Chapter 18
Global Experiences on Wastewater Irrigation: Challenges and Prospects

Mohammad Valipour and Vijay P. Singh

Abstract The need for irrigated agriculture is growing day by day and the largest water withdrawals from renewable water resources are for irrigation. In addition, the available water resources are decreasing and we need to use non-conventional water resources for irrigation due to looming water crisis (Raschid-Sally and Jayakody, Drivers and characteristics of wastewater agriculture in developing countries: results from a global assessment. International Water Management Institute, Colombo, 35p, (IWMI Research Report 127), 2008). However, the volume of treating and using wastewater is limited due to the lack of adequate data and knowledge and/or negative effects of improper wastewater management (i.e. use of untreated wastewater). A comprehensive evaluation of what has been done is necessary in order to explore wastewater irrigation and to avoid trial-and-error policies. Although a study of wastewater irrigation from crops, soil, groundwater, health, irrigation equipments, modern technologies, and other environmental aspects is useful, management studies in comparison with other aspects can help lead to more reliable and more extensive findings and finally a better decision on using wastewater for irrigation. The chapter presents challenges and prospects that may help decision making for the use of wastewater in irrigation.

Keywords Crop • Environment • Health • Irrigation • Soil • Wastewater

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18.1 The Concept of Using Wastewater for Irrigation

More than 60 % of the global population could suffer from water scarcity by 2025 or 2030 (Qadir et al. 2007; Rijsberman 2006; Wallace 2000). Renewable water resources per capita have decreased for all regions in the world with the exception of Caucasus and Eastern Europe (see also Redondo and Lomax 1997), as shown in Fig. 18.1.

Figure 18.1 shows alarms of water crisis in the future; if the trends are as shown (due to uncontrolled population growth); renewable water resources per capita were significantly higher for maritime Southeast Asia than for mainland Southeast Asia in the first half of century; however, these have become less in mainland Southeast Asia in recent years. Renewable water resources per capita were significantly higher for

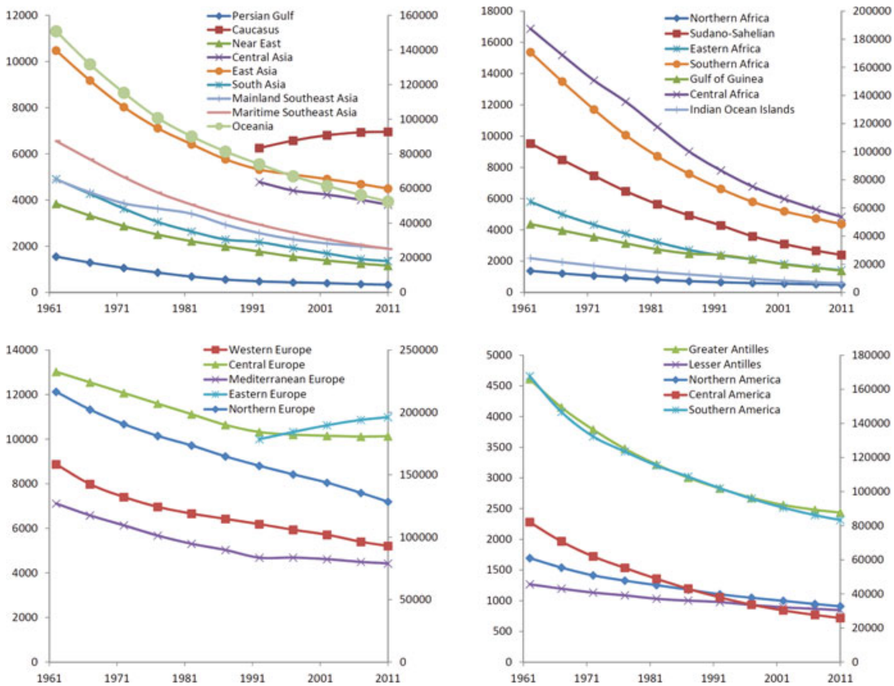

Fig. 18.1 Status of average renewable water resources per capita (m^3/inhab/year) in different regions of the world: Asia and Oceania: the *left axis* belongs to Caucasus, East Asia, Central Asia, Near East, and Persian Gulf; and the *right axis* belongs to Oceania, Maritime Southeast Asia, Mainland Southeast Asia, and South Asia; all over Africa: the *left axis* belongs to Southern Africa, Sudano-Sahelian, Eastern Africa, and Northern Africa; and the *right axis* belongs to Central Africa, Gulf of Guinea, and Indian Ocean Islands; Europe: the *left axis* belongs to Eastern Europe, Central Europe, Western Europe, and Mediterranean Europe; and the *right axis* belongs to Northern Europe; Americas: the *left axis* belongs to Greater Antilles and Lesser Antilles; and the *right axis* belongs to Southern America, Central America, and Northern America (in Caucasus, Central Asia, and Eastern Europe, volumes of renewable water resources per capita have been calculated for years after 1991 due to collapse of the USSR)

Central America than for Northern America in the 1960s and 1970s; however they have become less in North America from the middle of the 1980s. The figure also shows that a warning sign is emerging for the Persian Gulf, Near East, North Africa, Central America, and North America. Meanwhile, water requirements for food production will significantly increase in order to eradicate poverty in developing countries by 2030 and 2050 (Fig. 18.2). Thus, we will be facing a serious challenge in the near future.

The greatest water withdrawal is due to the agricultural sector (Fig. 18.3a). However, there have been decreases in water withdrawals over the past three decades due to population and industrial growth (Fischer et al. 2007). Contrasting with Fig. 18.2, it shows the importance of agricultural water management now and in the future. Compared to rainfed agriculture, irrigation is advancing (Valipour 2012a, b, c, 2014a, b, c, 2015a, b, c, d, e, f, g, h, i, 2016a, b; Valipour et al. 2012, 2013, 2015; Valipour and Eslamian 2014; Yannopoulos et al. 2015; Mahdizadeh Khasraghi et al. 2015). In addition, Fig. 18.3a confirms the growth of other sectors compared to the agricultural sector. However, a considerable increase is citable for Czech, Canada, Croatia, and Denmark (Fig. 18.3b). This leads to increased pressure on renewable water resources and must be adjusted by appropriate management policies.

It may be noted that there is an increase in irrigation water withdrawal for Macedonia and Mongolia with respect to Fig. 18.2. Nevertheless, the area equipped for irrigation per cultivated area (irrigation systems growth) has increased and also more than 40 % of irrigation potential has not yet been developed (Fig. 18.3c).

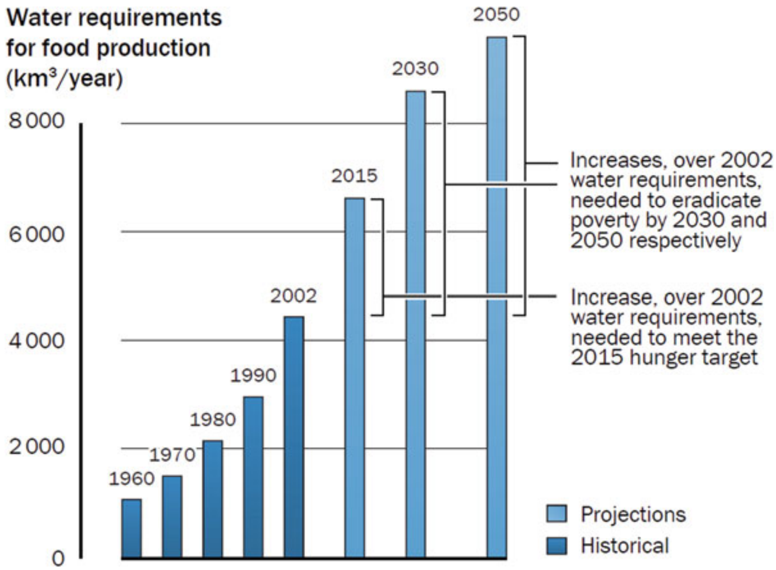

Fig. 18.2 The requirements for water in agriculture in developing countries will need to increase in order to meet the Millennium Development Goal (half, between 1990 and 2015, the proportion of people who suffer from hunger). To decrease hunger the outputs in agriculture will need to increase, and thus the water use. The data has been calculated for developing countries with minimum set of calories (Stockholm Environment Institute 2005)

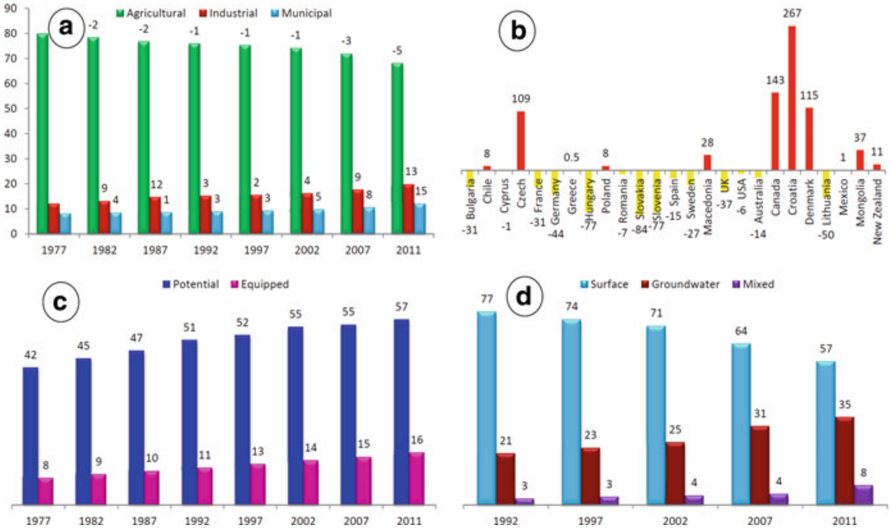

Fig. 18.3 Status of irrigation in the world (**a**) role of each sector in water withdrawal; *Agricultural* indicates agricultural water withdrawal as percent of total water withdrawal (%), *Industrial* indicates industrial water withdrawal as percent of total water withdrawal (%), *Municipal* indicates municipal water withdrawal as percent of total withdrawal (%), the values are changes in comparison with the previous period (%), (**b**) changes of water withdrawal for irrigation (%) during 2002–2011, (**c**) *Potential* indicates percent of irrigation potential equipped for irrigation (%), Equipped is area equipped for irrigation to cultivated area (%), (**d**) pressure on water resources in the previous two decades, *Surface* indicates percent of area equipped for irrigation by surface water (%), *Groundwater* indicates percent of area equipped for irrigation by groundwater (%), *Mixed* indicates percent of area equipped for irrigation by mixed surface water and groundwater (%)

Furthermore, developed irrigation potential is more than 100 % – Algeria (112 %), Barbados (152 %), Cyprus (109 %), Libya (175 %), and Malta (160 %) and it may apply for other countries in the future based on considerable growth of this index in recent years (FAO 2013; You et al. 2011). Therefore, compared to the decrease in agricultural water withdrawal (Fig. 18.3a), there is an increase in the tendency for irrigation for agriculture (Fig. 18.3c) in order to provide more food (Fig. 18.2), and this again underlines the water crisis for irrigation.

