Chapter 1

Natural Ecological Remediation and Reuse of Sewage Water in Agriculture and Its Effects on Plant Health

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Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.75455

Abstract

In rural and urban areas of most emergent countries, the application of sewerage and wastewater for irrigation is a regular practice. In these areas, polluted water is often the only supply of water for irrigation. The use of wastewater for crop growth is a centuries old practice that is getting renewed attention due to rising shortage of freshwater resources in many arid and semiarid regions of the globe. Wastewater is extensively used as an inexpensive substitute to conservative irrigation water, supporting livelihoods and generating significant value to the agriculture of urban and periurban areas in spite of the associated health and environmental risks. Water is becoming an increasingly limited resource in many dried and partially dried regions of the world due to which planners are being forced to think about other sources of water that might be used inexpensively and efficiently to encourage additional progress. It is concluded that sewage water is the richest source of micro- and macronutrients and this aims for the better growth of plants. However, sewage should be treated prior to its reuse for agriculture in order to reduce the risks of harmful effects on human and animal health.

Keywords: sewage water, developing countries, nutrients, chemical fertilizer

1. Introduction

In rural and urban areas of most emergent countries, the application of sewerage and wastewater for irrigation is a regular practice. In these areas, polluted water is often the only supply of water for irrigation. Yet small farmers often prefer wastewater where other water sources are also available because wastewater has high nutrient content which may reduce or even eliminate the need for other costly chemical fertilizers [1]. The use of wastewater for crop growth is a centuries old practice in many arid and semi-arid regions of the globe [2]. Farmers often have no alternative, so they depend on unprocessed wastewater as there is no wastewater collection and treatment and freshwater is either out of stock or too expensive [3, 4]. The uses of wastewater in agriculture create key risks to the health of the community due to chemical and microbial contaminants. Wastewater use can also produce ecological risks in terms of soil and groundwater contamination. Irrigation with wastewater can have a number of benefits and environmental applications if appropriately planned, implemented, and managed [5].

Many wastewater irrigators are generally landless people who are not land-owning farmers; they lease small plots to grow income-generating crops like vegetables that flourish when watered with nutrient-rich sewage [6]. Across Africa, Asia, and Latin America, the micro-economies of sewage water support a large number of low-income individuals. Stoppage or overregulation of these practices could take away the only income source of numerous landless people. However, in these countries, the sewage water is not processed before use for irrigation. Wastewater treatment is generally carried out in developed countries, where major investment on wastewater treatment has been made over the past 40–50 years in order to achieve high treatment levels. Most sewage water is treated in North America, usually up to secondary and, in numerous cases, up to tertiary levels [7]. The USA has made improvement as a result of a financial support program in which 56 billion USD were allocated to local governments from 1972 to 1989 to construct secondary management amenities, but they changed these grants by state revolving funds for loans to municipalities [8].

Sewage treatment (**Figure 1**) is regarded as vital in affluent countries in order to guard human health and avoid pollution of rivers and lakes, but for the majority of developing countries, this solution is too costly. Therefore, in case of developing countries, application of wastewater in agriculture is a more reasonable option and economically sound than uninhibited removal of industrial and municipal effluents addicted to lakes and streams [4]. The sewage flows to a downstream location that is hazardous due to which the population inside the streams and water sources are at risk. Such risks can be decreased or proscribed by wastewater treatment in a wastewater treatment plant consisting of physical, chemical, and biological processes [9]. Wastewater treatment may also produce sludge, which is also risky for health because it is a polluted by-product and requires secure managing and removal [10].

