

## University of Nebraska - Lincoln DigitalCommons@University of Nebraska - Lincoln

Water for Food Faculty Publications

Water for Food

2010

# The Challenges of Wastewater Irrigation in Developing Countries

M. Qadir

*International Center for Agricultural Research in the Dry Areas, m.qadir@cgiar.org*

D. Wichelns

*Hanover College*

L. Raschid-Sally

*International Water Management Institute, l.raschid@cgiar.org*

Peter G. McCornick


*International Water Management Institute and Duke University, pmccornick@nebraska.edu*

P. Drechsel

*International Water Management Institute, p.drechsel@cgiar.org*

*See next page for additional authors*

Follow this and additional works at: <http://digitalcommons.unl.edu/wffdocs>

 Part of the [Environmental Health and Protection Commons](#), [Environmental Monitoring Commons](#), [Hydraulic Engineering Commons](#), [Hydrology Commons](#), [Natural Resource Economics Commons](#), [Natural Resources and Conservation Commons](#), [Natural Resources Management and Policy Commons](#), [Sustainability Commons](#), and the [Water Resource Management Commons](#)

Qadir, M.; Wichelns, D.; Raschid-Sally, L.; McCornick, Peter G.; Drechsel, P.; Bahri, A.; and Minhas, P. S., "The Challenges of Wastewater Irrigation in Developing Countries" (2010). *Water for Food Faculty Publications*. 11.  
<http://digitalcommons.unl.edu/wffdocs/11>

This Article is brought to you for free and open access by the Water for Food at DigitalCommons@University of Nebraska - Lincoln. It has been accepted for inclusion in Water for Food Faculty Publications by an authorized administrator of DigitalCommons@University of Nebraska - Lincoln.

---

**Authors**

M. Qadir, D. Wichelns, L. Raschid-Sally, Peter G. McCornick, P. Drechsel, A. Bahri, and P. S. Minhas

Published in *Agricultural Water Management* 97 (2010), pp. 561–568; doi: 10.1016/j.agwat.2008.11.004  
Copyright © 2008 Elsevier B.V. Used by permission.  
Published December 16, 2008.

# The Challenges of Wastewater Irrigation in Developing Countries

M. Qadir,<sup>1,2</sup> D. Wichelns,<sup>3</sup> L. Raschid-Sally,<sup>4</sup> P. G. McCornick,<sup>2,5</sup>

P. Drechsel,<sup>4</sup> A. Bahri,<sup>4</sup> and P. S. Minhas<sup>6</sup>

1. International Center for Agricultural Research in the Dry Areas (ICARDA), Aleppo, Syria
2. International Water Management Institute (IWMI), Colombo, Sri Lanka
3. Department of Economics, Hanover College, Hanover, Indiana, USA
4. International Water Management Institute (IWMI), West Africa Office, Cantonments, Accra, Ghana
5. Nicholas Institute for Environmental Policy Solutions, Duke University, Durham, North Carolina, USA
6. Indian Council of Agricultural Research (ICAR), Pusa, New Delhi, India

*Corresponding author* – M. Qadir, telephone +963 21 2213433, email [m.qadir@cgiar.org](mailto:m.qadir@cgiar.org)

## Abstract

The volume of wastewater generated by domestic, industrial, and commercial sources has increased with population, urbanization, improved living conditions, and economic development. The productive use of wastewater has also increased, as millions of small-scale farmers in urban and peri-urban areas of developing countries depend on wastewater or wastewater-polluted water sources to irrigate high-value edible crops for urban markets, often as they have no alternative sources of irrigation water. Undesirable constituents in wastewater can harm human health and the environment. Hence, wastewater irrigation is an issue of concern to public agencies responsible for maintaining public health and environmental quality. For diverse reasons, many developing countries are still unable to implement comprehensive wastewater treatment programs. Therefore in the near term, risk management and interim solutions are needed to prevent adverse impacts from wastewater irrigation. A combination of source control and farm-level and post-harvest measures can be used to protect farm workers and consumers. The WHO guidelines revised in 2006 for wastewater use suggest measures beyond the traditional recommendations of producing only industrial or nonedible crops, as in many situations it is impossible to enforce a change in the current cash crop pattern, or

provide alternative vegetable supply to urban markets. There are several opportunities for improving wastewater management via improved policies, institutional dialogues, and financial mechanisms, which would reduce the risks in agriculture. Effluent standards combined with incentives or enforcement can motivate improvements in water management by household and industrial sectors discharging wastewater from point sources. Segregation of chemical pollutants from urban wastewater facilitates treatment and reduces risk. Strengthening institutional capacity and establishing links between water delivery and sanitation sectors through interinstitutional coordination leads to more efficient management of wastewater and risk reduction.

**Keywords:** wastewater reuse, wastewater irrigation management, wastewater reuse policies, institutional aspects

## 1. Introduction

As urban populations in developing countries increase, and residents seek better living standards, larger amounts of freshwater are diverted to domestic, commercial, and industrial sectors, which generate greater volumes of wastewater (Lazarova and Bahri, 2005; Qadir et al., 2007a; Asano et al., 2007). Commonly wastewater is discharged with little or no treatment in natural water bodies, which can become highly polluted. Farmers in urban and peri-urban areas of nearly all developing countries who are in need of water for irrigation often have no other choice than using wastewater.<sup>1</sup> They even deliberately use undiluted wastewater, as it provides nutrients or is more reliable or cheaper than other water sources (Keraita and Drechsel, 2004; Scott et al., 2004). Despite farmers' good reasoning, this practice can severely harm human health and the environment (Qadir et al., 2007b) mainly because of associated pathogens but also because of heavy metals and other undesirable constituents, depending on the source. Additionally, farmers, consumers, and some government agencies in many countries are not fully aware of the potential impacts of irrigation with wastewater.

The absence of financial and technical resources in many developing countries makes comprehensive wastewater collection and treatment a long-term future strategy. It is therefore required that in the near term, risk-management and interim solutions are needed to prevent adverse environmental and health impacts from wastewater irrigation (IWMI, 2006; WHO, 2006). These include user and consumer health protection through interventions at the farm level, post-harvest measures, and public policies to motivate better management of wastewater.

In this paper, we review the current status of wastewater treatment and use in developing countries. We describe risk reduction and management measures, public policies, and institutional interventions that can improve wastewater management and minimize negative impacts on health and the environment.

