Potential of Wastewater Disposal Through Tree Plantations

R.K. Yadav, P.S. Minhas, Khajanchi-Lal, and J.C. Dagar

Abstract

The adverse effects of irrigation with treated and untreated wastewater include health risks due to pathogens, salts, nutrients, and toxic elements that contaminate the food chain and the environment. However, the areas especially those afflicted by water scarcity can afford for recycling and reuse of wastewater in tree plantations as an effective and sustainable strategy. This is associated with high water, nutrient, and pollutant (metal) assimilation capacity of tree plantations. In woody species, wood, bark, and roots form important sinks for biologically available metals. Since these tissues are slow to enter the decomposition cycle, accumulated metals remain immobilized for considerably longer periods. Urban plantations and green areas along with nonedible crops like aromatic grasses and floriculture crops further offer many economic, social, recreational, and biodiversity conservation benefits. Nevertheless, as a caution, it is stated that the deep-rooted perennials have the ability, but are not guaranteed, to profligate wastewater disposal under all the soil and climatic conditions. Therefore, the regulatory mechanisms must be evoked to control loading rates for safe disposal of wastewater and protection of groundwater from being contaminated.

Introduction

Increasing supplies of water to meet the expanding demand of nonagricultural sectors are resulting in generation of huge volumes of wastewater in commensuration with rapidly increasing population, urbanization, improved living standards, and changing dietary habits. In most of the countries, urban drainage and disposal systems are common and the wastewaters consist of effluents from residential, institutional, commercial and

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industrial establishments and urban runoff water arising from rains or storms. These contain a variety of contaminants that require suitable treatment before use in agriculture. After appropriate treatment, wastewater can be recycled for irrigation of crops and aquaculture, landscape, urban and industrial uses, recreational and environmental uses, and artificial groundwater recharge, but irrigation continues to be the most prevalent practice. About 20 million hectares of agricultural land are irrigated with treated and untreated wastewater throughout the world (Raschid-Sally and Jayakody 2008). Since most of the low- to middle-income developing countries do not have sufficient resources to treat wastewaters, raw or diluted wastewaters are mainly used for irrigation of crops or disposed either in surface water bodies or on land. Despite substantial benefits of wastewater use in agriculture through supplementing nutrients and water resources and supporting the livelihood of millions of smallholder farmers, use of untreated wastewater directly or polluted water from rivers and streams poses potential risks of pathogen and toxic chemical contamination of crops and to the public health and environment in the form of soil and groundwater pollution (Minhas and Samra 2004; Drechsel and Evans 2010; Drechsel et al. 2010).

As an alternative, irrigation of tree species grown for fuel and timber with wastewater is another approach, which can help in overcoming health hazards associated with sewage farming (Braatz and Kandiah 1998; Thawale et al. 2006). Developing and enlivening the green belts around the cities with forest trees under wastewater irrigation can further revive the ecological balance and improve environmental quality by self-treatment of wastewater through land application and forest irrigation. Tree plantations are often expected to use water at higher rates than the shorter vegetation. This is because of greater aerodynamic roughness of tree plantations, clothesline effect in tree rows, and deeper rooting system for accessing water down to several meters of soil. Thus, the systems of agroforestry, which have come to be known as HRTS (high-rate transpiration systems), are the land application systems based upon the transpiration capacity of tree species that promote the treatment of wastewater through the renovating capability of a living soil filter enabling recycling and reuse of wastewater and conservation of nutrient energy into biomass and thereby bringing multiple benefits to society such as fuel wood, environmental sanitation and eco-restoration. However, to ensure optimal plantation growth and environmental protection, loading rates of wastewater and its constituents should match the water and nutrient requirements of proposed plantations. Keeping above in view, some of the interventions for minimizing the adverse effects of wastewater irrigation, especially for the safer disposal of wastewater in urban plantations and landscapes for greening urban areas, have been discussed here.

Management Interventions for Risk Reduction Using Wastewater

The risks of using untreated or partially treated wastewater in agriculture can be reduced through wastewater treatment and nontreatment options or a combination of both (WHO 2006). These include the following:

Water Quality Improvements

The first and foremost step for improvement in wastewater quality is primary treatment. This is simply a sedimentation process in which organic and inorganic solids are allowed to settle and then removed. The process reduces the biological oxygen demand (BOD) by 25–50 %, the total suspended solids by 50–70 %, and the oil and grease contents by 55–65 %. Some organic nitrogen, phosphorus, and heavy metals are also removed. Primary-treated effluents may be of acceptable quality for irrigation (Ayers and Westcot 1985) of trees, orchards, vineyards, fodder crops, and some processed food crops.

Secondary treatment can be implemented using methods such as waste-stabilization ponds, constructed wetlands, infiltration–percolation, and upflow anaerobic sludge blanket reactors (Mara 2003). Storing reclaimed water in reservoirs improves microbiological quality and provides peak-equalization capacity, which increases the reliability of supply and improves the rate of reuse (Qadir et al. 2010). Constructed wetlands also serve as habitat for wildlife and anthropogenic wastewater discharge and treatment and stabilize other related ecological disturbances. Aquatic plants such as *Typha latifolia*, *Phragmites karka*, *Eichhornia crassipes*, *Salvinia molesta, Pistia stratiotes*, *Scirpus tabernaemontani*, *Colocasia esculenta*, and *Azolla filiculoides* established in wetlands can also be used for paper pulp. The wetland acts as a biofilter, removing sediments and pollutants such as heavy metals from the water. Groundwater recharge with deep percolation through soil aquifer treatment (SAT) can remove microorganisms, provided that soil properties are appropriate and the process is properly managed (Asano and Cotruvo 2004).