Use of sewage water for irrigation has many applications (**Figure 2**), including crop irrigation, aquaculture, irrigation of landscape, and fake groundwater recharge [11]. This is one of the longest and well-known traditions in most parts of the world. According to estimation, the total area under wastewater irrigation is about 20 million hectares throughout the world [12]. It has been found that the maximum number of crop plants viz. lettuce, mangoes, tomatoes, and coconut are irrigated with sewage water, and a large quantity of this water is unprocessed [12]. Sewage and industrial wastewater is commonly used to water farming fields in developing countries including Pakistan [13, 14]. Sewage irrigation has proven beneficial effects on plant health and soil quality in countries having low water resources

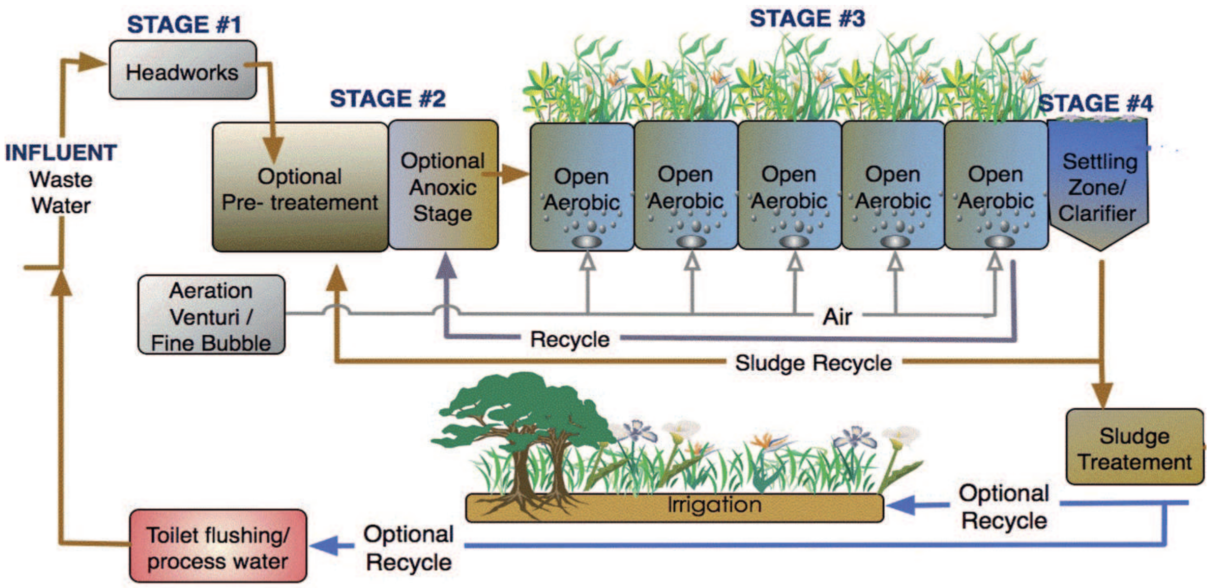

Figure 1. Ecological sewage treatment (http://ingienous.com/sectors/the-environment/eliminating-waste-and-inefficiency/sewage-treatment-via-bionutrient-recycling/).

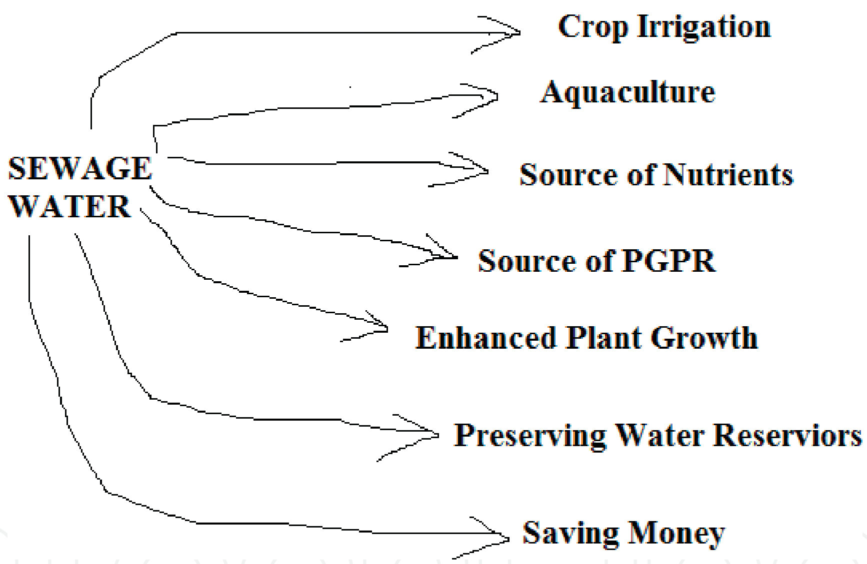

Figure 2. Impacts of sewage water irrigation on plants and freshwater reservoirs.