## 2. Wastewater generation, treatment, and current use

With urban water use, only 15% to 25% of water diverted or withdrawn is consumed, and the rest is returned as wastewater to the urban hydrologic system. The wastewater is usually a mix of domestic and industrial wastewater and stormwater. Industrial wastewater

often contains elevated levels of metals, metalloids, and volatile or semivolatile compounds, while domestic wastewater is most harmful because of its pathogenic load.

In many Asian and African cities, population growth has outpaced improvements in sanitation and wastewater infrastructure, making management of urban wastewater a tremendous challenge. Some specific examples include India, where only 24% of wastewater from households and industry is treated, and Pakistan, where only 2% is treated (IWMI, 2003; Minhas and Samra, 2003). In West African cities, usually less than 10% of the generated wastewater is collected in piped sewage systems and receives primary or secondary treatment (Drechsel et al., 2006). In many developing countries, large centralized wastewater collection and treatment systems have proven difficult to sustain. Decentralized systems that are more flexible for long-term operation and financial sustainability and compatible with demands for local effluent use have been promoted in many areas (Raschid-Sally and Parkinson, 2004), although not without challenges. In Ghana, for example, only 7 of 44 smaller treatment plants are functional and probably none meets the designed effluent standards (Obuobie et al., 2006).

Reliable estimates of projected wastewater use in agriculture are needed for better planning and managing risks, but limited information makes estimating future use difficult (Qadir et al., 2007a). Data collection and comparison are challenging, due in part to the lack of a universally accepted typology (Van der Hoek, 2004). In some cases, information exists, but government policies make access difficult, or the information is available only as gray literature. A further reason is that these farming activities remain informal and are not in official statistics (Drechsel et al., 2006). Jimenez and Asano (2004) and IWMI (2006) suggest that at least 3.5 million ha are irrigated globally with untreated, partly treated, diluted, or treated wastewater. There is little consolidated information about wastewater use in China.

Worldwide more than 800 million farmers are engaged in urban agriculture. Of this group, about 200 million practice market-oriented farming on open spaces, often using poor-quality irrigation water when good-quality water is not available. Irrigated agriculture in proximity to urban markets is important in hot climates of the developing world where refrigerated transport and storage are limited. Farmers enhance household income by producing perishable crops such as leafy vegetables for sale in local markets, providing a supply of vitamin-rich vegetables. For instance in most West African cities, 60% to 100% of the vegetables consumed are produced in urban and peri-urban areas (Drechsel et al., 2006).

Economic benefits from agriculture depending on raw wastewater or polluted streams have so far been inadequately differentiated and quantified (Buechler and Devi, 2006; Obuobie et al., 2006; Drechsel et al., 2006). There is now greater interest in doing so to understand the importance of wastewater as a source of livelihoods.

Besides crop farming, wastewater is used also for aquaculture in Africa, and in Central, South, and Southeast Asia (Bangladesh, Cambodia, China, India, Indonesia, and Vietnam). In many areas, treated wastewater is used for fodder production, groundwater recharge, or other environmental purposes, such as enhancing water supply for wetlands, wildlife refuges, riparian habitats, and urban lakes and ponds. In other areas, large wetland areas are misused as a natural treatment facility, like at Vientiane, Laos (Asano, 1998; Asano et al., 2007).

### 3. Implications for farmers' and consumers' health

Human health risks from wastewater irrigation include firstly farmers' and consumers' exposure to pathogens, including helminth infections, and secondly, organic and inorganic trace elements. Farmers and their families using wastewater are exposed to health risks from parasitic worms, protozoa, viruses, and bacteria. Many farmers cannot afford treatment for some of the health problems caused by the exposure. Generally, farmers irrigating with wastewater have higher rates of helminth infections than farmers using freshwater, but there are exceptions (Trang et al., 2006). In addition, skin and nail problems may occur among farmers using wastewater (Van der Hoek et al., 2002; Trang et al., 2007). The relationship among possible health risks, pathogen concentrations, and water quality guidelines is described in Box 1.

#### **Box 1. Health risks and water quality guidelines**

There are many studies especially not only on farmers' exposure and risk of intestinal nematode infections but also on actual and possible links between the consumption of crops irrigated with wastewater and the risk of hookworm and *Ascaris* infections or the increased risks of enteric disease. A pertinent contemporary overview is provided by WHO (2006). Based on an ever-increasing amount of information, the World Health Organization recently revised its guidelines for safe use in agriculture. The revised guidelines for fecal coliforms and helminth eggs have been replaced by a health-based target approach and tolerable burden of disease expressed as Disability-Adjusted Life Years (DALYs) to be achieved by combinations of treatment and nontreatment options for health risk reduction. This approach gives governments in developing countries greater flexibility in applying the guidelines even in situations where wastewater treatment still remains a challenge (WHO, 2006).

Women are a particularly important target group not only for being a vulnerable group but also to apply risk-reduction methods. In many countries women provide much of the labor required to produce vegetables and perform much of the weeding and transplanting that can expose them to long periods of contact with wastewater. Women generally prepare meals, creating the opportunity for transferring pathogens to the family members unless good hygiene is maintained. In West Africa, where in 10 of 13 countries mostly men grow vegetables, women dominate the marketing process, especially retail, of most vegetables; thus the main target group for risk reduction measures is markets (Drechsel et al., 2007).

Post-harvest contamination in markets can be an important factor that affects public health, but the significance varies (Amoah et al., 2007a; Ensink et al., 2007), which makes it an often-neglected issue in the wastewater discussion. Indeed, in most developing countries, wastewater is just one of several sources of pathogens. Therefore, the promotion of improved hygiene and safe food preparation remain crucial even where the irrigation water appears safe.

Many farm households in developing countries irrigating with wastewater are not aware of the risks or the potential environmental consequences. Household members might be illiterate, lack adequate information and resources, and have been exposed to

poor sanitary conditions for most of their lives. Therefore, many farmers accept these health risks for the benefits of their occupation, and in the general context of their living conditions where wastewater contact through irrigation, might only be one of many sanitary challenges (Box 2).