Human Exposure Control

Protective measures such as wearing of gloves, boots, and mask, washing hands properly, and changing irrigation methods can reduce farmers' exposure. The sprinklers should not be used for irrigation. Public awareness campaigns are also important in minimizing the transmittance of diseases through wastewater use.

Phytoremediation

Phytoremediation is an emerging technology using selected plants to clean up the contaminated environment from hazardous contaminants to improve the environment quality. Heavy metals (HMs), the most potential contaminants in wastewater, cannot be degraded biologically but only transformed from one oxidation state to another or form organic complexes. Among the 300 accessions of 30 plant species, *Brassica* (*juncea, napus, rapa*) exhibited moderately enhanced Zn and Cd accumulation (Ebbs et al. 1997). The fern *Pteris vittata* was capable of accumulation of As to the extent of only 0.7 mg g^{-1} dry weight of plant, and aquatic *Azolla caroliniana* and terrestrial *Populus nigra* could accumulate 0.2 mg As g^{-1} dry weight of plant root (Tangahu et al. 2011). Some species have shown hyperaccumulation of different metals such as *Brassica campestris, B. carinata*, *B. juncea*, and *B. nigra* >100 mg Pb g^{-1} dry weight and *B. napus*, *B. oleracea*, and *Helianthus annuus* >50 mg Pb g^{-1} dry weight and *B. juncea* >1 mg Hg g^{-1} dry weight but with every chance of food chain contamination. However, if cultivated for fuel wood, trees as component of agroforestry can serve the purpose of phytoremediation. Similarly, Lal et al. (2008) observed that cut flowers such as marigold (*Tagetes erecta*), chrysanthemum (*C. indicum*), and gladiolus (*Gladiolus grandiflorus*) have shown promise in Cd-contaminated environment while *Jasmine sambac*, *Jasmine grandiflorum*, and *Polianthes tuberosa* are the other ornamental and cut flower species suitable for urban greening and avenue culture with wastewater irrigation (Augustine 2002). Lal et al. (2013) observed that lemon grass (*Cymbopogon flexuosus*) could be successfully grown using primary-treated municipal wastewater for achieving higher productivity without contamination of the end product – the essential oil. Lemon grass could also accumulate heavy metals such as Cd, Cr, Ni, and Pb from wastewater used for irrigation containing these metals acting as phytoremedial agent.

More than 400 plant species have been identified as metal hyper-accumulators (Reeves 2003; Lone et al. 2008; Table 1) which include either high-biomass plants such as willow (*Salix* spp.)

Table 1 Number of plant species that are reported to have hyper-accumulation traits (metal concentration >1000 mg kg^{-1} dry weight)

Metal	Number of species	Metal	Number of species
As	04	Pb	14
Cd	01	Se	20
Co	34	Zn	04
Cu	34	Hg	01
Ni	>320		

Source: Reeves (2003), Lone et al. (2008), and Tangahu et al. (2011)

or those that have low biomass but high hyperaccumulating characteristics such as species of *Thlaspi* and *Arabidopsis*.

Farm-Level Wastewater Management

Improved wastewater irrigation management at farm level includes suitable practices such as crop selection, irrigation management, and other soil-based interventions. Such interventions can reduce potential health and environmental risks to only some extent. However, global surveys indicate that three-fifth of diluted or untreated wastewater is used for raising vegetables and cereals (Raschid-Sally and Jayakody 2007). Thus, there are always chances of food chain contamination as many of the vegetables are consumed raw and also contain metals beyond the permissible levels. A safer alternative could be the production of urban forestry, agroforestry, and avenue and roadside plantations grown for fuel and timber and also the other crops where the economic component is nonedible and thus do not come directly in the food chain.

When choosing irrigation methods, farmers should consider the quality of water supply to manage use-associated potential health and environmental implications due to pathogenic and metal contamination of crops. Furrow irrigation, especially subsurface drippers, provides higher health protection to farmers and consumers as compared to flooding (Minhas and Samra 2004). An additional possibility is the cessation of irrigation, prior to harvest, to allow pathogens' natural die-off.

Soil-based interventions without the production of edible plants are important, particularly in the case when wastewater is contaminated with heavy metals, which usually accumulate in surface soil layers. For moderate levels of metals and metalloids in wastewater, there is no particular management needed if the soils are calcareous; however, there can be a problem in acidic soils, which require lime treatment, and when irrigating with wastewater containing elevated levels of sodium, soil structure deterioration may occur and we require application of a calcium source such as gypsum (Qadir et al. 2010). Care has also to be taken regarding detrimental effects of salts, nitrates, metals, and pathogens reaching groundwater; the shallower the water table, the more the danger.

Harvest and Post-harvest Interventions

These interventions involve the process of harvest, post-harvest cleaning, and handling during transport, marketing, storage, and preparation in kitchens. Minhas et al. (2006) gave details of these processes and also suggested to harvest cereal and fodder crops above a certain height from the ground to minimize pathogens. They also advocated the introduction of low-cost and relatively safer practices such as washing and post-harvest handling methods to reduce the pathogenic load of wastewater-irrigated crops.