The question arises how irrigation water requirements should be met? Compared to surface water resources, the use of groundwater is increasing because of climate change, population growth and excessive water consumption, and as shown in Fig. 18.3d, irrigation is not exempt from this issue (Doll et al. 2012; Green et al. 2011; Siebert et al. 2010). This leads to greater pressure on groundwater resources. In addition, development of dams (Fig. 18.4) may impact groundwater levels (Heidarian et al. 2011).

Although the development of dams can increase groundwater levels in some conditions, it is also alarming for countries with considerable water resources dependency ratio (Fig. 18.4), because the water resources of more than 60 % of countries depend on other countries (upstream). Many advantages of the develop-

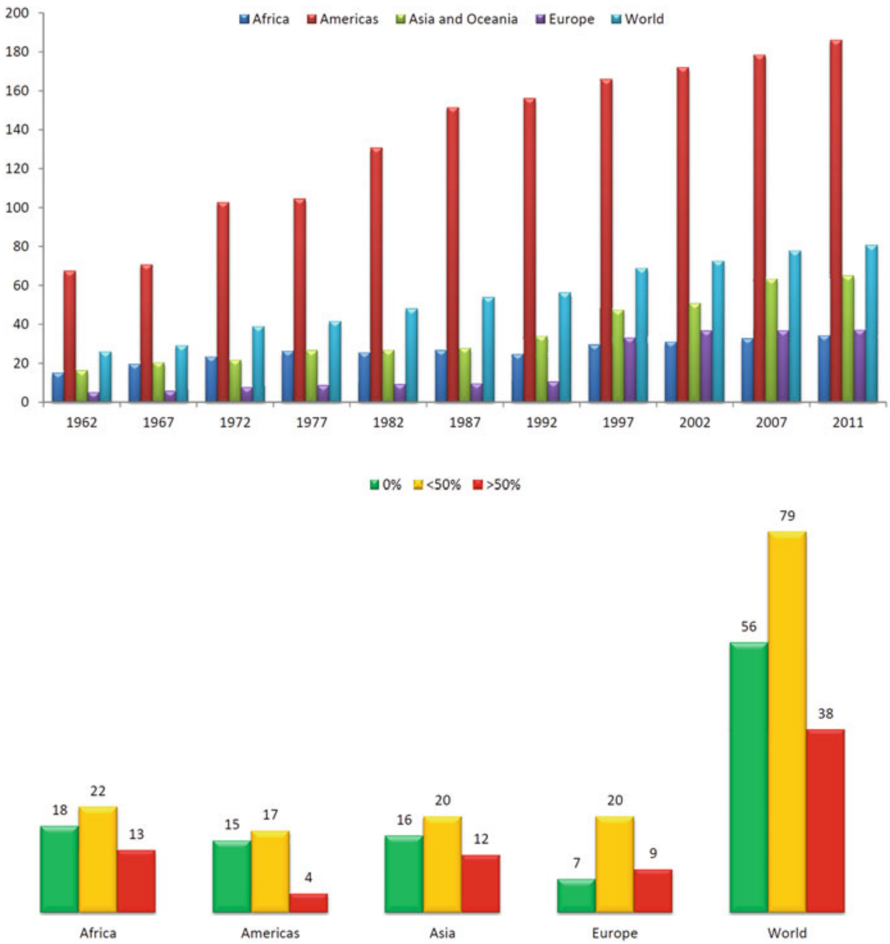

Fig. 18.4 The above chart shows status of average dam capacity (km^3) in the previous half of century (after 1992, dam capacity of Russia has been added to Europe) and the below chart shows number of countries with different dependency ratios in the world (The world data are the average of all continents)

ment of dams withstanding, dams limit countries with a considerable dependency ratio. Thus, the use of conventional waters is limited and is difficult from day to day. In addition, the cost of virtual water is too high (Dominguez 2010) and is not affordable for most developing countries. Therefore, wastewater, as a non-conventional water resource, can help provide for a proportion of irrigation water and reduce pressure on conventional water resources. However, wastewater should be treated in order to comply with the standards of irrigation water quality (WHO 1989, 2006). As shown in Fig. 18.5, more than half of wastewater is not treated and even all of the treated wastewater is not used, whether for irrigation or other sectors.

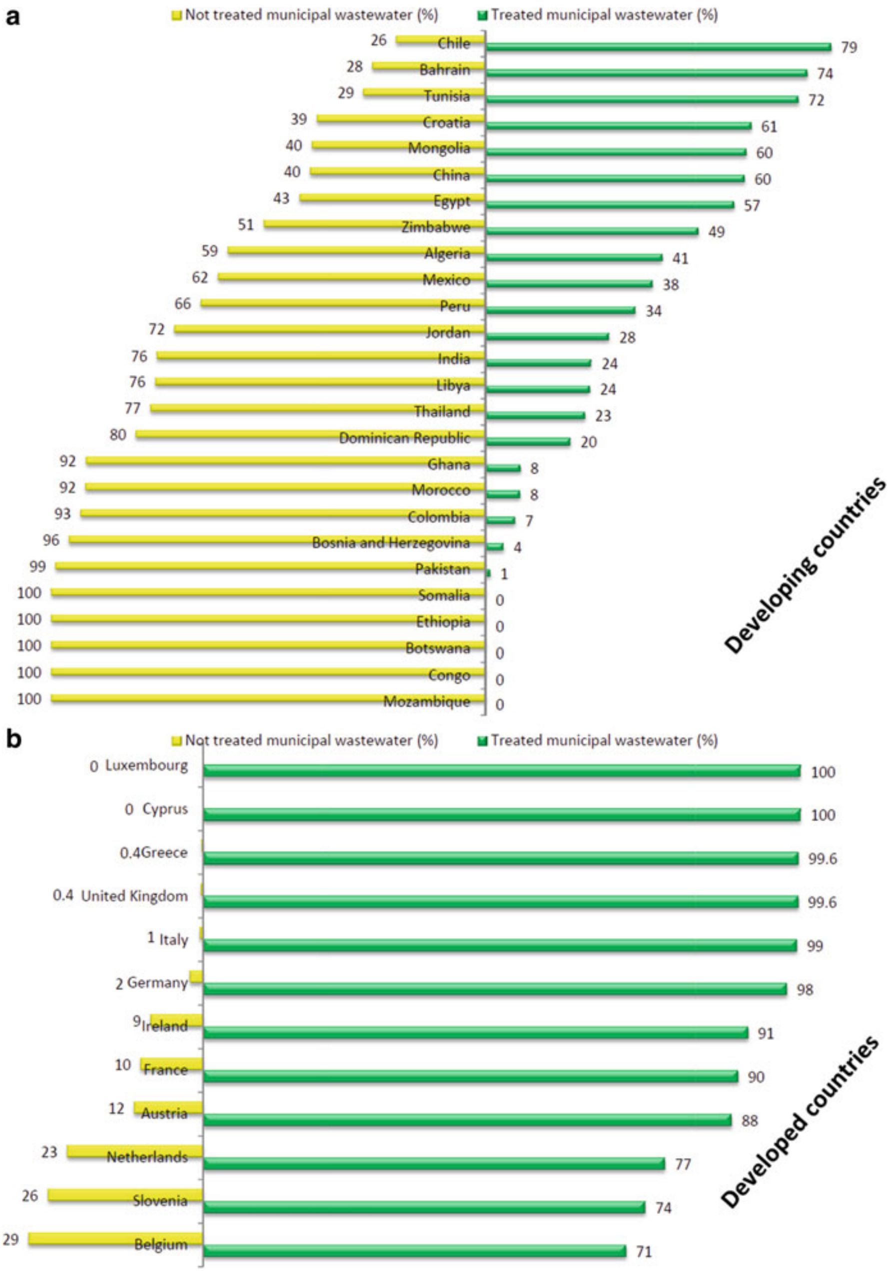

Fig. 18.5 Status of average collected municipal wastewater based on total available data for all countries in the recent two decades from 1992 to 2011