**Box 2. Limitations of current risk assessments**

Many studies indicating negative health impacts lack statistical rigor (Blumenthal and Peasey, 2002) and have not measured the concentrations of pathogens in the water used. In addition, most studies have linked a high prevalence of infection in a population with widespread use of wastewater in agriculture. These studies are epidemiologically flawed, as they do not assess the risk of exposure at the individual level. Studies are needed that compare health risks from wastewater contact (or the consumption of wastewater contaminated food) with risks from other unsanitary conditions that farming families and consumers are exposed to, like unsafe street food, children playing on waste dumps, or the common lack of toilets and access to safe drinking water. There is also insufficient information on the possibility of additional heavy metal contaminations, often as this requires more technical and financial sophistication not available in many developing countries. Few studies have combined the epidemiological component with water quality assessment and quantitative microbial risk assessment. Some studies meeting that criterion have been conducted under different conditions, making comparison and extrapolation of findings difficult. Finally, studies are needed which consider the adaptation and partial resistance of local populations to the commonly elevated pathogen exposure in cities of developing countries.

From the point of view of the authorities, the primary risk groups are, however, the consumers of wastewater-irrigated produce such as fresh vegetables. In Accra, for example, about 1000 farmers supply the urban street food sector with lettuce, nearly all of which is contaminated. Every day more than 200,000 urban dwellers benefit from this production but are also put at risk (Obuobie et al., 2006; Amoah et al., 2007a). Most consumers are not aware of the source of the produce and the use of polluted irrigation water.

Besides pathogens, chemical contaminants can be of concern especially in those countries where industrial development has started and industrial effluent enters domestic wastewater and natural streams. A survey along the Musi River in India revealed the transfer of metal ions from wastewater to cow's milk through Para grass fodder irrigated with wastewater. Milk samples were contaminated with different metal ions like Cd, Cr, Ni, Pb, and Fe ranging from 12 to 40 times the permissible levels (Minhas and Samra, 2004). Leafy vegetables accumulate greater amounts of certain metals like cadmium than do non-leafy species. Generally, metal concentrations in plant tissue increase with metal concentrations in irrigation water, and concentrations in roots usually are higher than concentrations in leaves. This challenge can be addressed only through water treatment. If data show increased metal levels in the food, wastewater irrigation is not encouraged.

#### 4. Biophysical management interventions for risk reduction

The risks of using untreated or only partially treated wastewater in agriculture can be reduced through wastewater treatment and nontreatment options or a combination of both (WHO, 2006). These include: (1) water quality improvements, (2) human exposure control, (3) farm-level wastewater management, and (4) harvest and post-harvest interventions.

##### 4.1. *Water quality improvements*

Initial improvements in water quality can be achieved in many developing countries by at least primary treatment of wastewater, particularly where wastewater is used for irrigation. Secondary treatment can be implemented at reasonable cost in some areas, using methods such as waste-stabilization ponds, constructed wetlands, infiltration-percolation, and up-flow anaerobic sludge blanket reactors (Mara, 2003). Important is to aim at standards, which can be achieved in the local context. The recent WHO guidelines provide complementary options for wastewater treatment and control of human exposure (WHO, 2006).

Storing reclaimed water in reservoirs improves microbiological quality and provides peak-equalization capacity, which increases the reliability of supply and improves the rate of reuse. Long retention times in the King Talal Reservoir in the Amman-Zarqa Basin of Jordan reduced fecal coliform levels in water downstream of the dam, although it was not initially intended for that purpose (Grabow and McCornick, 2007).

Integrating management of wastewater reuse to minimize treatment costs and increase agricultural productivity is gaining interest in many countries. In Drarga Morocco, untreated wastewater was being discharged, contaminating drinking water supplies. An institutional partnership involving local water management stakeholders, urban water users, and agricultural water user groups was set up and to ensure sustainability of the treatment and reuse program, a fee has been imposed for domestic water supply and other cost-recovery mechanisms have been implemented (USEPA and USAID, 2004).

Groundwater recharge via deep percolation can remove microorganisms, provided soil properties are appropriate and the process is properly managed. Key components include appropriate flooding and drying cycles, maintaining adequate microbiological populations, and maintaining sufficient distance and transient time between infiltration basins and water supply wells (Asano and Cotruvo, 2004). In Tula Valley, Mexico, almost half of the untreated wastewater infiltrates through soil, which acts as a filter and removes pollutants. However, salinity and nitrate levels in groundwater are increasing. Continuous monitoring of the aquifer is needed to identify emerging health problems (Jimenez and Chávez, 2004).

In those countries that have adopted legislation and policies to protect water quality and regulate wastewater use, unrealistic criteria often make implementation difficult or become an expensive target only to be addressed in the long term. Meaningful criteria need to be established in accordance with local, technical, economic, social, and cultural contexts. In addition, improving water quality requires new approaches to wastewater management in cities—subdividing cities into manageable units, like the example of Bangkok,



which has made stepwise successes possible (Albert Wright, personal communication, 2007).

#### ***4.2. Human exposure control***

Protective measures such as wearing boots and gloves, and changing irrigation methods can reduce farmer exposure. Farmers also can wash their arms and legs after immersion in wastewater to prevent the spread of infection. However, these methods reduce risk to different degrees which need to be understood and prioritized and supported, through awareness campaigns. Public agencies can also implement child immunization campaigns against diseases that can be transmitted through wastewater use, and they can target selected groups (those generating wastewater and those using it) for periodic antihelminthic campaigns (USEPA and USAID, 2004; WHO, 2006).

#### ***4.3. Farm-level wastewater management***

Improved wastewater irrigation depends on the implementation of suitable farm-level practices and post-harvest interventions, which are classified as nontreatment options and can be divided into the following major categories: (1) crop selection and diversification in terms of market value, irrigation requirements, and tolerance of ambient stresses; (2) irrigation management based on water quality, and irrigation methods, rates, and scheduling; and (3) soil-based considerations such as soil characteristics, soil preparation practices, application of fertilizers and amendments if needed, and soil health aspects.

##### ***4.3.1. Crop restrictions and diversification***

A recent global survey found that vegetables (32% frequency of responses) are besides cereals (27%) the most common crops produced with diluted or raw wastewater (Raschid-Sally and Jayakody, 2007). As especially vegetables are often consumed raw and in direct contact with the water, crop restrictions are most helpful in reducing human health hazards. In the Aleppo region of Syria, today less than 7% of the area under wastewater irrigation is cultivated with vegetables because government officials uproot vegetables found to be growing there. However in most cases, restrictions are difficult to enforce because demand for vegetables is high in cities and only certain cash crops achieve the level of profits farmers need to maintain their livelihoods (Drechsel et al., 2002).

An alternative could be the production of agroforestry species grown for fuel and timber (Minhas and Samra, 2004), be it subsidized or if there is a related profitable market demand. The likelihood of implementing successful restrictions on crop choices is higher when water resources are managed by public agencies, irrigation projects have strong central management, and there is good funding for law enforcement (Lazarova and Bahri, 2005).