Urban Plantations for Wastewater Disposal

Use of wastewater for irrigation is an age-old practice; however, large-scale controlled irrigation in established sewage farms for disposal and prevention of pollution in surface water bodies dates back to only the last century. Although crops were raised on these farms, the crop productivity was a secondary consideration. The El-Gabal El-Asfar sewage farm (Egypt) was established in 1911 covering 200 ha of tree plantations to dispose Cairo City's untreated wastewater and was expanded to 1260 ha in the mid-1980s with conversion of forests to *Citrus* along with the production of cereals and vegetables (Braatz and Kandiah 1998). Pioneering work on the application of treated municipal wastewater on forest lands as a means of purification and groundwater recharge was carried out in Central Pennsylvania, USA, during 1963 to 1977 (FAO 1978). Effluent irrigation on tree plantations in Victoria, Australia, commenced in 1973 (Myers et al. 1996). These provide the benchmark potential productivity of wastewater-irrigated 14-year-old *Eucalyptus grandis* and *E. saligna* in terms of mean annual increment (MAI) in wood volume of 41 and 31 $m^3ha^{-1}year^{-1}$ (Baker 1998; Duncan et al. 1998). Wastewater-irrigated 4-year-old *E. globulus* plantations at 1333 and 2667 stems ha^{-1} stocking density also produced annual volume growth and MAI of 126 and 91 m^3 ha^{-1} and 27 and 36 m^3 ha^{-1}, respectively, while the corresponding MAI values for *E. grandis* were 19 and 26 m^3 ha^{-1}. Hopmans et al. (1990) also observed MAI of 33 $m^3ha^{-1}year^{-1}$ for *E. saligna* at 1500 stems ha^{-1} and 31 m^3ha^{-1} for *E. grandis*. This indicates that short-rotation coppicing of these two species can serve as a suitable option for wastewater disposal (Boardman 1996).

Untreated sewage was used to irrigate *Acacia salicina*, *Eucalyptus camaldulensis*, and *Tamarix aphylla* (Armitage 1985); mixed hardwood stand consisting mainly of oaks (*Quercus* spp.), red pine (*Pinus resinosa*), and white spruce (*Picea glauca*) (Braatz 1996) in Australia; and *neem* (*Azadirachta indica*) and date palm (*Phoenix dactylifera*) in UAE forestry plantations for urban greening. In Murray–Darling Basin (Australia), area under wastewater-irrigated tree plantations increased from 500 to 1500 ha in > 60 variable-size effluent sites (CSIRO 1995). Most of these studies were aimed on handling the disposal of wastewater problem, however, to utilize the nutrient potential of wastewater; economic gains are also considered in recent plantations. For example, in Egypt, Omran et al. (1998) observed better growth of orange trees; increase in water and nutrient availability through effluent application influenced the growth of trees such as *Pinus radiata* (Sheriff et al. 1986), *Eucalyptus grandis* (Stewart et al. 1990), *Populus deltoides*, *E. tereticornis*, *Leucaena leucocephala* (Das and Kaul 1992), *Casuarina glauca*, *E. camaldulensis, Tamarix aphylla* (El-Lakany 1995), *Hardwickia binata* (Paliwal et al. 1998), *Acacia nilotica* trees (Singh and Bhati 2004), *Dalbergia sissoo* (Singh and Bhati 2005), olive tree *Olea europaea* (Aghabarati et al. 2008), *Casuarina equisetifolia* (Kumar and Reddy 2010), *Pinus eldarica* (Tabari et al. 2011), and *E. tereticornis* (Minhas et al. 2015). The availability of sufficient quantity of nutrition in wastewater induced luxuriant growth of the most of these plantations. Tabari et al. (2011) observed in afforested *Pinus eldarica* (15-year-old) stands that trees showed better growth in the field irrigated using municipal water than in plots irrigated with well water, as indicated by the increased diameter at breast height (DBH), basal area, and standing volume of trees in wastewater-irrigated fields (Table 2).

Table 2 Growth parameters of 15-year-old *Pinus eldarica* when irrigated with wastewater and well water

Irrigation type	DBH (cm)	Height (m)	Basal area (cm^2)	Standing volume (m^3)
Wastewater	17.95	10.04	264.2	0.139
Well water	13.50	9.02	135.0	0.65

Source: Tabari et al. (2011)
DBH diameter at breast height

Selecting Appropriate Tree Plantations

Selection of plantation species for urban agroforestry or greening with beneficial use of wastewater will depend on the prevailing environmental conditions for which they are planned. However, after due consideration of given local climate and soils and wastewater quality and quantity, the following important traits should be considered in species selection:

- Fast growth, although it is relative to the quality of the wood or other products produced. Generally, fast growth is suitable for pulpwood and materials for panel products but not for sawn wood products because of the often lower density of fast-grown wood. Some species (e.g., *Populus* and *Eucalyptus*) that traditionally have been grown fast in plantations can be managed for saw wood by lengthening rotations, aggressive thinning, and early pruning. However, for wastewater use, urban tree species should have the following characteristics:

- Tolerance to soil conditions, i.e., reaction, salinity, metal load, and excess water.
- Tolerance to climatic conditions like temperatures, insolation, and wind conditions.
- Ease of propagation, including a reliable seed supply if seedlings are used.
- Evergreeness; this allows the plantation to utilize higher quantities of wastewater.