such as Mediterranean Basin and the Middle East, for instance, Bahrain, Cyprus, Kuwait, Malta, Israel, Qatar, Oman, Saudi Arabia, and the United Arab Emirates [15]. Numerous investigations have reported positive impacts of sewage irrigation on plants and soil properties. Wastewater can be used as an important plant nutrient source for soils with low fertility. Municipal wastewater could possibly be used for crop irrigation with negligible environmental concerns if it does not contain excessive heavy metals. Use of wastewater for irrigation purposes can decrease the necessity for fertilizers [16]. For these reasons, both treated and untreated wastewaters have been used for irrigation worldwide. Earlier studies, carried out in areas irrigated with wastewater over a long period of time, have confirmed improved soil biological activity and nutrient cycling as a result of the resulting input of easily degradable organic material and nutrients [4].

The application of wastewater to cropland and forests is a smart option for disposal because it can improve the physical properties and nutrient content in soils. Wastewater can often contain substantial concentrations of organic and inorganic nutrients, for example, nitrogen and phosphate, which are crucial for crop growth. One possible advantage is that the soil microorganisms have been observed to have increased metabolic activity when a sewage effluent is reused in irrigation [17]. Castro et al. [18] reported that dry and fresh weight, average height, and diameter were significantly higher in treated wastewater-irrigated plants. The highest values were observed in the second crop season. El-Nahhal et al. [18] investigated the effects of sewage water on the growth of Chinese cabbage and found that the sewage water was effective in supplying the necessary nutrients required for the normal growth of plants and noted higher biomass in plants irrigated with wastewater as compared to fresh water. Castro et al. [19] reported significant increase in fresh and dry weights, average height, and diameter of *Lactuca sativa* irrigated with sewage water when compared to control. Alghobar et al. [20] reported improved chemical properties and fertility status of soils irrigated with sewage water. They also found enhanced growth in grass crop after irrigation with sewage water.

Safary and Hajrasoliha [21] carried out experiments on plants irrigated with sewage water and noted that after 7 years of irrigation with sewage significantly enhanced carbon, nitrogen, and phosphorus contents and decreased soil salinity and sodicity. Rattan et al. [22] reported the beneficial effects of sewage effluents when applied to cereals, vegetables, and fodder crops. Singh et al. [23] used sewage water for irrigation of several crop plants including wheat, gram, palak, methi, and berseem. They recorded improvement in physiochemical properties of soil, nutrient stats of soil, and yield of crops as compared to plants irrigated with normal groundwater. Wang et al. [24] also noted that long-term irrigation with sewage water significantly enhanced soil micro- and macronutrient content that in turn enhanced plant growth. Recently, Khan and Bano [25] reported the beneficial effects of sewage irrigation on the total chlorophyll and carotenoids content of maize plant. They also recorded increased nutrient content in plants and soil.

To fully understand the vital issue of wastewater reuse with regard to benefits and mitigate the risks, this chapter was aimed at determining the effects of sewage on the growth parameters of plants and to review the natural ecological and engineered approaches for the treatment of sewage water before its application to irrigation. Regulations of wastewater reuse in different countries are also reviewed and discussed.