##### ***4.3.2. Irrigation management***

Commonly, urban and peri-urban farmers use flood and furrow irrigation or simply watering cans (Martijn and Redwood, 2005; Drechsel et al., 2006). When choosing irrigation methods, extension services should advise farmers to consider the quality of their water

supply, the possibility of contaminating crops with pathogens when irrigating, and potential health and environmental implications. Of course, the choice does not only depend on water quality but also on affordability, tenure security, labor availability and other production factors. Often even appropriate water hoses are not available or imported and not affordable. Flood irrigation is the lowest cost method, if the topography is favorable or farmers can afford a pump. However, water use efficiency is low, thus successful where water is not a limiting factor. Furrow irrigation provides a higher level of health protection, but requires favorable topography and land leveling. Irrigation with sprinklers and watering cans are not recommended as this spreads the water on the crop surface, although cans are usually the cheapest investment option and favored for fragile vegetable beds. Sprinklers require in addition a pump and hose, have medium to high cost, and medium water use efficiency. Irrigating at night and not irrigating during windy conditions are important considerations when using sprinklers. Drip irrigation, especially with subsurface drippers, can effectively protect farmers and consumers by minimizing crop and human exposure, but irrigation kits with appropriate planting density and pretreatment of wastewater is needed to avoid clogging of emitters (Minhas and Samra, 2004). Where watering cans are the preferred method, there are further options possible to reduce the load of pathogens during water fetching and application (Keraita et al., 2007a,b).

An additional possibility is the cessation of irrigation, prior to harvest to allow natural pathogen die-off. Field trials in Tunisia with forage crops and sorghum showed that the bacterial contamination after irrigation with secondary-treated wastewater varied with crop species, season, the number of days after cessation of irrigation, and weather. For both sorghum and alfalfa, 7–10 days between the last irrigation and cutting were needed to achieve natural decontamination (UNDP, 1987). In field tests conducted in Ghana on lettuce, cessation resulted in a significant loss of fresh weight. Although 4–5 days without irrigation would significantly increase food safety, a yield loss of about 25% was not acceptable to farmers. A compromise with higher adoption potential would be a cessation of 2 days, with a yield reduction of 10% (Keraita et al., 2007c; Drechsel et al., 2007).

#### 4.3.3. *Soil-based interventions*

Soil-based interventions without the production of edible plants are important, particularly in the case of inorganic contaminants, such as heavy metals, which derive from industries and usually accumulate in the upper part of the soil due to strong adsorption and precipitation phenomena. For moderate levels of metals and metalloids in wastewater, there is no particular management needed if the soils are calcareous. However, some metal ions can be a problem in acid soils, which need specific management such as liming, avoiding the use of fertilizers with acidic reactions, and selecting crops that do not accumulate the metals of concern. When irrigating with wastewater containing elevated levels of sodium, care should be taken to avoid soil structure deterioration. Application of a calcium source such as gypsum is desirable under such conditions, but availability and price may limit its use.

The quality and depth of groundwater prior to wastewater irrigation determine the detrimental effects of salts, nitrates, metals, and pathogens reaching groundwater. The deeper the groundwater, the longer it will take to have such effects.

#### **4.4. Harvest and post-harvest interventions**

These interventions involve the process of harvest, post-harvest cleaning, handling during transport, market display, storage, and preparation in kitchens. While harvesting, cereal and forage cut above a certain height (~5–10 cm above ground) can contain considerably fewer pathogens (Minhas et al., 2006). In West Africa, the harvested material is washed free of soil in the same water source used for irrigation. Therefore, introducing safer farming methods can be effective only if washing practices at farm are improved (Obuobie et al., 2006). Minimizing contamination during transportation, display in markets, and washing (refreshing, cooling) vegetables at retail are further post-harvest entry points for health risk reduction (Drechsel et al., 2007).

Cooking vegetables remains the most effective way of achieving complete reduction of pathogens (WHO, 2006), but washing is important with vegetables like lettuce, which are served uncooked. In West Africa it was shown that washing methods vary widely between Anglophone and Francophone countries with significant differences depending on the disinfectant, contact time, and water temperature used. In general, a reduction of *E. coli* levels by 2–3 log<sub>10</sub> units can be achieved. The effective removal of helminth eggs requires good agitation and rubbing of the leaves (Amoah et al., 2007b).

As most of the pathogenic contaminations are exogenic, the removal of the exposed portions of vegetables such as the outer leaves in cabbage, and peeling the vegetables reduces the health risks from pathogens (Minhas et al., 2006; Amoah et al., 2007b). However, heavy metals and other toxic metabolites, once taken up, are rather impossible to remove.

#### **5. Policies and institutional aspects**

Public authorities often do not have sufficient knowledge of the technical and management options available for reducing environmental and health risks, or the capacity to enforce regulations. Moreover, fear of economic repercussions in agricultural trade may make governments reluctant to acknowledge the use of wastewater for irrigation, which prevents them from implementing food safety and other phyto-sanitary measures. Jordan's export market was seriously affected in 1991 when countries in the region restricted imports of fruits and vegetables irrigated with inadequately treated wastewater (McCornick et al., 2004). Jordan implemented an aggressive campaign to rehabilitate and improve wastewater treatment plants and introduced enforceable standards to protect the health of farmers and consumers. The government continues to focus on this sensitive situation, given the importance of international trade. This example reveals that the impacts of wastewater use can be indirect and wide-ranging.

Policies to reduce the negative impacts of wastewater use while supporting its benefits can target the situations before the wastewater is generated, while it is being used, and after crops have been irrigated and products are prepared for sale and consumption. Two features complicate policymaking pertaining to wastewater use in agriculture: most wastewater is generated outside the agricultural sector, which requires a dialogue across the rural-urban divide linking the agricultural and sanitation sectors. In addition, public concern varies with the type of water involved, treatment levels, general education and awareness, and the amount of information available (Toze, 2006). Where possible, it is

helpful to distinguish between industrial and domestic wastewater as addressing health risks related to pathogens from domestic wastewater can be easier and less costly than addressing chemical risks from industrial wastewater.

### 5.1. Consider wastewater a resource requiring good management

Within the framework of integrated natural resources management, wastewater can be viewed as both an effluent and a renewable resource. Where water is used several times, society saves costs, and where wastewater is used for productive purposes, like irrigation, society gains additional value from the crops produced and from the improvements in livelihoods. Irrigation also provides a method of utilizing nutrients (Box 3) and “treating” wastewater that might otherwise require a more costly treatment or disposal.