In Egypt, substantial volumes of wastewater generated in cities and villages are used in forest plantations (MSEA 2006). Zalesny et al. (2015) recommended some plantation species, based on their suitability, growth potential, use, and economic value, for wastewater irrigation. These include pine (*Pinus* spp.), eucalyptus (*Eucalyptus* spp.), and poplar (*Populus* spp.) for pulpwood or sawn wood, mahogany (*Khaya ivorensis*) and teak (*Tectona grandis*) for high-value products, and beech wood (*Gmelina arborea*) for only pulpwood. *Salix* has an excellent capacity to take up metals such as cadmium and cesium (Cs-137) from the soil and could be used for environmental protection. Cesium and potassium have been found to compete in the metabolism of the plant, and thus uptake of cesium could be increased by reducing potassium fertilization. Salt tolerance will also be an important criterion for potentially saline effluent disposal on urban sites and environments, while water use is the main consideration in controlling groundwater pollution. Information on salt tolerance of different plantation crops is available in chapters "Global Perspectives on Agroforestry for the Management of Salt-affected Soils and Agroforestry to Rehabilitate the Indian Coastal Saline Areas" of this book. *Eucalyptus* species are generally considered to be effective for wastewater utilization purposes. *Eucalyptus camaldulensis* is a hardy tree that grows under a wide range of climatic conditions and soil types has been found quite successful. Some provenances of the species even tolerate saline water and soil conditions quite well. *Acacia nilotica*, *Dalbergia sissoo*, and *Tecomella undulata, Populus*, and *Tamarix* are other species that have performed quite well in plantations under excess soil moisture conditions (Bhutta and Chaudhry 2000). In addition to considerations of quantity and composition of wastewaters, economic benefits accruing from urban plantations is another major factors that decides the choice of plantation species.

There are many species of trees adapted to urban and suburban growing conditions, such as *Leucaena leucocephala*, that provide high-quality fodder for livestock. Similarly, a large percentage of urban dwellers, especially the poor, use firewood as their primary cooking and heating fuel and depend on nearby green areas for their source of wood. Urban greening can provide sustainable fuel wood plantings to meet the needs of these urban residents. Fruits, nuts, and fiber are some of the other forest products that could be harvested from wastewater-irrigated urban and suburban plantations and green areas. Most trees that provide these products are found in private lots and gardens. Generally, the ornamental value is the main consideration of selecting suitable horticultural plantation species for greening public urban areas as these are less subject to damage and theft.

In the peri-urban areas of Hubli in Karnataka state of India, all farmers bordering the wastewater *nalla* (small channel) engage in less water-requiring wastewater-irrigated agroforestry plantations on their private properties which reduces exposure to wastewater. In some areas, the main wastewater-irrigated agroforestry land uses are orchards and agrisilviculture which consists of spatially mixed tree–crop combinations. The two important tree species are sapota (*Achras zapota*) and guava (*Psidium guajava*) and other common species are coconut, mango, areca nut, and teak. Species grown on farm boundaries included neem (*Azadirachta indica*), tamarind (*Tamarindus indica*), *Eucalyptus* spp., poplar (*Populus deltoides*), *Acacia* spp., coconut (*Cocos nucifera*), and teak (*Tectona grandis*). About 20–25 % yield advantage has been observed from wastewater irrigation in comparison to tube well water-irrigated fields (Bradford et al. 2003).

Regulating Wastewater Use Disposal in Urban Plantations

Wastewater-irrigated urban forestry/agroforestry plantations have been recognized as a strategy to use urban wastewater, while also rehabilitating and greening wastelands. The availability of permanent streams of wastewater has enabled urban farmers to diversify their cropping practices. Spatial distribution of plantations, flowers, or agroforestry systems results from a combination of availability and composition of wastewater, labor, soil type, area, and its landscape within urban or peri-urban areas. As such, present scenario of wastewater use in close urban and peri-urban areas of developing countries includes adoption of a year-round intensive vegetable system. Further away from the cities, less intensive farming systems are practiced, without consideration of adverse effects of wastewater irrigation. However, the wastewater still offers advantages in terms of early-season irrigation and increasing growth and production from green plantations, flower crops, and fruit trees in agroforestry systems.