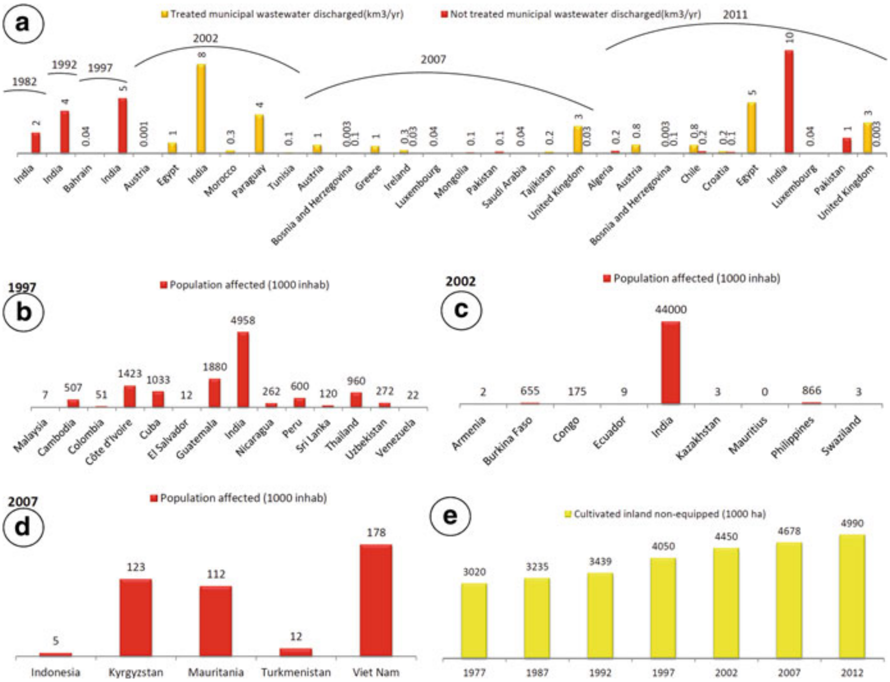

Fig. 18.6 Challenges and prospects for wastewater, (**a**) all of available data for discharged wastewater to inlands, wetlands, and coastal areas, (**b–d**) affected population to disease due to discharge of wastewater and water pollution, (**e**) available data for cultivated inland (non-equipped for irrigation) in the same regions that wastewater is discharged (Fig. 18.5a), note that the actual values are very higher than presented data and these are only reported data

Figure 18.6a shows that the volume of discharged wastewater (not treated) is increasing in India and Pakistan (with 76 % and 99 % non-wastewater treated respectively, based on Fig. 18.5) as well as the volume of discharged wastewater (treated) is increasing for Egypt (with 57 % wastewater treated based on Fig. 18.5) and Austria. However, with respect to Fig. 18.5, one can see the United Kingdom (with 99.6 % wastewater treated), Luxembourg (with full wastewater treated), and Bosnia and Herzegovina without increase in discharged wastewater (treated and not treated).

Although data on discharged wastewater are very limited (Sato et al. 2013), the information on wastewater or lack thereof is also an alarm for health and environmental issues. As shown in Fig. 18.6b–d, a considerable percentage of the population has been affected by water pollution and discharged wastewater, and the affected population is increasing due to the increase of this trend (compare the status in India in Fig. 18.6a with Fig. 18.6b, c). Based on Fig. 18.5, Congo, Colombia, Peru, and Thailand, with considerable affected population (Fig. 18.6b, c), have low treated wastewater (0, 7, 34, and 23, respectively). However, the volume of non-equipped cultivated area (rainfed agriculture) has increased (Fig. 18.6d) in the

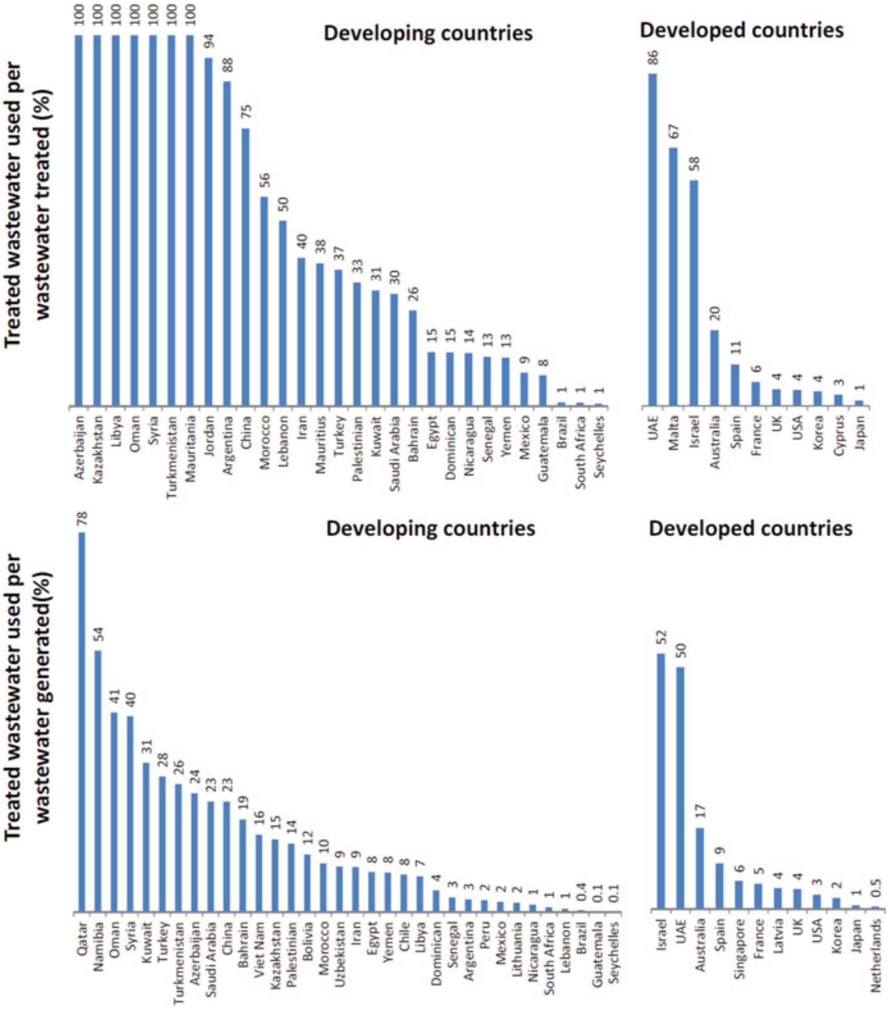

Fig. 18.7 All available data for treated wastewater used (not only for irrigation but also for all sectors as using wastewater for irrigation is lower than these data) in the world note that these data are approximately (in a few cases reporting year for wastewater used is not matched to reporting year for generated or wastewater treated)

same regions in which we see the discharge of wastewater (Fig. 18.6a) as well as the growth of diseases due to this discharge (Fig. 18.6b–d). This is interesting when we know that these areas have good potential for wastewater irrigation (Kivaisi 2001; Morari and Giardini 2009; Siracusa and La Rosa 2006; Verhoeven and Meuleman 1999). Despite what has been mentioned above, Fig. 18.7 shows that the use of wastewater for irrigation is quite low throughout the world.

Although all of the wastewater treated in Azerbaijan, Kazakhstan, Libya, Oman, Syria, and Turkmenistan is used, the volumes of wastewater used per generated wastewater are 24 %, 15 %, 7 %, 41 %, 40 %, and 26 %, respectively, for these countries. Further, the disposal of untreated wastewater increases the risk of diseases in these countries (see Kazakhstan, Turkmenistan, and Mauritania in Fig. 18.6c, d). A comparison of Peru, Guatemala, Uzbekistan, Nicaragua, and Viet Nam in Figs. 18.6b–d and 18.7 (considerable population affected and low wastewater treated and used) highlights the importance of proper use of treated wastewater instead of its disposal.

In some developing countries, city planners and administrators view wastewater as a disposal problem. They are not concerned with the impact on the livelihoods it presently generates or with the health of stakeholders. Politics and corruption play an important role in the decision to construct expensive treatment plants that often fail to function properly, if at all, once they are commissioned (Bhamoriya 2004). Strong traditional water rights, lack of urban planning, and weak institutions are constraints to the improvement of wastewater management in some urban and peri-urban areas (Huibers et al. 2004).

Although a considerable part of wastewater is refined in the United Kingdom, France, the Netherlands, Bahrain, Egypt, Mexico, and Peru (Fig. 18.5), the wastewater used in these countries is too low (Fig. 18.7). While the volumes of wastewater used are 100 % and 94 % for Libya and Jordan, respectively (Fig. 18.7), the volumes of wastewater treated are only 24 % and 28 %, respectively (Fig. 18.5). In general, average volumes of wastewater used per wastewater generated and wastewater used per wastewater treated are 15 % and 41 % in the world (based on the available data in Fig. 18.7). Now, the question arises: Why is the use of wastewater for irrigation low? How can it be increased? For answering these questions we should critique the previous studies to identify the challenges and prospects of using wastewater for irrigation.

18.2 Assessment of Wastewater Irrigation from Different Aspects

Wastewater irrigation has been studied from many different aspects. This section provides a review of the important results of the various aspects of using wastewater for irrigation (for period from the 1970s to 2013). The meaning of “wastewater” in this chapter is “wastewater treated” or else “untreated wastewater” has been used.

18.2.1 Health

There are many investigations on the connection of wastewater irrigation and health. Because of the potential public health risks involved, Katzenelson et al. (1976) recommended strong wastewater treatment measures, including effective bacterial and viral inactivation through disinfection for all cases of sewage irrigation or land disposal near residential areas. In addition, according to the findings, during reclaimed water irrigation the uptake of chemicals to food grown in the soil will be an important exposure route for human risk assessment (Weber et al. 2006). Policy efforts should be geared toward updating the knowledge, skills and attitudes of producers through frequent training and workshops, so that untreated wastewater irrigation farmers would better appreciate health-related risks of waste water irrigation and how to adopt risk mitigating strategies (Owusu et al. 2012). However, some works were related to limited regions, particularly in Asia and Africa. In Asia, for instance, in Israel, field soils, receiving either raw city wastewater or normal irrigation water, were found to be rich in pathogenic and potentially pathogenic CH-resistant fungi, including dermatophytes (Ali-Shtayeh et al. 1998). In the other research, exposure to wastewater with high Giardia concentrations carries an increased risk for (asymptomatic) Giardia infection, as in Pakistan (Ensink et al. 2006). In Republic of Korea, agricultural activity was thought to be safer after 1–2 days, when a paddy field was irrigated with reclaimed wastewater. Also, children were found to have a greater risk of infection with *E. coli* (An et al. 2007). In an examination in China, Khan et al. (2008) showed wastewater irrigated grown plants were contaminated with heavy metals and exceeded the permissible limits for vegetables set by SEPA and WHO. Baghapour et al. (2013) found that the effluent physicochemical quality in Iran was appropriate for irrigation; however, considering the microbial parameters, the effluent quality reduced dramatically which shows that pathogens in effluent can be a threat to the public health. Wastewater irrigation is the main source of metal accumulation in food crops in Pakistan, which on human consumption may lead to adverse health outcomes on a large scale. Hence, there is a dire need to strictly monitor wastewater irrigation systems and also tube-well irrigated systems and develop different strategies to prevent the accumulation of heavy metals in food crops that may ultimately minimise chronic health risks to the exposed population (Khan et al. 2013).