2. Natural ecological and engineered sewage treatment

Sewage treatment (**Figures 3** and **4**) is the process of eradicating microorganism, heavy metal, and other types of contaminants from wastewater. The practice of wastewater treatment varies

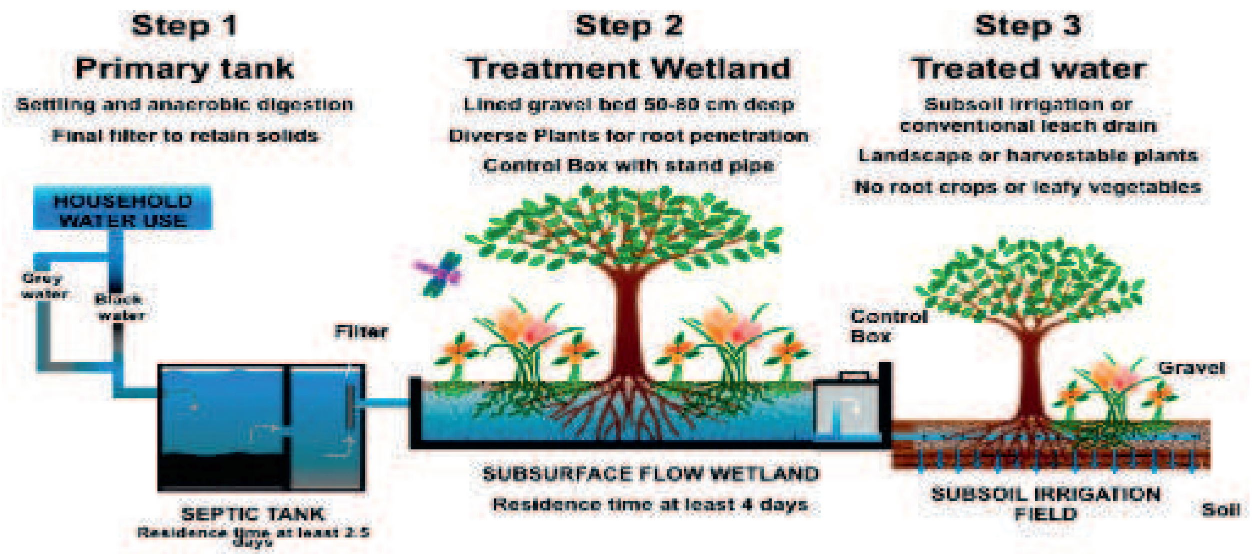

Figure 3. Biological treatment of wastewater for reuse in agriculture. (http://saleemindia.blogspot.com/2017/01/constructed-wetlands-for-sewage.html).