Plants such as *Eucalyptus*, poplar (*Populus* spp.), pine (*Pinus* spp.), bamboo (*Bambusa arundinacea*), acacia (*Acacia mangium*), neem (*Azadirachta indica*), and Indian rose wood (*Dalbergia sissoo*) which have high-rate transpiration system (HRTS) can be effectively utilized as safer alternative for beneficial disposal of wastewater. Such plants can transpire higher quantum of wastewater than the potential evapotranspiration possible from the site soil matrix alone. The higher wastewater use in plantations is due to the combination of deeper rooting, extended growing seasons, and higher inputs of radiant energy because of lower albedos as compared to herbaceous covers or crop lands. Khanzada et al. (1998) monitored the water use of *Acacia nilotica*, *A. ampliceps*, and *Prosopis pallida* on 3–5-year-old plantation sites with contrasting soil and water quality conditions in the Indus Valley in Pakistan. *A. nilotica* used the maximum water, which varied from 1248 to 2225 mm depending upon plantation growth conditions. Under tropical semiarid conditions of Northwest India, Minhas et al. (2015) monitored the transpiration rates of wastewater-irrigated *Eucalyptus* plantations to range between 418–473, 1373–1417, and 1567–1628 mm during 7–10 years of planting under low (163), recommended (517), and high (1963 stems per ha) stocking density (per ha), respectively (Fig. 1). When compared to reference evapotranspiration computed using the Penman method (ETref), the sap flow for recommended density varied between 0.87–1.23 × ETref with an average 1.03 × ETref. Similarly, at Wagga Wagga, Myers et al. (1996) observed that *P. radiata* and *Eucalyptus grandis* attained comparable water use and *Eucalyptus* at closed canopy had the maximum daily water use rate of < 8 mm d^{-1} and varied between 0.84–0.93 × Epan (open pan evaporation). Thus, overall water use by trees varies with specific site conditions defining soil type, evaporative demands, and even the depth to groundwater and its salinity (details in chapter "Use of Tree Plantations in Water Table Drawdown and Combating Soil Salinity"). Under favorable conditions (sandy and deep soils, shallow water table of good quality, cooler climate), trees may draw soil water at about 0.8 × Epan, but these may reduce to about 0.2 × Epan under less optimal conditions (clayey and shallow soils, saline/deeper water table, hot and dry summer, etc.). Nevertheless, their major advantage in wastewater use can be viewed in terms of year-round water with drawls unless being deciduous. Also the exact amount of nutrients taken up by *Eucalyptus* depends upon climate and plantation vigor (Rockwood et al. 1996, 2004). To avoid the groundwater contamination, due to wastewater use in plantations, the wastewater application should be regulated as per the evapotranspiration and nutrient use potential of the site plantations. Nutrients present in the wastewater should be used by the plants and partly retained in the soil matrix without affecting the soil ecosystem.

Heavy Metal Recycling Potential

To tackle the limitations of conventional wastewater treatment systems and avoid food chain

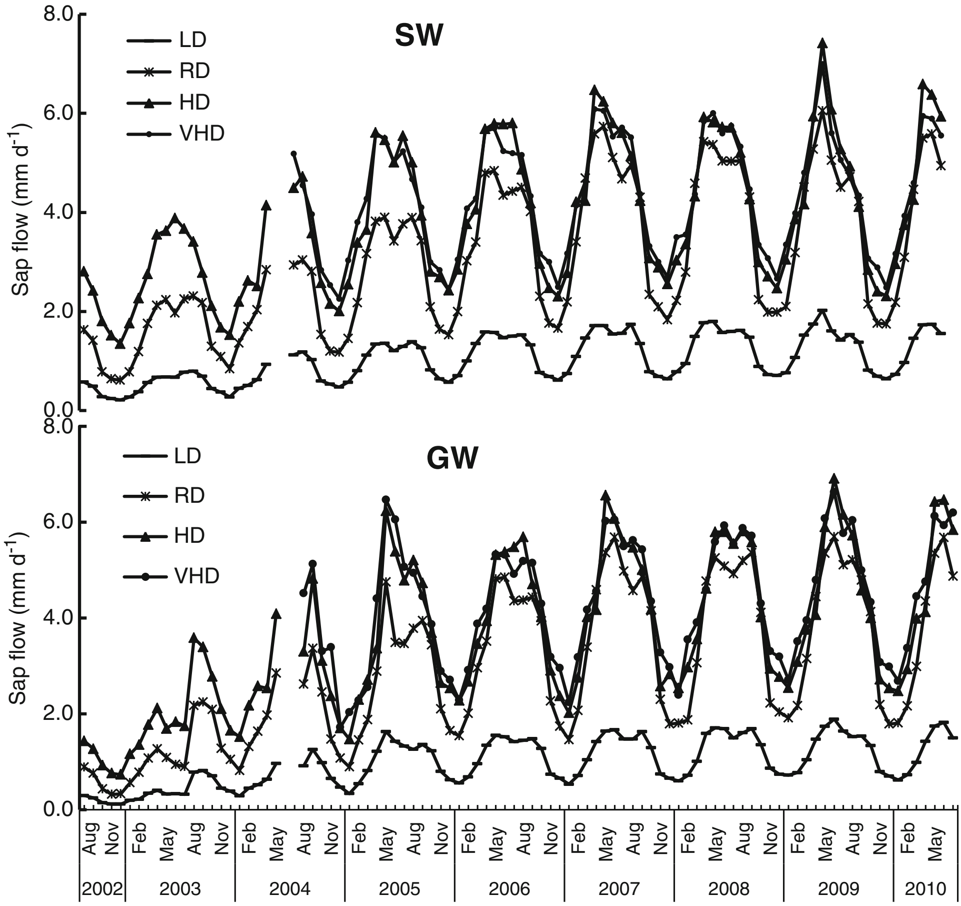

Fig. 1 Monthly average of mean daily sap-flow values per hectare (mm d^{-1}) for groundwater-irrigated (GW) and sewage water-irrigated (SW) *Eucalyptus* plantations (LD, RD, HD, and VHD denote low (163), recommended (517), high (1993), and very high density (3520 stems ha^{-1})) (Source: Minhas et al. 2015)