In Africa, El-Gohary et al. (1998) characterized the concentration of some elements of wastewater and concluded that bacteriological examination of the dried sludge indicated a reduction of nine logs of faecal coliform and faecal streptococci as compared to thickened sludge. Analysis of Ni, Cu, Pb and Cr in the dried sludge in Egypt indicated that their concentrations were within permissible limits. There are also some works on the connection between malaria and wastewater irrigation. For instance, Agunwamba (2001) observed that the occurrences of diarrhoea, typhoid fever and malaria among the groups were used as indices of irrigation farmers and consumers. The health status of farmers and consumers in Nigeria was poorer than that of non-farmers and non-consumers. Also, some studies focus on public health impacts of wastewater irrigation. The negative human health impacts can be minimized when good management practices are implemented, as in Morocco and Palestine (Fatta et al. 2004). In Zimbabwe, Mutengu et al. (2007) found that the public health risk of soil contamination by heavy metals and health risks by plant uptake of heavy metals seemed to be negligible probably because of the source of effluent. Keraita et al. (2007a) carried out a study on untreated wastewater irrigation in Ghana and their results showed that cheaper and simple irrigation methods need to be developed and assessed in order to reduce health risks. Such methods are more likely to succeed in informal urban irrigation settings, where low tenure security prevents farmers from investing in sophisticated methods or on-site treatment ponds. In another research in Ghana, Keraita et al. (2007b) showed cessation of untreated wastewater irrigation before harvesting is not effective in reducing contamination during wet season. In other study in Ghana, Qadir et al. (2010) proposed isolation of industrial effluents to reduce the most harmful wastewater components, to minimise pathogens, and to protect consumers from agricultural produce for developing countries.

18.2.2 Groundwater

Many investigations focused on the connection between wastewater irrigation and quality of groundwater. There are some works in Americas on this topic, for example, in the U.S.A., Mooers and Alexander (1994) found essentially no relationship between the source of Cl and NO_3 in the vicinity of irrigation fields. However, the most investigations belong to Mediterranean countries and Asia.

In Mediterranean countries, Esteller et al. (2001) concluded that main differences between the intervals were modifications of CO_2 interchange and the behaviour of sodium. In Spain the synergic effect of different processes involved was a good level of purification. Kass et al. (2005) showed that salinity and composition of groundwater in the water table region in Israel were highly variable over a distance of less than 1 km and were controlled by irrigation water and the processes in the overlying unsaturated zone. Abd El Lateef et al. (2006) showed that fertile soil and desert soil were widely variable in water holding capacity, organic matter, pH value, $CaCO_3$, salinity, cation exchange capacity, and soil bulk density in the topsoil. In Egypt, groundwater was examined for the presence of pathogenic bacteria, faecal coliform bacteria and helminth ova. Although no associated microbiological risk has been observed in aquifers due to the effective soil filtration, the soil–water interaction may render groundwater quality inappropriate for use due to the salinity increase in Spain (Candela et al. 2007). Examination of physical and chemical parameters in Tunisia showed an increase in the concentrations of nutrients in groundwater below the irrigation zone, which confirmed again the infiltration of wastewater effluents (Bouri et al. 2008). McNeill et al. (2009) showed that the utilisation of cesspits for wastewater disposal in Palestine had a negative impact on the underlying groundwater, so the construction of a wastewater network and treatment plant is imperative.

In Asia, for instance, in China nitrate enters groundwater via wastewater irrigation and groundwater flow from non-leveelined canals. High hardness and linearity among major ionic species in groundwater indicate the dissolution and mixing processes along the groundwater flow path (Chen et al. 2006). Jalali et al. (2008) showed in Iran that if wastewater was applied to soil for a long enough period, leaching concentrations will reach groundwater at elevated levels. Wu and Cao

(2010) informed that concentrations of metals in groundwater from wells were lower than the China Groundwater Quality Standard and the WHO guideline values for drinking water, but a substantial build up of Hg and Cd in river sediments and wastewater-irrigated soils was observed. During long-term sewage irrigation, principal component analysis for organ chlorine pesticides (OCPs) content in groundwater in China showed that the occurrence and distribution of OCPs in groundwater systems can mainly be attributed to the influence of flow field of groundwater and also to the current pesticide use (Zhang et al. 2013).

18.2.3 Crops

Oron and DeMalach (1987) showed the maximum yield of cotton in Israel was obtained under twin row planting (in comparison with single rows), irrigated twice a week with a commercial amount of effluent. In Sweden, a wastewater treatment system, using willow coppice crops as recipients, thus combining treatment and biomass production for energy purposes, can be a realistic economic alternative for small and medium sized treatment plants, compared with conventional technical systems (Rosenqvist et al. 1997). When the treated effluent was used to irrigate crops in Jordan, a very low coliform count was found on fruit skin. However, there was an increase in eggplant production, probably due to the nutritive value of the effluent (Al-Nakshabandi et al. 1997). In other research in Jordan, Shahalam et al. (1998) showed that the yields resulting from the use of wastewater without fertiliser were compatible with those with the use of freshwater with fertiliser. Haruvy et al. (1999) claimed that agricultural yields and/or prices in Israel may decrease according to differences between levels of nutrients needed by crops and those available in wastewater irrigation.

Some works reported the negative aspect of wastewater irrigation for crops. For instance, Murillo et al. (2000) deduced that olive trees rapidly responded to wastewater application. The wastewater use in Spain significantly reduced olive yield, compared to that obtained in the control fields. However, other works indicated a positive role of wastewater irrigation for crops. In Egypt, significant differences were found between treatments in root length, shoot height and root and nodule dry weight (Sayed 2003). At both the laboratory scale and full scale, the anaerobic treatment is suitable for the treatment of Pisco wastewater (The *Pisco wastewater* system consists of mains, mostly running from the south toward the north to the stabilisation of lagoons for treatment), and that the nutrient content of treated water can be beneficial for plant growth, reducing the need for fertilisers in Chile (Jeison et al. 2003). Al-Lahham et al. (2003) showed that microbial contamination increased at tomato surface and scar, while the fruit flesh was totally uncontaminated. The tomato fruit size and weight increased in both varieties with the increasing percentage of treated wastewater. The pH was not affected, but the firmness, TSS, and weight loss decreased as a function of the increasing treated wastewater percentage in Jordan.

Agronomic results indicated no major limitations to the use of tertiary effluent as an irrigation source in an ornamental (one case) plant nursery. In Italy, the nutrient content of the tertiary effluent was able to maintain good plant growth as well as fertigated water for most of the tested species (Lubello et al. 2004). Strict protection measures, stringent guidelines and an integrated system for the treatment and recycling of wastewater are needed to minimise the negative impacts of wastewater irrigation on cops, as in Iran (Qishlaqi and Moore 2006). Kiziloglu et al. (2007) claimed that the contents of P, Zn, Cd, and pH were increased in cultivated plants by wastewater irrigation. In Brussels, wastewater irrigation decreased leaf dry matter P and Zn in Broccoli, but increased Cd and Co in sprouts leaves. In Greece the high heavy metal content in the edible plant parts, and the heavy load of FC and E. coli are high health risk factors. In China the quality of crops that made use of treated sewage was not distinctively different from that of those that did not use treated sewage but yields for the former were much higher than they were for the latter (Wang et al. 2007). In Italy the negligible microbial contamination of fruit and washing solution (up to 40 MPN/100 mL) suggested that the treated wastewater can be used as a valid alternative for irrigation of tomatoes (Aiello et al. 2007). Kiziloglu et al. (2007) found in Turkey that wastewater increased yield and the N, P, K, Fe, Mn, Zn, Cu, B, and Mo contents of cabbage plants.

Rusan et al. (2007) found in Jordan that continuous irrigation with wastewater led to the accumulation of salts, plant nutrients and heavy metals beyond crop tolerance levels. Compared to soils irrigated with groundwater, the results of soils irrigated with wastewater revealed a significant decrease in the soil pH and an increase in salt, the organic matter content and CEC in the soil and macro and micro element concentrations in the leaves and may improve plant growth, reduce fertiliser application and increase productivity of poorly fertile soils in Turkey (Kiziloglu et al. 2008). In China, Chiou (2008) claimed that the high total nitrogen of reclaimed water from secondary treatment made it unfavourable for crop growth. In the Republic of Korea Chung et al. (2008) indicated in the soils and crops after wastewater irrigation, high-molecular weight polycyclic aromatic hydrocarbons PAHs (PAHs have been identified as carcinogenic and mutagenic, and are considered pollutants of concern for the potency of potential adverse health impacts; the same holds true of their presence at significant levels over time in human diets.) were not detected, but low-molecular weight PAHs were only detected at trace levels. No significant contamination was recorded on fruits harvested by irrigated olive trees in Italy, even under the worst-case conditions (Palese et al. 2009).

Pedrero and Alarcon (2009) indicated that the possibility to mix reclaimed wastewater with well water was a good solution to avoid the problems of wastewater irrigation. In Spain the high salinity and Boron concentration were the main problems for lemon trees (Pedrero and Alarcon 2009). Non-significant injuries caused by salts and/or heavy metals were observed on the shoot growth of trees irrigated with wastewater irrigation. Application of wastewater irrigation in Tunisia significantly increased the concentration of N, P and K in the leaves, whereas heavy metals (Zn and Mn) showed a significant increase only after the second year of irrigation (Bedbabis et al. 2010a). Irrigation with wastewater over 4 years did not affect free acidity, and specific ultraviolet absorbance on olive (Bedbabis et al. 2010b). In Italy and Serbia, low levels of E. coli and no helminth eggs were found in treated wastewater used for irrigation. Only one potato sample was positive for E. coli during the 2-year study. Potatoes, irrespective of the irrigation method and type of water applied, were safe for consumption (Forslund et al. 2010).