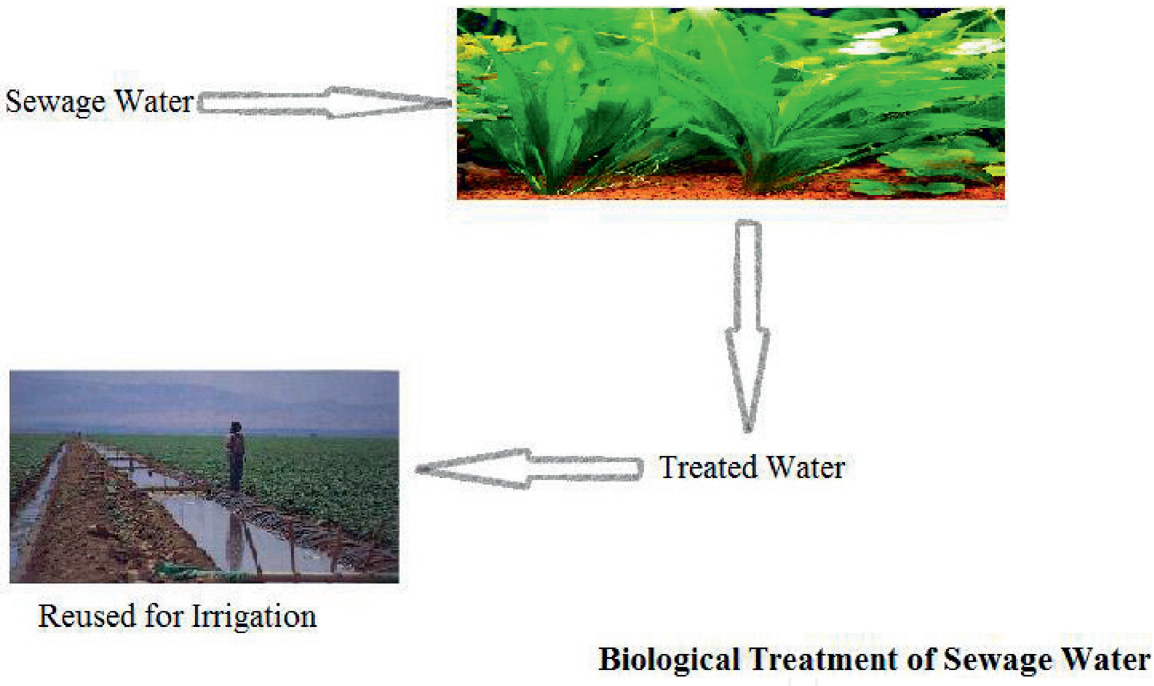

Figure 4. Reuse of sewage water for irrigation after treatment.

from one region to another across the world. In developed countries, a centralized aerobic wastewater treatment, consisting of plants, has been carried out for both industrial and domestic wastewater. Sewage treatment using natural ecological approach has been carried out throughout the world because certain terrestrial and aquatic plants have the ability to accrue large quantities of certain metals in their shoots [26]. The use of wetland and aquatic plants, such as water velvet and duckweed for the removal of contaminants from the sewage water, is considered the most effective method for the removal of heavy metals.

Zayed et al. [27] tested the potential of duckweed for the removal of Cd, Cr, Cu, Ni, Pb, and Se and found that duckweed was a good accumulator of Cd, Se, and Cu. Zhu et al. [28] reported the dominant role of water hyacinth in the sewage treatment as this plant possesses a very good fibrous root system and a large biomass. They found that the water hyacinth was excellent in accumulation of organic and inorganic nutrients and trace elements including Cd, Pb, and Ag. Dos Santos and Lenzi [29] carried out experiments with aquatic *Eiochhornia crassipes* and found it useful for the removal of Pb from contaminated water. Wang et al. [30] investigated the role of five different wetland species including duckweed, sharp dock, water hyacinth, calamus, and water dropwort for their possible use in treating the polluted waters. They reported that water hyacinth and duckweed were good accumulators of Cd, water dropwort accumulated Hg, calamus was the best for the accumulation of Pb, while sharp dock was a good accumulator of N and P. Li et al. [31] conducted hydroponic experiment in order to investigate the role of three hydrophytes, that is, *Gladiolus*, *Isoetes taiwanensis and Echinodorus amazonicus* for the accumulation of Cd from contaminated water. They found that the *Gladiolus* was the best Cd accumulator as compared to other two plants. Lone et al. [32] examined the efficacy of Cu elimination from the contaminated water by *Elsholtzia argyi* and *Elsholtzia splendens* in hydroponics. The results show that *Elsholtzia argyi* showed better Cu phytofiltration than *Elsholtzia splendens*, which was associated with better ability to absorb higher Cu concentrations and translocation to shoots. Tangahu et al. [33] investigated the role of different wetland plant species for the treatment of sewage water. They found that most of the wetland species were capable for accumulation of N, P, Cd, Pb, and Hg.

Among the ferns, *Pteris vitta* has been identified as hyperaccumulator of As-contaminated soils and waters. It can accumulate up to 7500 mg of As/kg on a contaminated site without showing toxicity symptoms [34]. Trees have been recommended as a low-cost and ecologically sound solution for the remediation of heavy metals from sewage water. This ability of the trees is due to their large biomass, which can absorb large quantities of contaminants present in wastewater [35]. Plants remove contaminants from sewage water by one of the following methods:

Phytoextraction: Plants remove heavy metals and other pollutants from the water and soil as well as groundwater and concentrate them into their harvestable parts [36]. These plants accumulate contaminants from the water in above-ground shoot.

Phytodegradation: In phytodegradation process, the pollutants present in contaminated water are degraded by plants and associated microbes [37]. Plant roots in conjunction with their rhizospheric microorganisms are utilized to remediate soils irrigated with sewage water.