#### Box 3. Fertilizer value of the wastewater—benefits and risks

Wastewater irrigation in the Tula Valley in Mexico provides 2400 kg organic matter, 195 kg nitrogen, and 81 kg phosphorus  $\text{ha}^{-1} \text{yr}^{-1}$ , contributing to significant increases in crop yields (Jimenez, 2005). Farmers in the valley oppose treatment which removes nutrients. Although the fertilizer value of wastewater is of great importance, periodic monitoring is required to adjust the amount of additional fertilizers or if possible dilute the wastewater. Excessive or imbalanced nutrient applications can cause undesirable vegetative growth, delayed or uneven maturity, and reduce crop quality and pollute groundwater and surface water. The difficulties in monitoring at farm level and the cost factor make such efforts problematical in most developing countries. There are no general rules possible, as the amount of nutrients applied via wastewater irrigation can vary considerably if the wastewater is raw, treated or diluted with stream water. The possible nutrient input to the soil with different amounts of treated wastewater is given in Table 1.

The farm-level nutrient value of wastewater varies with constituent loads, frequency and amount of application, soil conditions, crop choices, and the cost and availability of alternative nutrient sources. Studies of the farm-level and aggregate implications of nutrient uptake from untreated wastewater vs. other sources are rare. The discussion on how far wastewater treatment could be optimized to maintain the desirable nutrient level for downstream irrigation is recent, and very little information is available (Lazarova and Bahri, 2005; Jimenez, 2005; Martijn and Redwood, 2005; Drechsel et al., 2004).

**Table 1.** Nutrient additions to soil, when irrigating with treated wastewater

| Nutrient   | Concentration ( $\text{mg L}^{-1}$ ) | Fertilizer contribution ( $\text{kg ha}^{-1}$ )  |  |
|------------|--------------------------------------|--|--|
|            |                                      | Irrigation at $3000 \text{ m}^3 \text{ ha}^{-1}$ | Irrigation at $5000 \text{ m}^3 \text{ ha}^{-1}$ |
| Nitrogen   | 16–62                                | 48–186   | 80–310   |
| Phosphorus | 4–24                                 | 12–72  | 20–120   |
| Potassium  | 2–69                                 | 6–207  | 10–345   |
| Calcium    | 18–208                               | 54–624   | 90–1040  |
| Magnesium  | 9–110                                | 27–330   | 45–550   |
| Sodium     | 27–182                               | 81–546   | 135–910  |

*Source:* Data describing nutrient concentrations in treated wastewater and the volume of irrigation water applied (Lazarova and Bahri, 2005)

Integrating reuse into wastewater management planning, and supporting wastewater management with fees from water supply to obtain cost recovery, minimize treatment costs and increase agricultural productivity, is gaining interest in many countries (Box 4).

**Box 4. Integrated wastewater treatment and irrigation in Tunisia**

Tunisia launched a national water reuse program in the early 1980s to increase usable water resources. Most municipal wastewater is from domestic sources and receives secondary biological treatment. Several treatment plants are located along the coast to protect coastal resorts and prevent marine pollution. In 2003, 187 million m<sup>3</sup> (78%) of the 240 million m<sup>3</sup> of wastewater collected in Tunisia received treatment. About 30% to 43% of the treated wastewater was used for agricultural and landscape irrigation. Reusing wastewater for irrigation is viewed as a way to increase water resources, provide supplemental nutrients, and protect coastal areas, water resources, and sensitive receiving bodies. Reclaimed water is used on 8000 ha to irrigate industrial and fodder crops, cereals, vineyards, citrus, and other fruit trees. Regulations allow the use of secondary-treated effluent on all crops except vegetables, whether eaten raw or cooked. Regional agricultural departments supervise the Water Law and water reuse decree and collect charges (about \$0.01 m<sup>-3</sup>) for large schemes. Water users' associations are in charge of the same for small perimeters. Golf courses are also irrigated with treated effluent, while groundwater recharge opportunities have been investigated, and some pilot projects are under implementation. Other reuse opportunities, such as industrial reuse and environmental and non-potable urban reuses, are under consideration (ONAS-SERAH, 2001). Interdepartmental coordination and follow-up commissions with representatives from the different ministries and their respective departments or agencies, the municipalities, and representatives of the users have been set up at national and regional levels so as to bridge the gaps between the needs of different parties, ensure the achievement of development objects, and preserve the human and natural environment.

The foremost challenge for public agencies in developing countries is to determine the appropriate scale at which treatment is possible and viable with a particular emphasis on the separation of industrial and domestic wastewater to facilitate the likelihood of safe reuse (Huibers and Van Lier, 2005; Martijn and Redwood, 2005; Raschid-Sally et al., 2005). The optimal treatment strategy will vary with the economic and institutional capacities, wastewater sources and constituents, and should preferably consider the requirements of reuse than standards which are difficult to maintain (Emongor and Ramolemana, 2004; Fine et al., 2006; Tidåker et al., 2006). Where treatment is not yet achievable, the new WHO guidelines offer a range of nontreatment options to reduce possible health risks during reuse (WHO, 2006).

In regions where farmers and others compete for a limited supply of wastewater, assigning property rights can motivate efficient use. Property rights can be coupled with responsibility for using wastewater appropriately and managing discharges from irrigated farmland. Special attention is needed in areas where wastewater is treated by a municipality or water company and allocated to new users; in order to protect the rights of farmers who were already using the wastewater. The notion of establishing property rights to wastewater (and even to urine and excreta in the "EcoSan" discussion) might seem odd to

some public officials, given the historical view of wastewater as effluent requiring disposal. However, with the increasing demand for wastewater to irrigate crops in urban and peri-urban settings, it will become necessary to allocate the limited wastewater supply among competing users, while also ensuring that the risks to human health and the environment from wastewater irrigation are minimized. Policy options include wastewater pricing, strict allocations, and tradable property rights, and the institutionalization of the new WHO guidelines.

### ***5.2. Implement economic incentives***

Improving the institutions and policies that influence the use of freshwater can reduce the cost of managing wastewater. Often water supply and sanitation are institutionally and economically unconnected and even where the institutional framework is adequate, public agencies have overlapping jurisdictions that prevent optimal implementation of desirable policies. Effluent standards, taxes, and tradable permits can be used to motivate improvements in water management by households and firms discharging wastewater from point sources.