During a field experiment using wastewater irrigation in India, Gupta et al. (2010) showed a decrease in total chlorophyll and total amino acid levels in vegetables and an increase in amounts of soluble sugars, total protein, ascorbic acid, and phenol except *Boron*. Loutfy et al. (2010) showed all the studied contaminants in Egypt were much higher in henna and rosemary plants irrigated with wastewater, while in the case of Moghat (dried powder of peeled roots of Glossostemon bruguieri plants) samples, no difference was observed between freshwater irrigated samples and wastewater irrigated samples. Despite enriched As, Cr and Ni in some paddy soils from andesite and serpentinites in Taiwan, Hseu et al. (2010) found these metals were not clearly accumulated in rice. The irrigation of olive trees and vegetable crops with treated wastewater in Jordan did not show any adverse effect on the chemical properties of fruits and leaves (Al-Hamaiedeh and Bino 2010). de Paula et al. (2010) showed that surplus wastewater pasture irrigation in Brazil caused minor increases in the physiological status of the soil microbial community but no detectable damage to the pasture or soil.

The average length of seedlings watered with drinking water and raw wastewater was similar in Mexico (Rojas-Valencia et al. 2011). In Iran, Moradmand and Beigi Harchegani (2011) claimed that soil and sweet chilli plant concentrations of lead and nickel were not significantly affected by wastewater irrigation. Pereira et al. (2011) showed that in the U.S.A. wastewater irrigation had a greater influence on the micro-nutrient than macronutrient concentration in citrus leaves, following the order: B > Zn > Mn and Ca > Cu > Mg > P > K. The physico-chemical quality of lagoon-treated wastewater was acceptable, whereas the bacteriological quality and helminths quality were not satisfactory. The reuse of wastewater irrigation improved yield and provided variable nutrients supply, depending on the year and element in West Africa (Irenikatche Akponikpe et al. 2011). Evett et al. (2011) concluded that successful irrigation of any tree species in Egypt demanded careful irrigation system design, irrigation scheduling based on the best scientific knowledge available, on-site measurement of weather data, and ongoing maintenance and repair of the irrigation system from pump intake to emitters and/or spaghetti tubing.

Lantana species is sensitive to saline reused water, while Polygala is a tolerant species. Thus, Polygala can be irrigated with reused saline water with acceptable growth and aesthetic results, while Lantana cannot be recommended for nursery growth or landscape use, when this type of water is used for irrigation, as in Spain (Banon et al. 2011). Moraetis et al. (2011) showed the fertilisation potential of wastewater was considerable, especially for N and K. In Greece, the total NPK fertilisation of the maize field with wastewater resulted in 6 times more N, 2 times less P and 50 times more K than conventional fertilisation rates. In Republic of Korea, Chung et al. (2011) found that the contents of Cd and Pb in brown rice were lower than the permitted limits in grains.

Application of sewage water increased the yield of Rabi crops compared to irrigation with well water; it also increased the total N, P, K and organic carbon content of soil. On the other hand, the indiscriminate long term use of sewage effluent for crop production could result in the concentration that may become phytotoxic. The use of sewage water with physical treatment can increase water resources for irrigation which may prove to be beneficial for agricultural production in India (Singh et al. 2012). In Italy Cirelli et al. (2012) concluded that the microbiological quality of the products was generally maintained, although the E. coli content in wastewater irrigation was often over the standard. The experimental system used wastewater irrigation to grow tomatoes successfully under semi-arid conditions, resulting in a 20 % yield increase when compared to yields from crops using conventional water. Both partially improving water quality and reducing irrigation rate have been shown to have positive impacts on social and environmental concerns, without harming agricultural productivity for alfalfa in Mexico (Chavez et al. 2012).

Kalavrouziotis et al. examined the capacity of cultivated plant species to accumulate heavy metals, and indirectly evaluate the soil pollution level. The highest water use efficiency for wheat, obtained in the 75 % wastewater containing irrigation treatment under the fertilised condition and the raw wastewater-irrigated treatment under the non-fertilised condition in Bangladesh, demonstrated the most effective use of water in these treatments (Mojid et al. 2012). Keser and Buyuk (2012) indicated wastewater in Turkey was not suitable for irrigation of parsley, because it had negative effects on plant and caused heavy metal accumulation. Herbaceous crops irrigated with wastewater can produce appreciable biomass and energy yields. This is also an environmentally and economically sound way of wastewater disposal in Italy (Zema et al. 2012). de Oliveira Marinho et al. (2013) found in Brazil that the production of marketable rose stems was higher in the tests using nitrified and anaerobic effluent than those using either fertilised or unfertilised water. There was no significant difference between the use of treated effluents and topdressing for reduction in the mineral fertilisers spending. Keser (2013) showed that the use of wastewater for irrigation in Turkey increased heavy metal content in both *Lepidium sativum* L. and *Eruca sativa* (Mill.) and affected their physiological and morphological properties. Jang et al. (2013) found that the wastewater irrigation did not present significant environmental risks for the rice paddy agroecosystem, although long-term monitoring is needed to fully characterise its effects. In Morocco, Hirich et al. (2013) showed stomatal conductance and growth parameters were affected by deficit irrigation treatments rather than by organic matter amendment. Mojid and Wyseure (2013) reported that irrigation in Bangladesh using wastewater was proposed for improving soil fertility as well as for alleviating water scarcity with the exception of some crops whose edible parts came in direct contact with wastewater and/or were eaten uncooked.

18.2.4 Soil

In the field experiments in the U.S.A., calcium amendments may be useful in both increasing the tolerance of plants to sodic wastewater irrigation and increasing soil infiltration rates (Howe and Wagner 1996). The coliform count on the soil surface due to wastewater irrigation in Jordan decreased drastically with depth (Al-Nakshabandi et al. 1997). Shahalam et al. (1998) found in Jordan that wastewater irrigation applied for a season had no significant effect on a silty loam soil. Simulation of both ponded and sprinkler irrigation in Italy with municipal wastewater resulted in reduced infiltration and increased surface ponding compared to the application of fresh water (Viviani and Iovino 2004). It is worth noting that all the phenomena leading to the formation of a denser level of concentration of heavy metals with lower conductivity at the surface of soil profiles might in general also be ascribed to the mechanical effect of water, irrespective of the extent and type of TDS of the wastewater applied in Italy (Coppola et al. 2004).

Negative effects of heavy metals have not been felt up to now, and the rate of accumulation predicts some effects in 10–30 years of continuing practices of wastewater irrigation in Israel (Rebhun 2004). In Iran, Heidarpour et al. (2007) showed that the most important concern was the increase of EC in the top soil layer with subsurface irrigation with treated wastewater, as this might inhibit plant growth. In addition, wastewater irrigation significantly affected potassium, while phosphorus and total nitrogen were not significantly affected. Kiziloglu et al. (2007) found in Turkey that application of wastewater increased soil salinity, organic matter, exchangeable Na, K, Ca, Mg, plant-available P, and micro-elements and decreased soil pH. Wang et al. (2007) concluded that treated sewage irrigation in China had no significant effect on the loess soil, and no cases of illness resulting from contact with the treated sewage were reported. With treated sewage irrigation, a slight increase in the organic content of the soil was observed. Wastewater application in Italy resulted in increased microbial contamination (Escherichia coli 3000 MPN/100 mL; Faecal Streptococci 1200 MPN/100 mL) in the soil surface (Aiello et al. 2007). The rapid mineralisation of testosterone shows that this steroid is less persistent but due to its lower sorption in the solid phase may leach more readily into the soil profile during wastewater irrigation (Stumpe and Marschner 2007).

Kiziloglu et al. (2008) showed that the major disadvantage of wastewater irrigation in Turkey was the accumulation of immobile heavy metals in the soil. In the U.S.A., soils have experienced periods of local saturation and soil transport, which are reflected by the distribution of redoximorphic features and A-horizon thickness across the study area. Both organic matter content and soil pH have increased considerably (Walker and Lin 2008). In China, Chiou (2008) concluded that in terms of reuse impact in soil contamination, the most possible heavy metal caused accumulation was arsenic. Although heavy metals-containing wastewater irrigation ceased more than 10 years ago, the soil in the Zhangshi Wastewater Irrigation Area in China is still heavily polluted by Cd and to a lesser degree by Zn and Cu, in light of the China Environmental Quality Standards (Zhang et al. 2008). In Iran, Jalali et al.

(2008) determined that the average exchangeable sodium percentage (ESP) of soils increased during leaching from 9 to 21 and 28.8–29.7 after applying 5.0 and 3.5 L (about 7 and 6 pore volumes) of wastewater to the soils columns, respectively. Lado and Ben-Hur (2009) showed in Israel that leaching of loamy and clay soils with effluent that contained high concentrations of suspended solids led to a significant reduction in hydraulic conductivity, caused by trapping of more suspended solids in the large numbers of small pores in the soils. In Jordan, Al-Hamaiedeh and Bino (2010) concluded that soil leaching with fresh water was highly recommended, because it reduced the accumulation of salts and organic matter in the soil. The heavy metal indicates that their mobility and their adsorption will depend on the metallic contents of wastewater, organic carbon tenors, clay fraction and irrigation time in Tunisia (Klay et al. 2010).