Phytostabilization: In this case, the availability and mobility of pollutants present in sewage are reduced by plants, thus reducing the risk of leaching of pollutants into groundwater [38].

Phytovolatilization: Plants volatilize pollutants present in sewage water. Plants extract volatile pollutants added in the soil due to irrigation with sewage water and volatilize them from the foliage [39].

http://dx.doi.org/10.5772/intechopen.75455

Rhizofiltration: It is the removal of pollutants from the contaminated waters by accumulation into plant biomass. Several aquatic species including sharp dock, duckweed, and so on, have been identified and tested for the phytoremediation of heavy metals from the polluted water [40].

Besides these natural ecological treatments, other engineered approaches are also widely carried out worldwide for wastewater treatment to remove pathogen and other harmful substances. These include".

Oxidation Ponds: Oxidation ponds are used for reducing the biochemical oxygen demand (BOD) of wastewater. This is a very effective and simple technology, which consists of a ring-shaped channel equipped with mechanical aeration devices. The wastewater is screened and aerated through these devices which circulates at 0.25–0.35 ms^{-1} [41].

Anaerobic Ponds: It is a biological treatment of wastewater in which naturally occurring bacteria are utilized for breaking the biodegradable compounds present in wastewater. These bacteria under anaerobic condition may remove high concentrations of BOD and chemical oxygen demand (COD). The presence of anaerobic bacteria in these ponds break the organic matter present in the effluents and thus release methane and CO_2 whereby sludge is deposited at the bottom, while crust is formed on the surface [42].

Aerobic Ponds: In aerobic treatment of wastewater, bacteria and algae are used that maintain aerobic condition throughout its depth. The aerobic ponds may be shallow or aerated [43].

Trickling Filter: This technique is used to remove or reduce pathogen and level of nitrogen in the wastewater as pathogens present in wastewater may cause serious threats to humans mostly in developing countries of the world. This trickling filter is composed of some porous material like rocks, sledge, or plastic medium having large surface area and permeability. The microorganism in the wastewater gets attached with the filter media [44].

Activated Sludge System: This is a biological wastewater treatment, which is mainly used for the removal of biodegradable compounds and pathogens present in wastewater. Its efficiency depends on retention time, temperature, pH, and the presence of other biological flora present in wastewater [43, 45].

3. Regulations in the use of sewage water

The World Health Organization (WHO), the US Environmental Protection Agency (USEPA), and the World Bank have reviewed the public health aspects concerning the use of sewage water for crop irrigation and prepared recommendations for the microbiological quality of treated wastewater used for this purpose. The limit of microorganism in sewage water used for irrigation of crop plants should not be more than 1000 fecal/100 ml of bacteria [46]. Similarly, the amount of other harmful substances in sewage water should be under minimal range. Rules and regulations in the use of sewage water vary from state to state and from country to country. In Pakistan, there is no national policy for the reuse of sewage water for crop irrigation. Furthermore, the industries do not follow the government guidelines, and there are also no government economic incentives for these industries. In Pakistan, the sewage water is used straightaway for agricultural purpose without any purification treatment. Only Islamabad and Karachi treat a minor portion (10%) of sewage water before disposal. All the effluents are discharged in Kabul River from various industries in Khyber Pakhtunkhwa (KPK) province [47]. In Lahore, a major city of Punjab province, only three industries have wastewater treatment plants. In some regions of the country, laws and regulations have been developed for the treatment of wastewater prior to use in irrigation, but their enforcement in reality is an issue due to the absence of resources and experience.

Problems in the disposition of wastewater tend to stem from distortions due to economy-wide policies, miscarriage of directed environmental policies, and failure of institution. Inefficient water pricing worsens the problem in urban areas, where water is provided free of charge, a policy that encourages the use of wastewater for irrigation. Similarly, environmental committees have been established, but their ability to deal with specified cases is very limited due to deficiency of staff [48].