Where farmers already use wastewater or polluted stream water, alternative land and water sources should be looked for as currently initiated by authorities in Ghana and Benin (Drechsel et al., 2006). Where the use of treated wastewater is promoted, incentives for its use are helpful allowing water users to choose among different water sources. Lower water prices and subsidies for purchasing new equipment can speed the pace at which farmers begin using wastewater. Incentives can be combined with monitoring to ensure compliance with incentive programs and safe use of wastewater.

### ***5.3. Improve financial management***

Public agencies in many developing countries have limited ability to invest in or even maintain wastewater treatment plants and programs to optimize wastewater reuse. Policies and institutional frameworks can be helpful in raising or allocating the needed funds. Appropriate high-volumetric charges for fresh water will encourage water savings and wastewater reuse instead of discharge into natural waterways or facilities operated by a wastewater agency. There is conceptual justification for programs that generate revenue by charging water users a fee per unit of effluent they generate (the polluter pays principle), particularly when the revenue is used to construct facilities for collecting, treating, and reusing wastewater.

### ***5.4. Protect and compensate the poor***

Public officials must consider potential impacts on the poor when designing policies and programs. The greatest challenge might be ensuring that low-income residents of peri-urban and rural areas who rely on polluted streams or wastewater for crop production are not deprived of their livelihoods. Many poor farmers have been using these water sources for years without (the need for) formal water rights. Banning the use of polluted water would affect, for example, around the city of Kumasi, about 12,700 households or 90,000 people, depending on dry-season irrigation (Cornish and Lawrence, 2001). Changing water management and sanitation practices in upper portions of a watershed or urban area, could

reduce the wastewater volume, quality, and direction of flow, thus affecting downstream users. Policies can be implemented to compensate poor farmers by providing them with alternative sources of irrigation water or giving them payments or training that would enable them to pursue alternative livelihood activities. Policies that enable the poor to reduce wastewater use gradually, while seeking other livelihood activities, might be wiser also from the urban food supply perspective, than policies simply restricting or banning wastewater use or others that cause sharp disruptions in wastewater supply.

#### ***5.5. Consult widely with individuals and organizations***

Public agencies must consult broadly with farmers, firms, and organizations that might be affected by policies on wastewater generation and use across the common administrative rural-urban divide. Multiple stakeholder involvement will improve the generation and dissemination of information and enhance the success of wastewater reuse projects and related food safety campaigns (Janosova et al., 2006; IWMI, 2006). Improvements in communication among government agencies and environmental organizations with expertise in wastewater issues also can enhance public policies for wastewater management.

In many countries, public agencies can improve the coordination of policy targets and methods to ensure that public goals regarding wastewater management are achieved. For example, coordination among the ministries of agriculture, water resources, public health, and economic development is needed to ensure that the goals and programs of one agency are not in conflict with the goals and programs of another. The total cost of achieving public goals will be minimized with effective interministry coordination.

#### ***5.6. Conduct public awareness programs***

Many farmers and consumers in developing countries are not aware of the potential health impacts of wastewater. Many also lack information on appropriate food hygiene practices. Public programs that inform farmers and consumers about health impacts and mitigation measures can reduce health problems and social costs. Information on post-harvest handling practices will also enhance consumer safety. Context-sensitive guidelines need to describe the types and amounts of wastewater that can be used effectively for irrigation (IWMI, 2006), while in many areas inspection and certification programs are needed to encourage consumer safety regarding vegetables and other produce sold in markets or prepared in public kitchens.

Special attention should be paid to gender when designing education programs on farmer, trader, and consumer safety. Educational efforts pertaining to wastewater will be most successful if they are designed to match the roles and availabilities of men and women in farming communities. In many farm households, women are directly involved in agriculture or produce marketing besides being responsible for food preparation. Women also might have limited time for attending special classes or training sessions.

#### ***5.7. Support research, development, and outreach***

Many farmers may use the nutrient content of wastewater more effectively if they had better information about nutrient levels in water supply, nutrient levels in soils, and crop

requirements. Public funding of research and development can be justified by the public benefits gained from using wastewater more effectively in agriculture.

Better data on the current nature and extent of wastewater use for irrigation can enhance the efforts of public agencies and researchers to address actual opportunities and threats. There is also a need for more holistic risk assessments (see Box 2). Information describing the volume and quality of wastewater used and the geographic distribution of wastewater use within peri-urban areas can be helpful when designing policies to improve water management and protect public health. Awareness creation could be supported by incentives offered to small-scale farmers to report on irrigation frequency, yields, and observable impacts on humans, plants, soils, and groundwater. Public agencies also might work with farmers to establish wastewater use monitoring programs.

#### ***5.8. Strengthen political will and investments in infrastructure***

The current backlog in addressing the Millennium Development Goal (MDG) on improved sanitation has been widely recognized. Donor agencies focused until now more on the (cheaper) support of water supply infrastructure than wastewater management. But also at the national level, inadequate efforts to improve wastewater management, treatment, and reuse cannot be attributed only to a lack of funds, technical information, or inadequate knowledge of policy impacts. In many areas, limited public involvement reflects a lack of political will, inadequate investment, or insufficient institutional capacity or coordination.

There is no simple way of strengthening political will. Public officials must appreciate the scarcity value of water and the impacts of poor water quality and inefficient use on public health, economic growth, the environment, and rural and urban households. Leaders must appreciate the positive trade-offs of improvements in sanitation on nearly every MDG. International agencies, donors, and nongovernmental organizations can provide political leaders with information, encourage innovative policy choices, and motivate greater public involvement in water management efforts. Emphasis should be placed on viable local solutions that allow resource recovery (including natural treatment systems and EcoSan) and less on systems designed for cities in other (developed) parts of the world (Nhapi and Gijzen, 2004).

#### ***5.9. Minimize risk and uncertainty***

Some of the implications of irrigating with wastewater are still uncertain, especially compared to other pathogen exposure routes and health risk factors. Given the inherent uncertainty and potential social costs, public agencies should consider adopting the precautionary principle when designing policies for irrigation or wastewater use. Policies should be based on the new WHO guidelines to minimize the potentially harmful short- to long-term impacts, if required even at the cost of lower near-term financial gains to farmers and consumers. Public awareness campaigns might be helpful in gaining support for policies that reflect the precautionary principle. Special efforts will be needed in areas where many residents are not literate and where farmers require alternative livelihood support because they depend on wastewater as their only source for irrigation.