contamination due to use in agriculture, alternative low-cost, eco-friendly methods need to be evolved for safer disposal and desired level of treatment. Phytoremediation, a cost-effective "green" technology, mainly relies on nutrients, salts, and metal-accumulating plants to remove polluting metals from soil or water (Salt et al. 1998; Reeves 2003; Lone et al. 2008). A list of about 400 terrestrial plants species, having 100–1000 times more accumulation potential for one or more heavy metals (HMs) than those normally accumulated by plants grown under the same conditions, has been prepared by Hooda (2007). In comparison to food arable crops, wastewater irrigation in plantations is a relatively safer, cost-efficient, and environmentally sound way to treat and dispose wastewater (Armitage 1985). On wastewater-irrigated soils, *Acacia nilotica*, *Dalbergia sissoo*, and *Acacia modesta* accumulated relatively higher HMs than several bushes and grass species. HM concentrations in these species varied as per the composition of wastewater in the order of Fe > Zn > Cr > Pb > Ni > Cd > As. All the species exhibited higher HM composition in the root as compared to shoot (Irshad et al. 2015). Though there is lack of reports on symptoms of HM toxicities in tree species, it indicates their tolerance mechanisms to withstand higher HM concentrations than agricultural crops (Riddell-Black 1993, 1994). It has been observed that even those trees which are not selected for metal tolerance generally survive in metal-contaminated soil but with reduced growth rate (Dickinson et al. 1992). Beneficial effects of organic load in wastewater and sludge on tree growth processes have been found to far outweigh any adverse impacts of the added metals. Prolonged sewage irrigation markedly increased the amount of Fe, Zn, Mn, Cu, Pb, and Ni in the leaves and fruits of *Citrus* and olive without adversely affecting their growth and accumulation of metals beyond the safe limits in fruits (Khalil 1990; Maurer et al. 1995; Aghabarati et al. 2008). Therefore, use of low-strength wastewater did not pose any threat to *Citrus* and olive trees and consumers from heavy metal accumulation. Batarseh et al. (2011) found the accumulation being independent of the heavy metal concentration in the wastewater, suggesting a selective uptake of the metals by the olive plants. Also the trend of heavy metal transfer from soil to olive fruits and leaves was almost the same, showing a consistency of transfer. Dinelli and Lombini (1996) observed that metal concentrations were generally higher in the early vegetative growth stage, due to a relatively high nutrient uptake compared to growth rate. This was followed by a period of vigorous growth, which diluted the concentrations until the flowering stage, in which the minimum values for almost all elements were obtained. Several tree species grown on sludge-amended spoil had the highest concentrations of Cd, Cu, Ni, and Zn in root tissues. Wood and bark are important sinks for biologically available metals, with additional sink tissue being formed each growing season. These tissues are slow to enter the decomposition cycle; accumulated metals can, therefore, be immobilized in a metabolically inactive compartment for a considerable period of time (Lepp 1996). Massive root systems of trees upon establishment bind the soil thus promoting soil stabilization. Moreover, addition of litter to the surface quickly leads to an organic cover over the contaminated soil. In addition, transpiration by the trees reduces downward and lateral flow of water in the soil and thus reduces the amounts of heavy metals transferred to groundwater and surface water. Deep-rooting plants could reduce the highly toxic Cr(VI) to Cr(III), which is much less soluble and, therefore, less bioavailable (James 2001). It could be because organic products of root metabolism, or resulting from the accumulation of organic matter, could act as reducing agents (Pulford and Watson 2003). Proper management of municipal effluent irrigation and periodic monitoring of soil and plant quality parameters are required to ensure successful, safe, long-term municipal effluent irrigation.

Wastewater Treatment and Nutrient Removal

A major concern with wastewater irrigation is the fate of excess from plantation sequestration potential of nitrogen (N) and phosphorus (P) in the environment as these cause pollution of surface water and groundwater (Duncan et al. 1998). While P will not usually be a problem in short to medium term, particularly on soils with high P adsorption capacity, there is always potential risk for leaching of N (as nitrate) to groundwater. Fast-growing trees initially accumulate significant amounts of N, but the net N requirement declines after canopy closure stage of plantation when recycling sets in via decomposition of litter and internal translocation. Therefore, removal of N and other nutrients by plantation can be maximized by growing trees in short rotations. However, short rotations (<6 years) may compromise water use and also limit the potential products to biomass for fuel rather than higher-value wood. Across *Eucalyptus* species, aboveground elemental uptake (mainly N, P, K) by coppiced or original trees generally increase in proportion to biomass accumulation with > half of N being in foliage. Duncan et al. (1998) observed that under high-N-strength (15 mg L^{-1}) wastewater irrigation, maximum amount of N was sequestered in the potentially harvestable biomass of 3-year short rotations; while longer rotations (12 years) could achieve a similar balance of inputs through assimilation of N equivalent to supply from only lower-strength (5 mg L^{-1}) effluents. Another serious issue associated with wastewater irrigation is the management of metallic pollution. The tree species for urban greening should be selected on the basis of nature of elements present in wastewater to be used. *Acacia, Mimosa, Anadenanthera*, and *Salix* are efficient in absorbing Cd; *Eucalyptus* and mangroves are efficient in Pb accumulation; *Genipa americana* is efficient in Cr absorption; and *Salix viminalis* can remove up to 20 % Cd and 5 % Zn.