Tarchouna et al. (2010) showed that despite the very sandy texture of irrigated (with treated wastewater) soils studied, both saturated and unsaturated hydraulic conductivity exhibited a significant diminution in the irrigated soil compared to the reference one in Mediterranean countries. In the U.S.A., Xu et al. (2010) argued that the increase of available soil profile heavy metals was not hazardous due to the leaching of metals, owing to the light soil texture and the low organic matter content of the plots studied. In regard to soil conditions, neither the soil nitrogen nor carbon was significantly impacted by wastewater irrigation (Hunt et al. 2011). Muyen et al. (2011) showed that irrigation can be a very attractive proposition, particularly for arid and semi-arid regions of Australia, if used with proper and adequate management plans in place but the degree of treatment particularly about N can be an important consideration. In Iran, Fluvaquentic Endoaquepts (a type of local plants) was highlighted to be a major contributor of the load and contamination rate of trace metals regarding geoaccumulation index, contamination factor, and degree of contamination (Rezapour and Samadi 2011). In another study in Israel, it appears that after each irrigation season, the potential activity of the microbial community returned to levels similar to or even slightly lower than those of freshwater-irrigated soil during the wet season, suggesting that the periodic irrigation did not significantly change the soil microbial activity (Elifantz et al. 2011). Morugan-Coronado et al. (2011) found in Mediterranean countries that electrical conductivity and sodium content of soil increased but no remarkable changes in soil organic carbon and microbial biomass carbon were seen due to the low organic carbon content of water used for irrigation.

In Mexico, soils irrigated with raw and wastewater treated showed an increase in the concentration of N, P, K, Fe, Zn, and Cu (Rojas-Valencia et al. 2011). In Iran, Rezapour et al. (2012) found with the exception of lower slope position, which indicated a remarkably increasing pattern of smectite (a type of clay minerals) in response to wastewater irrigation and unfavorable drainage condition, the relative abundance of clay minerals in view of the peak position and intensity followed almost the same pattern in both wastewater-irrigated and control landscape. Samia et al. (2012) noted that Cr, Cu, Al, Zn, and Cd mobility depended on the clay yield. However, the polycyclic aromatic hydrocarbons and Pb mobility are also related to humic substance quantities. In Tunisia, Cr and Cu have affinities both to clay and humic substance quantities.

Kayikcioglu (2012) detected a decrease in the microbial activities in soil, depending on irrigation with wastewater in Mediterranean countries. Adrover et al. (2012) claimed that after more than 20 years of treated wastewater irrigation, no negative changes have been observed in the evaluated soil properties of the Island of Mallorca in Spain, with the exception of an increase in the soil pH caused by greater sodium supply. In China, Shi et al. (2012) found that due to the spatial distribution of Fluoroquinolones (Fluoroquinolones are broad-spectrum antibiotics that play an important role in treatment of serious bacterial infections) in wastewater irrigation was a potential source of antibiotics. In the other research in China, Li et al. (2012) successfully applied two types of widely used wastewaters treated with fluidised-bed reactor (FBR) and biological aerated filter (BAF) processes. Laurenson et al. (2012) predicted in New Zealand that managing salt, in particular sodium and potassium, in wastewater would be necessary in order to maintain the soil physical, chemical and biological health in the long term. In Nigeria Egwu and Agbenin (2013) found that reports of excess Pb concentrations in leafy vegetables raised in soils were consistent with high free Pb^{2+} activities maintained in the soil solution by these predominantly sandy-textured soils. In Israel, Nadav et al. (2013) detected that the lowest degree of water repellency was consistently exhibited by the soil with the highest specific surface area irrigated with the highest quality wastewater. Gatica and Cytryn (2013) found that although recent studies seem to indicate that irrigation with wastewater did not significantly induce antibiotic resistance reservoirs in soil, the impact of the abovementioned factors was not yet clear in the context of mobile genes transfer between wastewater-associated bacteria and soil.

18.2.5 Environment

In Jordan, because the As-Samra stabilisation pond system receives wastewater irrigation more than twice the designed capacity in terms of biological and hydraulic loadings, the effluent contains high levels of organic matter in which coliforms and other heterotrophic bacteria could survive the sudden stress imposed by chlorine (Al-Nakshuhundi et al. 1997). Laposata and Dunson (2000) found that the wastewater effluent irrigation in the U.S.A. was not acutely toxic to terrestrial salamanders under natural conditions. Toze (2006) showed that the use of wastewater reduces the pressure on the environment by reducing the use of environmental waters but the presence of pathogens and chemical contaminants as well as salinity and impacts on soil structure are the factors that need to be considered. The study of wastewater irrigation in Israel supports the collaboration among economic entities and indicates economic and environmental advantages which can serve decision-makers (Axelrad and Feinerman 2009). McNeill et al. (2009) found in Palestine that the reuse of wastewater can improve environmental conditions and enhance agricultural activities. Rezapour et al. (2011) showed that in Iran although heavy metal levels were below the permitted range, it seems that proper management of wastewater irrigation along with periodic analysis of heavy metals and their bioavailability are required to guarantee ecosystem health. In Viet Nam Trinh et al. (2013) indicated that wastewater reuse in the agricultural sector had good potential as a climate change adaptation strategy. The authors showed that wastewater effluent can be used to irrigate at least to 22,719 ha of paddy rice (16 % of the rice-cultivated area in the city) at three crops per year. The fertilising properties of the water would eliminate part of the demand for synthetic fertilisers, providing a maximum of 22 % of the nitrogen (N) and 14 % of the phosphorus (P) requirement for the winter–spring crop. On a yearly basis, recovery of wastewater could reduce the discharge of N by 15–27 % and the discharge of P by 8–17 %.

18.2.6 Irrigation Equipment

Adin and Sacks (1991) showed that the clogging rate was more affected by particle size than by particle-number density in wastewater irrigation. There are differences between emitters of various manufacturers as to their sensitivity to clogging. This should be considered when choosing the emitters for the drip irrigation system, particularly for reclaimed water. The clogging hazard of an emitter with a higher discharge rate is smaller than that of a similar emitter with lower discharge rates. Clogging of the drip irrigation system was not a significant problem when treated wastewater was used for irrigation in Jordan, and was easily controlled with acid and chlorine (Al-Nakshabandi et al. 1997).

In a biochemical study in Italy, Capra and Scicolone (2007) found that the use of wastewater with a TSS greater than 50 mg/L did not permit optimal emission uniformity to be achieved. Correlations of biofilm biomass and discharge reduction after 360 h irrigation were computed that suggested that phospholipid fatty acids (PFLAs) provided the best correlation coefficient. Comparatively, in a physicochemical study in China the emitters with unsymmetrical dentate structure and shorter flow path (Emitter C) had the best anti-clogging capability (Yan et al. 2009). In an experimental study in China, chemical precipitation was found to be the primary source of emitter clogging for both the treated sewage effluent and freshwater treatments, which was mainly due to their relatively higher total dissolved solids and alkalinity. Flushing emitters and drip lines using freshwater did not efficiently alleviate emitter clogging caused by chemical precipitation (Liu and Huang 2009).

Treated wastewater reuse in agriculture is a common practice in the Mediterranean countries (particularly in Spain and Greece) and there is a considerable interest in the long-term effects of treated wastewater on crops intended for human consumption with minor disadvantages for irrigation equipment (Pedrero et al. 2010). The tested pressure compensating emitters are recommended over the non-pressure ones when applying the municipal tertiary effluent. Results recommended that an air/vacuum relief valve be used for subsurface drip irrigation to avoid ingestion of soil particles due to back siphoning. Flushing at a velocity of 0.6 m/s was adequate as found in Spain when it was performed monthly or only at the end of irrigation season (Puig-Bargues et al. 2010). In France, relations between biofilm development and velocity distribution on NPC flow paths were observed and the pipe diameter appeared to be a parameter inducing emitter clogging (Gamri et al. 2013).

18.2.7 Modern Technologies

Micro filtration filtrate (a new technology) water will not cause any clogging problem related to its EC, SAR, and ESP, as found in Kuwait (Al-Shammiri et al. 2005). Lopez et al. (2006) showed that the microbial quality of treated effluents in membrane filtration was higher than that of local well-water used for irrigation; after simplified treatment, in order to save the agronomic potential of organic matter and nutrients present in urban wastewater, olive trees were irrigated with effluents produced by skipping biological processes and this resulted in a yield increase of 50 % in storage reservoirs capacity; TSS, BOD_5, COD and nutrients concentrations achieved the in-force Italian limits for wastewater agricultural reuse, and in constructed wetlands the values of TSS, BOD_5, COD, total nitrogen (TN) and total phosphorus (TP) removals were 85 %, 65 %, 75 %, 42 % and 32 %, respectively. In Europe, Bixio et al. (2006) inferred that technological innovation and the establishment of a best practice framework would help, but even more, a change was needed in the underlying stakeholders' perception of the water cycle.

The combination of aerobic biological process with physical filtration and disinfection is considered to be the most economical and feasible solution for wastewater recycling (Li et al. 2009). Bdour et al. (2009) recommended the cyclical or a closed-loop treatment system to achieve ecological wastewater treatment. There are plenty of research needs to improve the methods of wastewater treatment in Mediterranean countries. In Italy, Liberti et al. (2002) showed some parasites such as 'Giardia lamblia cysts' and 'Cryptosporidium parvum oocysts' were both affected by ultra violet (UV) radiation and that potential UV-promoted formation of disinfection by-product (DBP) did not occur according to the liquid chromatograph/mass spectrometer (LC/MS) analytical evidence. Costs ranged from 17.5 to 35 euro/1000 m^3 for effluent clarified-filtered (F) and clarified (CL), respectively. The quality of the water produced in China and Italy by the Safir field treatment system (SAFIR FTS) and membrane biobooster (MBR) treatment (Battilani et al. 2010) fulfilled the irrigation water quality standards required by the most reliable international guidelines, only the most restrictive regulation as the Italian law for treated wastewater direct reuse in agriculture (D. Lgs. 152/06) was not always fulfilled. Nevertheless, the technologies developed and tested in SAFIR proved to be an effective barrier against those pollutants which can threaten food quality and safety. The MBR and FTS technologies allowed a safe direct and indirect water reuse. The correct application of these technologies could be considered as a "quality label" guaranteeing food safety, thus fulfilling quality standards worldwide required by the retailer's organisations (Battilani et al. 2010).

When the effluent of sand filters is fed into UV disinfection, 90 mWs/cm^2 will be adequate to reach the desired disinfection target, as in Turkey (Evcimen and Kerc 2011). Recently, new software have been designed to reduce risk of using wastewater (and assessment of other environmental aspects) in civil and energy projects. Solar and H_2O_2/solar disinfection processes can be thought of as a potential means for enhancing the microbial quality of wastewater effluents used for irrigation of edible crops (Bichai et al. 2013).