## 6. Conclusions

Irrigation with raw or diluted wastewater will continue to increase in many areas of developing countries as long as wastewater treatment does not keep pace with urban growth and urban food demands have to be met. The increasing availability and use of wastewater will generate additional challenges for public agencies charged with minimizing potential impacts on public health and the environment.

Where funding for major improvements in wastewater collection and treatment remains limited, public agencies must consider implementing preventive measures, such as the isolation of industrial effluents to reduce the most harmful wastewater components, farm-level efforts to minimize pathogen contact with crops and farm workers, and post-harvest measures and awareness campaigns to protect consumers of agricultural produce. Over time, substantial investments in sustainable sanitation facilities are needed. These should follow a step-wise approach to keep with local opportunities and constraints than foreign standards. As investments are made, policies must be implemented to protect the livelihoods of poor farmers and traders depending on wastewater irrigated crop production for income generation.

## Note

1. In the following text we refer this term to the use of raw, partly treated, or diluted (as in polluted natural water bodies) wastewater, from predominantly domestic sources, unless it is otherwise specified.

## References

- Amoah, P., Drechsel, P., Abaidoo, R. C., Henseler, M., 2007a. Irrigated urban vegetable production in Ghana: microbiological contamination in farms and markets and associated consumer risk groups. *J. Water Health* 5, 455–466.
- Amoah, P., Drechsel, P., Abaidoo, R., Klutse, A., 2007b. Effectiveness of common and improved sanitary washing methods in selected cities of West Africa for the reduction of coliform bacteria and helminth eggs on vegetables. *Trop. Med. Int. Health* 12 (s2), 40–50.
- Asano, T., 1998. Wastewater reclamation and reuse. *Water Quality Management Library Series*, vol. 10. Technomic Publishing Co. Inc.
- Asano, T., Cotruvo, J. A., 2004. Groundwater recharge with reclaimed municipal wastewater: health and regulatory considerations. *Water Res.* 38, 1941–1951.
- Asano, T., Burton, F., Leverenz, H., Tsuchihashi, R., Tchobanoglous, G., 2007. *Water Reuse: Issues, Technologies, and Applications* (McGraw-Hill). Metcalf & Eddy Inc.
- Blumenthal, U., Peasey, A., 2002. *Critical Review of Epidemiological Evidence of the Health Effects of Wastewater and Excreta Use in Agriculture*. WHO, Geneva.
- Buechler, S., Devi, G., 2006. Adaptations of wastewater-irrigated farming systems: a case of Hyderabad, India. In: van Veenhuizen, R. (Ed.), *Cities Farming for the Future: Urban Agriculture for Green and Productive Cities*. RUAF Foundation, IDRC and IIRR, pp. 267–270.
- Cornish, G. A., Lawrence, P., 2001. Informal irrigation in peri-urban areas: a summary of findings and recommendations. DFID's Water KAR Project R7132, Report OD 144. HR Wallingford, Wallingford, UK, 54 pp.

- Drechsel, P., Blumenthal, U. J., Keraita, B., 2002. Balancing health and livelihoods: adjusting wastewater irrigation guidelines for resource-poor countries. *Urban Agric. Mag.* 8, 7–9.
- Drechsel, P., Giordano, M., Gyiele, L. A., 2004. Valuing nutrients in soil and water: concepts and techniques with examples from IWMI studies in the developing world. In: Research Report 82, International Water Management Institute (IWMI), Colombo, Sri Lanka.
- Drechsel, P., Graefe, S., Sonou, M., Cofie, O. O., 2006. Informal irrigation in urban West Africa: an overview. In: Research Report 102, IWMI, Colombo, Sri Lanka.
- Drechsel, P., Keraita, B., Amoah, P., Abaidoo, R. C., Raschid-Sally, L., Bahri, A., 2007. Reducing health risks from wastewater use in urban and peri-urban sub-Saharan Africa—applying the 2006 WHO guidelines. In: Paper submitted to 6th IWA Conference on Wastewater Reclamation and Reuse for Sustainability, October 9–12, 2007, Antwerp, Belgium.
- Emongor, V. E., Ramolemana, G. M., 2004. Treated sewage effluent (water) potential to be used for horticultural production in Botswana. *Phys. Chem. Earth A/B/C* 29 (15–18), 1101–1108.
- Ensink, J., Tariq, M., Dalsgaard, A., 2007. Wastewater-irrigated vegetables: market handling versus irrigation water quality. *Trop. Med. Int. Health* 12 (s2), 2–7.
- Fine, P., Halperin, R., Hadas, E., 2006. Economic considerations for wastewater upgrading alternatives: an Israeli test case. *J. Environ. Manage.* 78 (2), 163–169.
- Grabow, G., McCornick, P. G., 2007. Planning for water allocation and water quality using a spreadsheet-based model. *J. Water Resour. Plann. Manage.* American Society of Civil Engineers. Manuscript number: WR/2005/022968.
- Huibers, F. P., Van Lier, J. B., 2005. Use of wastewater in agriculture: the water chain approach. *Irrig. Drain.* 54 (Suppl. 1), S-3–S-9.
- IWMI (International Water Management Institute), 2003. Confronting the realities of wastewater use in agriculture. Water Policy Briefing 9. IWMI, Colombo, Sri Lanka.
- IWMI, 2006. Recycling realities: managing health risks to make wastewater an asset. Water Policy Briefing 17. IWMI, Colombo, Sri Lanka.
- Janosova, B., Miklankova, J., Hlavinek, P., Wintgens, T., 2006. Drivers for wastewater reuse: regional analysis in the Czech Republic. *Desalination* 187, 103–114.
- Jimenez, B., 2005. Treatment technology and standards for agricultural wastewater reuse: a case study in Mexico. *Irrig. Drain.* 54 (Suppl. 1), S22–S33.
- Jimenez, B., Asano, T., 2004. Acknowledge all approaches: the global outlook on reuse. *Water* 21 (December (2004)), 32–37.
- Jimenez, B., Chávez, A., 2004. Quality assessment of an aquifer recharged with wastewater for its potential use as drinking source: El-Mezquital Valley case. *Water Sci. Technol.* 50, 269–276.
- Keraita, B., Konradsen, F., Drechsel, P., Abaidoo, R. C., 2007a. Effect of low-cost irrigation methods on microbial contamination of lettuce irrigated with untreated wastewater. *Trop. Med. Int. Health* 12 (s2), 15–22.
- Keraita, B., Drechsel, P., Konradsen, F., 2007b. Using on-farm sedimentation ponds to reduce health risks in wastewater irrigated urban vegetable farming in Ghana. In: Proceedings of the 6th IWA Specialist Conference on Wastewater Reclamation and Reuse for Sustainability, October 2007, Belgium.
- Keraita, B., Konradsen, F., Drechsel, P., Abaidoo, R. C., 2007c. Reducing microbial contamination on wastewater-irrigated lettuce by cessation of irrigation before harvesting. *Trop. Med. Int. Health* 12 (s2), 8–14.
- Keraita, B. N., Drechsel, P., 2004. Agricultural use of untreated urban wastewater in Ghana. In: Scott, C. A., Faruqui, N. I., Raschid-Sally, L. (Eds.), *Wastewater Use in Irrigated Agriculture*. CABI Publishing, Wallingford, UK, pp. 101–112.