In the USA, standards are set for the reuse of wastewater in agriculture. These standards vary from state to state. In California, strictest standards have been developed for **the reuse of wastewater** [49]. California, with the lengthiest history about the regulating of reclaimed wastewater in agriculture, which only permits high-quality effluents to be used on crops. Similarly, Arizona, Florida, Hawaii, and Texas have also active water reuse programs. These states developed comprehensive, numerical water quality criteria for different water uses, including crop irrigation. Florida usually has the limits of the reuse of reclaimed water for irrigation of crop plants that are skinned and cooked before consumption [50]. **Billions of dollars are being spent on recycling of wastewater and reused in large quantities in different countries of the world (Figures 5** and **6).**

There have been no reports of contagious disease linked with agricultural reuse projects, and current criteria are considered to be acceptable in most states of the USA. Most states differentiate between produce from crops that are commercially treated or cooked before consumption, and need more strict water quality levels for produce crops. Yet, states differ in the manner in which wastewater irrigation can be implemented.

Microbiological standards for the harmless reuse of wastewater for irrigation in Latin America are varied as, for example, Brazil has no legislation. Argentina has a general reuse water law, which aimed to prevent surface water contamination which did not mention wastewater specifically [51]. Chile, introduced guidelines for the discharge of domestic and industrial effluents into rivers, lakes, and the sea; however, use of wastewater for irrigation has not been included in the legislation. Peru established roles for the reuse of wastewater after primary and secondary treatments; however, it has not established any bacterial nor nematode treatment. The Saudi Standards for effluents are strict and inadvertently enforce needless limitations on disposal and reuse of wastewater, which prevent its application for irrigation [52]. Some countries of the world have developed standards for wastewater reuse that only permit the controlled reuse of wastewater for irrigation of crop plants. Many of these are based on the WHO guidelines, including Mexico, France, Spain and Andalusia Province. Microbiological standards for wastewater reuse in agriculture have been established in Mexico over the last

Figure 5. Expenditures on recycling and reuse technologies used for wastewater treatments (https://recycling.conferenceseries.com/).