18.2.8 Management

Afshar and Marino (1989) indicated in the U.S.A. that a chance-constrained linear-programming model minimised the required capacity and provided information on the reliability of the system or its failure. The net cost to municipalities of wastewater treatment and disposal can be affected substantially by economically selecting optimal sets of cropping enterprises (Segarra et al. 1996). The soil biosystem was altered with the application of sewage effluent in Canada. Monitoring data from two large effluent irrigation projects in Saskatchewan have shown that the soil biosystem is altered with the application of sewage effluent. Effluent irrigation is sustainable provided proper management practices are followed (Hogg et al. 1997). Hussain and Al-Saati (1999) showed that the use of wastewater for irrigation had a special significance due to the scarce non-renewable water resources of Saudi Arabia as well as to the presence of an appreciable amount of crop nutrients.

Angelakis et al. (1999) observed the need for sharing a common rationale for developing wastewater reclamation and reuse standards on both sides of the Mediterranean countries. The study of wastewater irrigation in Israel showed the need for setting risk-based criteria for wastewater reclamation rather than single water quality guidelines (van Ginneken and Oron 2000). Ringler et al. (2000) showed that the only countries with wastewater reuse for irrigation in Latin America and Caribbean were Argentina, Barbados, Brazil, Guatemala, and Jamaica, which indicates insufficient attention to wastewater irrigation in these regions. Jaber and Mohsen (2001) deduced in Jordan that the availability of wastewater was more than water importation and less than desalinated water and water harvesting. In some cases the most viable approach is to acknowledge irrigation as a land-based treatment method, which requires sharing of costs and responsibilities between wastewater producers, government institutions and farmers in developing countries (Martijn and Redwood 2005).

In Northern Ireland cost savings in treatment plants are much more important than cost savings and higher yield in the short rotation willow coppice plantation (Rosenqvist and Dawson 2005). Jia et al. (2006) showed that in China irrigation scheduling and proper management were more important to water quality than remedial actions, such as controlled drainage or vegetative buffers. In Nepal, according to Rutkowski et al. (2007), the negative attitude of some farmers towards wastewater stemmed from their inability to control wastewater application leading to flooding and loss of crops. Selection of suitable sites, taking into account the local stratigraphy, geology and groundwater conditions, may help in improving the performance of the soil aquifer treatment process during wastewater irrigation, as in Kuwait (Akber et al. 2008).

Angelakis and Durham (2008) emphasised the establishment of guidelines for wastewater use in Europe. After a period featured by a few initiatives for increasing the availability of local water resources and the lack of clear regulations, regional authorities in Italy have, under the pressure of several factors, planned, at a regional scale, the reuse of wastewater treated mainly in the agricultural sector (Lopez and Vurro 2008). Wastewater supplementation could increase profits by $20 million annually; alternatively, wastewater replacement could conserve 35 Mm^3 of water in local rivers each year in China (Murray and Ray 2010). Scheierling et al. (2011) deduced that achieving safe wastewater irrigation required steady progress over several decades. In Europe, treatment requirements for restricted and unrestricted irrigation would be identical, that means treatment cost for unrestricted irrigation is lower and thus this treatment level is more probable to be feasible and practicable. In unrestricted irrigation the microbiological criteria of quality are less stringent than those in the WHO 1989 guidelines. In the WHO 2006 guidelines the 6–7 log unit pathogen reduction can be achieved by treatment to a lower quality (≤104 E. coli per 100 mL, as in the case of restricted irrigation), but moreover supplemented by post-treatment health-protection control measures, such as post-harvest pathogen die-off, produce washing, produce disinfection, etc. On the other hand, the health based target can be achieved for unrestricted irrigation by a 6–7 log unit pathogen reduction (obtained by a combination of wastewater treatment and other post-treatment health-protection measures), for restricted irrigation it is achieved by a 2–3 log unit pathogen reduction (Tassoula 2011). Agrafioti and Diamadopoulos (2012) showed water recycling could reserve 19.16 Mm^3 of fresh water, which corresponded to 4.3 % of total irrigation requirements in Greece. Molle et al. (2012) concluded that an economic approach along with risk assessment would avoid disproportionate costs of grain security. Integration of both farmer and scientific knowledge would strengthen long-term predictions of practical and realistic situations, demonstrating the added value participatory modelling provides in Australia (van Opstal et al. 2012). It is strongly believed that it is more important to evaluate all the necessary parameters regarding the wastewater reuse under the model used in Greece than making decisions based mainly on measurable criteria, such as the economic ones (Bakopoulou et al. 2012). Planned reuse that seeks to maintain the benefits and minimise risks will require an integrated approach. The key to the success of endeavors to make the transition to planned strategic reuse programmers is a coherent legal and institutional framework with formal mechanisms to coordinate the actions of multiple government authorities, sound application of the ‘polluter pays’ principle, conversion of farmers towards more appropriate practices for wastewater use, public awareness campaigns to establish social acceptability for reuse, and consistent government and civil society commitment over the long term with the realisation that there are no immediate solutions (Scott et al. 2004). Institutions and organisations at the level of village or neighborhood shape the ways in which wastewater is managed through members active in these organisations (Buechler 2004).

18.3 Summation and Conclusions

Studies show that using wastewater for irrigation is considerable from various aspects and we cannot adopt an optimum decision without a comprehensive review. Figure 18.8 shows a brief about various aspects of wastewater irrigation in the different regions. Most studies have been done in Mediterranean countries (44 %) and one can see considerable wastewater treated (Cyprus, Greece, Italy, Slovenia, Tunisia, Croatia, Egypt, Algeria, and Libya) and wastewater used (Israel, Syria, Turkey, Libya, Jordan, Malta, Morocco, Palestine, and Lebanon) in this region according to Figs. 18.5 and 18.7, respectively. Moreover, Fig. 18.6b–d shows that there is no population affected in this region (or the population affected is very low). The maximum percentage of the Mediterranean countries is because they are most in the number of water-stressed countries (Near East, Northern Africa, and Mediterranean Europe) (Fig. 18.1). The second place has been allocated to Asia (24 %) and one can see a considerable wastewater treated (Bahrain, Mongolia, China, Jordan, India, and Thailand) as well as both considerable wastewater used (Iran, Qatar, UAE, Oman, Kuwait, Turkmenistan, Saudi Arabia, China, Kazakhstan, and Bahrain) and minor wastewater used (Viet Nam, Uzbekistan, Yemen, Singapore, Korea, and Japan), as shown in Figs. 18.5 and 18.7, respectively. Therefore, the status of study, treatment, and use of wastewater for irrigation is highlighted in the Persian Gulf due to water crisis conditions (Figs. 18.1 and 18.2). Meanwhile, Fig. 18.6b–d shows 13 countries with population affected (Malaysia, Cambodia, India, Sri Lanka, Thailand, Uzbekistan, Armenia, Kazakhstan, Philippines, Indonesia, Kyrgyzstan, Turkmenistan, and Viet Nam) in Asia that no suitable research has been done there (Fig. 18.8). The third place belongs to Americas (19 %) and one can see considerable wastewater treated (Chile, Mexico, Peru, and Dominican Republic) versus poor wastewater used (Dominican, Nicaragua, Mexico, Guatemala, U.S.A., Brazil, Bolivia, Chile, and Peru), as shown in Figs. 18.5 and 18.7, respectively. Meanwhile, Fig. 18.6b, c shows eight countries with population affected (Colombia, Cuba, El Salvador, Guatemala, Nicaragua, Peru, Venezuela, and Ecuador) in Americas that no suitable research study has been done there (Fig. 18.8).

In Europe, Africa, and Oceania (10 % of studies), one can see considerable wastewater treated (Luxemburg, the U.K., Germany, France, Ireland, Austria, Netherlands, Belgium, Zimbabwe) versus poor wastewater treated (Bosnia and Herzegovina, Somalia, Ethiopia, Botswana, Congo, and Mozambique) and poor wastewater used (Australia, France, the U.K., Senegal, Latvia, Lithuania, South Africa, the Netherlands, and Seychelles). Meanwhile, Fig. 18.6b–d shows that one can see five countries with populations affected (Cote d'lvoire, Burkina Faso, Congo, Swaziland, and Mauritania) in Africa where no suitable research has been done (Fig. 18.8). Although a study of wastewater irrigation from crops, soil, groundwater, health, irrigation equipments, modern technologies, and other environmental aspects is useful, increased investigation (management studies) in comparison with other aspects can help lead to more reliable and more extensive findings and finally a better decision on using wastewater for irrigation. The cases mentioned emphasise

Fig. 18.8 Various aspects of wastewater irrigation in the different regions

the need for proper recognition of challenges and prospects of wastewater irrigation to design a brighter future for more attention to this issue. In the following, a list of major challenges and prospects is presented.

18.3.1 Challenges Under Normal Conditions

The type of irrigation method selected will depend on water supply conditions, climate, soil, crops to be grown, cost of irrigation method and the ability of the farmer to manage the system. However, when using wastewater as the source of irrigation other factors, such as contamination of plants and harvested product, farm workers, and the environment, and salinity and toxicity hazards, will need to be considered. There is considerable scope for reducing the undesirable effects of wastewater use in irrigation through selection of appropriate irrigation methods (FAO 1992). Toxicity symptoms can appear in almost any crop if concentrations of toxic materials are sufficiently high. Toxicity often accompanies or complicates salinity or infiltration, although it may appear even when salinity is not a problem (FAO 1992).

Comprehensive management approaches in the longer term will need to encompass treatment, regulation, farmer user groups, forward market linkages that ensure food and consumer safety, and effective public awareness campaigns (Scott et al. 2004). Clear policy guidelines on how to optimise the benefits and minimise the risks of untreated wastewater are lacking (van der Hoek 2004). Current government policies focus on the regulation of wastewater use and wastewater treatment and are unable to offer practical solutions to the user (van der Hoek 2004). For a complete understanding of issues related to wastewater use at a basin level, the macro-, meso- and micro-levels need to be studied from a multi-disciplinary perspective addressing socio-economic, health and technical issues (Buechler 2004). It is important to recognise that in many situations where wastewater is used in agriculture, the effective treatment of such wastewater may not be available for many years (Carr et al. 2004).