- Lazarova, V., Bahri, A., 2005. *Water Reuse for Irrigation: Agriculture, Landscapes, and Turf Grass*. CRC Press, Boca Raton, USA.
- Mara, D., 2003. *Domestic Wastewater Treatment in Developing Countries*. Earthscan, UK.
- Martijn, E., Redwood, M., 2005. Wastewater irrigation in developing countries—limitations for farmers to adopt appropriate practices. *Irrig. Drain.* 54 (Suppl.1), S-63–S-70.
- McCornick, P. G., Hijazi, A., Sheikh, B., 2004. From wastewater reuse to water reclamation: progression of water reuse standards in Jordan. In: Scott, C. A., Faruqui, N. I., Raschid-Sally, L. (Eds.), *Wastewater Use in Irrigated Agriculture*. CABI Publishing, UK.
- Minhas, P. S., Samra, J. S., 2003. *Quality Assessment of Water Resources in Indo-Gangetic Basin Part in India*. Central Soil Salinity Research Institute, Karnal, India, 68 p.
- Minhas, P. S., Samra, J. S., 2004. *Wastewater Use in Peri-urban Agriculture: Impacts and Opportunities*. Central Soil Salinity Research Institute, Karnal, India, 75 p.
- Minhas, P. S., Sharma, N., Yadav, R. K., Joshi, P. K., 2006. Prevalence and control of pathogenic contamination in some sewage irrigated vegetable, forage and cereal grain crops. *Bioresour. Technol.* 97, 1174–1178.
- Nhapi, I., Gijzen, H. J., 2004. Wastewater management in Zimbabwe in the context of sustainability. *Water Policy* 6, 501–517.
- Obuobie, E., Keraita, B., Danso, G., Amoah, P., Cofie, O. O., Raschid-Sally, L., Drechsel, P., 2006. Irrigated urban vegetable production in Ghana: characteristics, benefits and risks. IWMI-RUAF-IDRC-CPWF, Accra, Ghana: IWMI, 150 pp. Available at [www.cityfarmer.org/GhanaIrrigateVegis.html](http://www.cityfarmer.org/GhanaIrrigateVegis.html).
- 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. Phase I: Diagnostic de la situation actuelle; Phase II: Orientations stratégiques pour l'amélioration de la réutilisation des eaux épurées. December 2001.
- Qadir, M., Wichelns, D., Raschid-Sally, L., Minhas, P. S., Drechsel, P., Bahri, A., McCornick, P., 2007a. Agricultural use of marginal-quality water—opportunities and challenges. In: Molden, D. (Ed.), *Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture*. Earthscan, London, UK.
- Qadir, M., Sharma, B. R., Bruggeman, A., Choukr-Allah, R., Karajeh, F., 2007b. Nonconventional water resources and opportunities for water augmentation to achieve food security in water scarce countries. *Agric. Water Manage.* 87, 2–22.
- Raschid-Sally, L., Jayakody, P., 2007. Understanding the drivers of wastewater agriculture in developing countries—results from a global assessment. In: Comprehensive Assessment Research Report Series, IWMI, Colombo, Sri Lanka.
- Raschid-Sally, L., Parkinson, J., 2004. Wastewater reuse for agriculture and aquaculture—current and future perspectives for low-income countries. *Waterlines J.* 23 (1), 2–4.
- Raschid-Sally, L., Carr, R., Buechler, S., 2005. Managing wastewater agriculture to improve livelihoods and environmental quality in poor countries. *Irrig. Drain.* 54, 11–22.
- Scott, C. A., Faruqui, N. I., Raschid-Sally, L., 2004. Wastewater use in irrigated agriculture: management challenges in developing countries. In: Scott, C. A., Faruqui, N. I., Raschid-Sally, L. (Eds.), *Wastewater Use in Irrigated Agriculture*. CABI Publishing, UK.
- Tidåker, P., Kärrman, F., Baky, A., Jönsson, H., 2006. Wastewater management integrated with farming—an environmental systems analysis of a Swedish country town. *Resour. Conserv. Recycl.* 47, 295–315.
- Toze, S., 2006. Reuse of effluent water—benefits and risks. *Agric. Water Manage.* 80, 147–159.
- Trang, D. T., Van der Hoek, W., Cam, P. D., Vinh, K. T., Hoa, N. V., Dalsgaard, A., 2006. Low risk for helminth infection in wastewater-fed rice cultivation in Vietnam. *J. Water Health* 4, 321–331.

- Trang, D. T., Van Der Hoek, W., Tuan, N. D., Cam, P. D., Viet, V. H., Luu, D. D., Konradsen, F., Dalsgaard, A., 2007. Skin disease among farmers using wastewater in rice cultivation in Nam Dinh, Vietnam. *Trop. Med. Int. Health* 12 (s2), 51–58.
- UNDP (United Nations Development Program), 1987. Reclaimed wastewater reuse in agriculture. Technical Report (in French), vol. 1, 3rd Part, 69 p.+ annexes. Project RAB/80/011, Water Resources in the North African Countries, Rural Engineering Research Center (Tunisia)—United Nations Development Program.
- US EPA (U.S. Environmental Protection Agency) and USAID (U.S. Agency for International Development), 2004. *Guidelines for Water Reuse*. Washington, DC.
- 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: Scott, C. A., Faruqui, N. I., Raschid-Sally, L. (Eds.), *Wastewater Use in Irrigated Agriculture*. CABI Publishing, UK.
- 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., Matsuno, Y., 2002. Urban wastewater: a valuable resource for agriculture. In: Research Report 63, IWMI, Sri Lanka.
- WHO, 2006. *Guidelines for the Safe Use of Wastewater, Excreta and Grey Water*. Volume 2. Wastewater Use in Agriculture. Geneva.