decreases the demand for freshwater for agriculture.

4. If it is treated and managed appropriately, treated wastewater can be used to provide several nutrients essential for plant growth. This directly benefits farmers because they have to make little or no investment in fertilizer (a significant farm input) or its application.

The benefits of using treated wastewater must also be considered against the human health, economic, and environmental costs of not using it. For example, treating and using wastewater would reduce the discharge of untreated wastewater into the environment (so reducing water pollution and the contamination of drinking water supplies), and would improve the socioeconomic situation of farmers, and thus their health and that of their families.

CONCLUDING REMARKS AND RECOMMENDATIONS

Domestic WWTR is one tool to address the food and water insecurity facing many Developing countries. In coming years, in most Middle East and North Africa 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.

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