The annual risk of contracting infectious diseases, including typhoid fever, rotavirus infection, cholera and hepatitis from eating raw vegetables irrigated with untreated wastewater, is in the range of 5–15 % of consumers eating such vegetables who will develop disease compared to 0.0001 % of those eating vegetables irrigated with wastewater treated effluent that meets the WHO guideline of 1000 faecal coliforms (FC)/100 mL (Fattal et al. 2004). A standard leading to "no measurable excess risk" to health is an unattainable and unhelpful medium term goal under the conditions of indirect wastewater use seen in many cities (Cornish and Kielen 2004). Despite strong government support, treated wastewater use in irrigation has faced several constraints, chief among them being problems of social acceptance, agronomic considerations and sanitation, and restrictive regulations that have tended to limit its full potential for development (Shetty 2004).

The farmers at most locations realised the contribution of wastewater to fertiliser and its availability year round at low/no cost, and hence they irrigated field crops with this water. Farmers faced the problems of odd smell, skin infection, injury to hands and legs, and damage to water lifting pumps in some areas (Mojid et al. 2010). The farmers' perceptions do not necessarily reflect the quality of water delivered to the farm. The farmers' actual and perceived capacity to control water quality, and the farmers' ability to manage the negative aspects of the wastewater that jeopardise productive agriculture are important (Carr et al. 2011).

Comprehensive wastewater collection and large treatment facilities will not be financially viable in many developing countries for many years. Therefore, it makes sense to examine the inevitable trade-offs involving the cost and potential risk reduction effects of non-treatment options and strategies that involve multiple barriers (Wichelns and Drechsel 2011). Nutrient management, choice of crops, soil properties, irrigation methods, health risk regulation, land and water rights and public education are limitations to the use of wastewater irrigation (Hanjra et al. 2012; Hussain et al. 2001, 2002).

In many developing countries, wastewater treatment is limited, as investments in treatment facilities have not kept pace with persistent increase in population and the consequent increase in wastewater volume. Thus, much of the wastewater generated is not treated, and much of the untreated wastewater is used for irrigation by small-scale farmers with little ability to optimise the volume or quality of the wastewater they receive (Sato et al. 2013).

The totality of four main parameters considered important for the quality of irrigation water, i.e. salinity, pathogens, nutrients, heavy metals, are rarely taken into account simultaneously in the evaluation of reclamation technologies. In the majority of literature, the suitability of treated municipal wastewaters for irrigation purposes is mainly based on salinity and pathogen removal (Norton-Brandao et al. 2013). A few studies, making a complete evaluation of the suitability of produced effluent for irrigation, i.e., taking all four main parameters into account, include constructed wetlands and integrated systems, which include successive treatment steps using MBR, gravel filter, granulated ferric hydroxide adsorber for heavy metals and UV (Norton-Brandao et al. 2013).

18.3.2 Prospects

Success in using wastewater treated for crop production will largely depend on adopting appropriate strategies aimed at optimising crop yields and quality, maintaining soil productivity and safeguarding the environment (FAO 1992). In terms of health hazards, treated effluent with a high microbiological quality is necessary for irrigation of certain crops, especially vegetable crops eaten raw, but a lower quality is acceptable for other selected crops, where there is no exposure to the public (FAO 1992).

Developing realistic guidelines for using wastewater in agriculture involves the establishment of appropriate health-based targets prior to defining appropriate risk-management strategies. Establishing appropriate health-based targets primarily involves an assessment of risks associated with wastewater use in agriculture, using evidence from available studies of epidemiological and microbiological risks, and risk-assessment studies. Consideration of what is an acceptable or tolerable risk is then necessary; this may involve the use of internationally derived estimates of tolerable risk, but these need to be put into the context of actual disease rates in a population related to all the exposures that lead to that disease, including other water- and sanitation-related exposures together with food-related exposure. Positive health impacts resulting from increased food security, improved nutrition, and additional household income should also be considered. Individual countries may therefore set different health targets, based on their own contexts (Carr et al. 2004).

Informed debate, that enables risks associated with different water qualities and irrigation practice to be assessed, may lead to the development of local water quality norms and wastewater management that accounts for the physical and social environments in which wastewater irrigation is actually practiced (Cornish and Kielen 2004). Proper form of wastewater irrigation not only offers an important financial gain to the growers, it may also represent a low-cost and beneficial means of using and "treating" wastewater within acceptable and controllable levels of disease risk (Cornish and Kielen 2004). An integrated water management (IWM) approach is surely needed to improve the present situation in some of urban and peri-urban areas (Huibers et al. 2004).

With appropriate regulations and wastewater treatment technology a win–win approach to safely reuse wastewater in agriculture at an affordable cost may be possible (Jimenez 2005). Increased funding for wastewater treatment and the education of stakeholders can help water scarce countries use wastewater for irrigation (Qadir et al. 2007). The gaps in knowledge of the true extent of the often informal use of wastewater at a country level must be addressed by governments through comprehensive assessments, which will allow them to evaluate trade-offs and decide on the hot spots that need immediate attention (Raschid-Sally and Jayakody 2008).

The WHO (2006) guidelines for the safe use of wastewater should be extensively applied, as they allow for incremental and adaptive risk reduction in contrast to strict water quality thresholds. This is a cost-effective and realistic approach for reducing health and environmental risks in low income countries (Raschid-Sally and Jayakody 2008).

To improve the safety of irrigation water sources used for agriculture and enhance the direct use of wastewater, it is imperative to separate domestic and industrial discharges in cities, and improve the sewage and septage disposal methods by moving away from ineffective conventional systems (Raschid-Sally and Jayakody 2008).

In addressing health risks, on the one hand, state authorities have a role to play in planning, financing and maintaining sanitation and waste disposal infrastructure that is commensurate with their capacities and responds to agricultural reuse requirements. On the other hand, as a comprehensive treatment will remain unlikely in the near future, outsourcing water quality improvements and health risk reduction to the user level and supporting such initiatives through farm tenure security, economic incentives like easy access to credit for safer farming, and social marketing for improving farmer knowledge and responsibility can lead to reducing public health risks more effectively, while maintaining the benefits of urban and peri-urban agriculture (Raschid-Sally and Jayakody 2008).

Countries must address the need to develop policies and locally viable practices for safer wastewater use to maintain its benefits for food supply and livelihoods while reducing health and environmental risks (Raschid-Sally and Jayakody 2008). Multi-criteria decision analysis with weighted goal programming can develop flexible management options that consider a given decision-maker preference in water scarce countries (Al-Juaidi et al. 2010). A combination of biophysical science, social, economic and policy analysis, and good politics and governance are required in order to reduce the impacts of wastewater-related health risks in the most effective way and to obtain win–win solutions from the sanitation, water and food crises triangle (Scott et al. 2010).

The likelihood of truly enhancing the livelihoods of households involved in agriculture, while reducing risks of producing and consuming crops irrigated with wastewater, can be increased through participatory and comprehensive discussions of scientific, economic and policy issues that comprise this important and timely topic in developing countries (Wichelns et al. 2011). Since traditional wastewater treatment methods are not capable of fully removing recalcitrant xenobiotic compounds, advanced technologies must be applied, such as Advanced Oxidation Processes (AOPs) and membrane-separation technologies, which are effective in simultaneously removing, both pathogens and xenobiotics, and perhaps their combined application may constitute today the best option for wastewater treatment and reuse schemes. Applications of AOPs and disinfection methods to recalcitrant pollutants have in anyway expanded in recent years. It is true to say though that the oxidation of the parent compounds (pharmaceuticals and other organic xenobiotics) provides only a partial indication of the efficiency of various treatment methods, since the possible generation of intermediates, more resistant to degradation, and with the characteristics of exhibiting equal or more toxic effects than the parent compounds must be considered as well (Fatta-Kassinos et al. 2011).

Currently there are a number of knowledge gaps related to the potential effects that the wastewater reuse practices might induce. These are related both with the identification of the compounds present in the treated effluent organic matter, which is also related to the gaps of knowledge in regards to degradation mechanisms and transformation products. Moreover, the puzzle in regards to risks that relate to non-target organisms in the environment, to plant and crops uptake and finally the fate and behaviour of various compounds in mixtures is only now starting to shape. Furthermore, knowledge is greatly lacking on the possibilities of pharmaceutical residues reaching humans through biomagnification in the food chain. Risk assessment protocols for antibiotics and resistant bacteria in water systems, based on better systems for antibiotics detection and antibiotic resistance microbial source tracking are also starting to be discussed (Fatta-Kassinos et al. 2011).

In developing countries, wastewater is the only water source available for irrigation throughout the year, wastewater irrigation reduces the need for purchasing fertiliser, involves less energy cost, if the alternative clean water source is deep groundwater, and enables farmers in peri-urban areas to produce high-value vegetables for sale in local markets (Sato et al. 2013).

Irrigation with treated wastewater likely will expand in developed countries, particularly in arid and semi-arid areas, where competition for freshwater supplies will continue to increase. Technical solutions and public policies generally are adequate in developed countries to accommodate increases in the treatment and use of wastewater (Sato et al. 2013).

It is likely that the demand for wastewater as a source of irrigation will increase in arid and semi-arid areas of developing countries at a faster pace than the development of technical solutions and institutions that might ensure the safe distribution and management of wastewater. Thus, the key technical and policy questions in developing countries include those pertaining to better methods for handling untreated wastewater on farms and in farm communities, better recommendations regarding crops and cultural practices most suitable for settings in which wastewater is the primary source of irrigation, and better methods for protecting farm workers and consumers from the potentially harmful pathogens and chemicals in wastewater (Sato et al. 2013). Finally, water crisis and wastewater problem are manmade problems and they must solved by man himself.

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