Sewage treatment plants are established in large cities only, and as such, there are no or a very few wastewater treatment facilities available in small and medium urban settlements of most of third-world countries. Apparently for these areas, decentralized natural treatment systems such as urban plantations with green areas and constructed wetlands could prove to be cost-effective and environment-friendly as an alternative wastewater treatment. Urban plantations in combination with the constructed wetlands (CWL) remove higher nitrogen (66–73 %) and phosphate (23–48 %) compared to un-vegetated wetlands (Juwarkar et al. 1995). Similarly, treatment performance and removal efficiencies of various types of CWL for BOD, TSS, and nutrients (total P and total N and NH_4-N) was compiled by Vymazal (2010). Under sewage irrigation and compost mulch application, *Eucalyptus* biomass yields were found to increase more than twice in comparison to those of *Populus* after 3 years of growth at Orlando (USA), revealing better performance of *Eucalyptus* both in terms of environmental and economic implications. Rockwood et al. (2004) observed that, under sewage irrigation, *Eucalyptus* can reduce N and P leaching by 75 %. Relative concentrations of N, P, and K in *Eucalyptus* plant tissues were reported to be in order of foliage > stem bark > branches > stem wood. HRTS plantations could remove N by 60–76.2 %, whereas the removal of phosphate was comparatively less than nitrogen and it ranged from 17.7 to 70.3 %. N removal efficiency of *Casuarina equisitifolia* was more as compared with *Dendrocalamus strictus*. In addition to N removal, these plantations also reduced wastewater biological oxygen demand (BOD) with removal efficiency ranging from 80.0 to 94.3 % (Thawale et al. 2006). Urban greening in the form of agroforestry system plantations has many advantages, which include sink potential for water and air pollutants, aesthetics, and biomass generation for energy.

Wastewater Treatment with Urban Plantations

The ponds, rivers, and wetlands with plantations as part of natural treatment of wastewater also serve for recreation, wildlife habitat, aesthetics, and educational use. Wetlands, one of the most biologically diverse ecosystems and a resource for tertiary wastewater treatment, increase habitats for flora and fauna in and along the waterways. The biological functions and physical aeration occurring in the wastewater during the passage of wastewater in the waterways remove many of the toxic effluents from the wastewater (ICLEI 1995). These plantations with wetlands in urban park systems are the low-cost wastewater treatment facilities for low-income cities. There are several alternatives to wastewater treatment and disposal that can be incorporated in green areas. As such wastewater can be used to irrigate urban and suburban agriculture and forests, horticultural projects (flowers for export), city landscaping and parks, and tree farms. All of these options provide for a safe and productive means of wastewater disposal (Braatz 1993). This reuse of wastewater not only recharges the aquifer but also reduces the demand on scarce freshwater resources. Controlled recycling wastewater into urban plantations and green park areas or forested, farmed and degraded lands may also be more economical than finding ways to dispose of it somewhere else.

Benefits of Wastewater Irrigation in Urban Plantations

The potential benefits of wastewater irrigation in tree plantations include relatively safer and low-cost treatment and disposal; augmenting nutrient and water supplies; environmental services such as climate improvement, soil enrichment, biodiversity improvement, and carbon sequestration, hence mitigating climate change; and livelihood security through various products such as timber, fuel wood, food, and employment. Some of these benefits are discussed here in brief.

Safe, Low-cost Treatment and Disposal

The cost of conventional methods of treatment of entire wastewater will be very high, prohibitively so for most developing countries. As a result, these countries depend on other forms of relatively cheaper disposal and treatment options. Among these, use in urban tree plantations and greening areas can be one such alternative. However, long-term sustainability of wastewater irrigation in tree plantations also depends on site-specific soil, climate, species, application techniques, and sociopolitical environment. There should be balance between wastewater disposal rates and evapotranspiration and nutrient-/pollutant-carrying capacity of the plantations grown at the site. Controlled application of wastewater in forestry plantations at 2.5 cm per week effectively filtered out excess N, P, and other constituents and made it acceptable for crop production and even drinking. Availability of nutrients from wastewater also improved tree growth by 80 to 186 % (Braatz and Kandiah 1998). In many cases, wastewater when passed through created wetlands was purified enough for irrigation of arable crops and agroforestry. Thus, low-strength municipal wastewater can be recycled through urban forestry plantation ecosystems with the benefits of increasing tree growth, restoring the water quality, and recharging groundwater reserves.