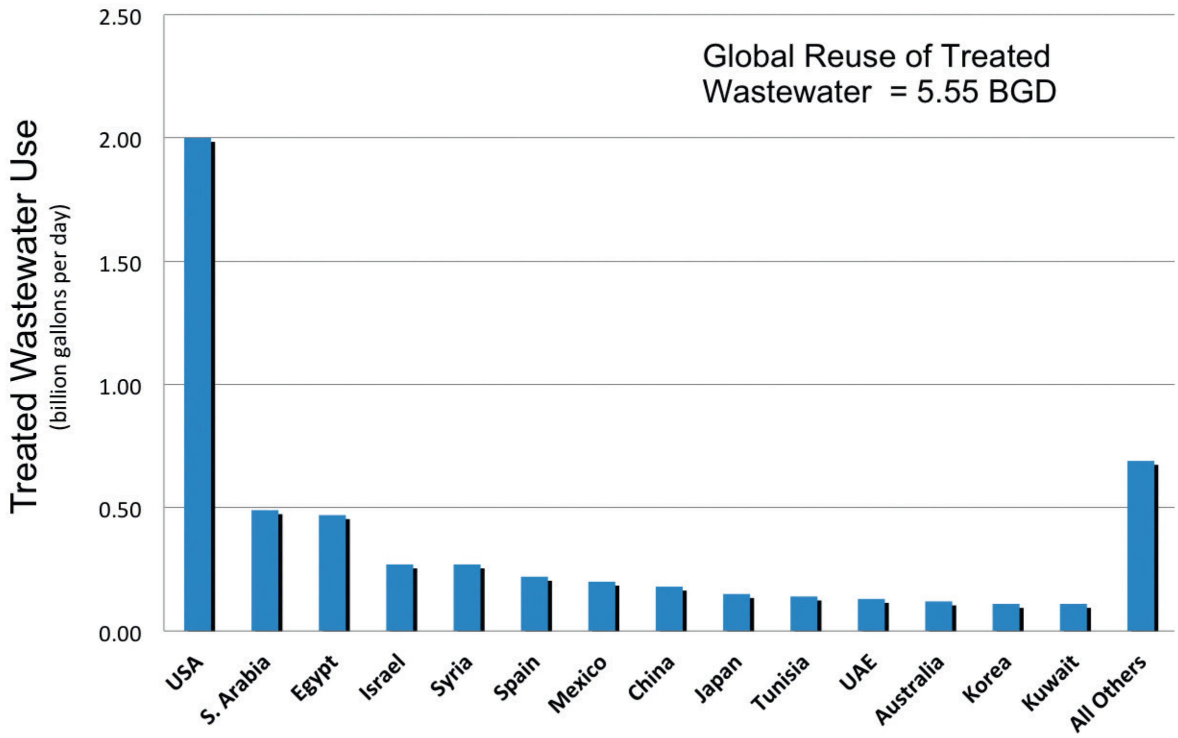

Figure 6. Reuse of wastewater per day in different countries of the world (http://nas-sites.org/waterreuse).

20 years. In France, the Ministry of Health delivered a provisional regulation on the reuse of wastewater for irrigation. The WHO guidelines for the reuse of wastewater for agriculture and aquacultural purposes had been published in 1989, which suggest different guidelines for different water qualities dependent on the endpoint of discharge [53].

3.1. Challenging issues

The most challenging issue with the use of sewage water for irrigation is the infection of farmers and consumers exposed to wastewater. Besides this, the presence of organic and inorganic elements may also have human health risks. Farmers and their relatives using sewage water are exposed to health risks from parasitic worms, protozoa, viruses, and bacteria. Some farmers cannot treat some of the health problems caused by pathogenic microorganisms due to weak economic conditions. Generally, farmers irrigating with wastewater have higher rates of helminth infections and, in addition, skin and nail problems may happen to farmers using wastewater [54]. Women are most vulnerable to these infections and mostly important target group. In several countries of the world, women offer much of the labor essential to produce vegetables and perform most of the weeding and transplanting that can expose them to long periods of contact with wastewater. Women usually cook meals, making chance for transferring pathogens to the family members if good hygiene is not sustained. In West Africa, where vegetables are produced in most of the countries, women dominate the marketing process, particularly retail, of most vegetables; thus, the main target group for risk reduction measures in markets [55]. Post-harvest infection in markets can be a vital issue disturbing public health, but the implication differs, which makes it an often ignored issue in the wastewater discussion [56].

Wastewater risks may be short or long term, depending on the resistance of humans and animals, while, in some cases, the impacts lies for a long period of time, especially in persons that continuously use wastewater. Beside human risks, continuous use of wastewater for irrigation results in soil salinity and sodicity. On the other hand, the presence of trace elements such as heavy metals, which are harmful for human health, can be found in sewage water effluents. The presence of microbial pollution becomes more severe with vegetables as many of them are consumed raw [57].

4. Water quality improvements

Preliminary improvements in water quality can be attained in several developing countries by at least primary treatment of sewage water, mainly where sewage water is used for irrigation. Secondary treatment can be applied at reasonable cost in some areas, using methods such as infiltration-percolation, constructed wetlands, waste-stabilization ponds and up-flow anaerobic sludge blanket reactors [58]. It is vital to aim at standards, which can be attained in the local context. WHO guidelines provide complementary alternatives for wastewater treatment and control of human exposure. Storage of reclaimed water in reservoirs develops microbiological quality and provides peak-equalization capacity, which surges the consistency of supply and increases the rate of reuse [59, 60].

5. Conclusion

Use of sewage water for irrigation not only improves the growth rate of plants but also reduces the cost of chemical fertilizers. The application of wastewater to cropland and forests is a

http://dx.doi.org/10.5772/intechopen.75455

smart option for disposal because it can improve the physical properties and nutrient content in soils. However, the practice of sewage water pre-treatment is uncommon in most developing countries of the world due to which several health issues may occur. Sewage water should be treated prior to its reuse for agriculture in order to reduce the risks of harmful effects on human and animal health. One of the viable solutions for developing countries seems to be the use of natural ecological approaches.

Conflict of interest

The author declares no conflict of interest.

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