Livelihood Source

Wastewater use in urban forestry plantations supports livelihoods of urban poor in many parts of the world. It is a common reality in urban and peri-urban areas of more than three-fourth of the cities of developing nations in Asia, Africa, and Latin America. The majority of urban poor in these cities have an urgent need for improvement in quality of life with employment opportunities, provision of shelter, potable water, and recreation. In these regions, care should be taken to design urban plantations and green areas to supplement these needs and improved quality of life. An important aspect of urban greening is the jobs for poor, skilled and unskilled, laborers. Urban greening projects are often labor intensive and provide both initial jobs, such as soil preparation, planting, etc., as well as more permanent employment in the form of maintenance and management of plantations and green areas. Project managers of forestry components of an urban greening program in Mexico City have estimated that the program needed 3380, 3700, 800, and 100 workers to produce and transport plants, for working in the plantations, for management, and for protection and surveillance, respectively, in existing green areas (IDB 1992). In addition to basic amenities, urban green space also satisfies diverse basic human needs as food, fuel, and shelter from trees and shrubs, because tree products, if sold, provide direct cash benefits and, if used within the household, they provide indirect cash benefits by freeing cash income for other uses. Trees themselves can improve existing savings/investments, secure tenure, or increase property value. As such, urban greening has many indirect benefits in terms of conservation of land and environment, controlling floods and erosion, saving energy, and providing habitat for wildlife in addition to recreation and health and other material benefits. However, in this chapter, our main focus remains on more safer and beneficial use of wastewater through plantations and urban green areas.

Urban plantations can provide significant material benefits in areas where poles, firewood, and fodder are in high demand. Tree species that produce poles for fence posts are highly valued, especially in arid regions where low-cost fencing materials are scarce. Poles are also used in construction, furniture making, and crafts. There are many species of trees adapted to urban and suburban growing conditions, such as *Leucaena leucocephala*, that provide high-quality fodder for livestock. Similarly, a large percentage of urban dwellers, especially the poor, use firewood as their primary cooking and heating fuel and depend on nearby green areas for their source of wood. Urban green park areas developed using wastewater can provide sustainable fuel wood plantings to meet the needs of these urban residents. Most trees that provide fruits, nuts, and fiber can be grown in private gardens.

Environmental Benefits

Urban plantations and green areas provide some direct and other indirect benefits related to improvement in quality of life. In addition to direct benefits such as fuel wood, food, fodder, and poles, these improve air, water, and land resources and provide also a safer outlet for disposal of urban wastes which help in the improvement of health, recreation, environmental education, aesthetics, and enhancement of landscape, especially for the urban poor. Plantations also help in controlling erosion, urban water supplies, and habitats for wildlife. Depending on management objectives of urban plantations, the focus is quite different in developed cities and relatively poorer urban dwellings; however, multipurpose urban plantations are beneficial in all conditions. Urban plantations and green areas should be designed on the basis of needs and desires of local populations so that these can serve maximum possible benefits. Overall, the term urban agroforestry including urban greening using plantations involves the management of urban and peri-urban plantation in a planned, integrated, and systematic manner to achieve the maximum environmental, social, and economic well-being of the urban society.

Carbon Sequestration

Tree plantations offer additional advantage of mitigating a predicted increase in atmospheric carbon concentration through their potential to absorb more carbon efficiently. *Eucalyptus* plantation can play an important role as carbon sinks and contribute significantly to the removal of CO_2 from the atmosphere (Prasad et al. 2012). During the process of photosynthesis, the atmospheric CO_2 is utilized by the leaves to produce photosynthetic pathway compounds, which get stored either in the roots or bole. The carbon absorption by tree plantations in a given area varies with plantation age corresponding to variations in growth as well as plantation density. Carbon absorption is also expected to increase with better tree growth caused by essential plant nutrients supplied through sewage irrigation. Minhas et al. (2015) recorded that rate of increments in stock volumes of wastewater-irrigated *Eucalyptus tereticornis* plantations increased with plantation density and age, and for densities <2000 stems ha^{-1}, it peaked during the 6th year of growth as compared to earlier in higher densities. The overall carbon temporal sequestration potential of different densities of wastewater and tube well water-irrigated *Eucalyptus* plantations varied from 19.9 Mg ha^{-1} for wastewater irrigation in 3rd year of growth to 351 Mg ha^{-1} (Table 3). Thus the wastewater irrigation in plantations can help in increasing the carbon sequestration potential of urban plantation.

Improvement in Climate and Energy Savings

While air pollution indices in many cities in more developed countries have dropped over the years, air pollution levels have been also rising in cities throughout much of Latin America and the Caribbean. Carter (1993) reported that average level of particulate suspension in the atmosphere of Mexico City increased from 615 % between 1974 and 1990. Those most affected by such detrimental air contaminants are children, the elderly, and poor people with respiratory prob-

Table 3 Temporal changes in carbon sequestration potential of sewage-irrigated (SW) and groundwater-irrigated (GW) *Eucalyptus* (Mg ha^{-1})

Plantation age (years)	Stocking density (stems ha^{-1})							
	165		520		1990		6530	
	SW	GW	SW	GW	SW	GW	SW	GW
3	19.9	21.0	117.0	113.4	83.2	82.3	150.4	144.2
7	41.7	39.6	264.7	253.8	156.2	151.5	193.4	181.1
10	52.0	46.6	351.0	328.6	237.6	229.1	214.8	196.4

Source: Minhas et al. (2015)

lems. Therefore, in these cities, an aggressive and multifaceted approach to combating pollution is all the more urgent. Growing plantations and developing green areas reduce air pollution and also improve city beautification. Air pollution is directly reduced when dust and smoke particles are trapped by the plantations. In addition, plants absorb toxic gases, especially vehicle exhausts, which are a major component of urban smog (Nowak et al. 1996). The temperature moderating effect of urban plantations can reduce temperature extremes and thus reduce the smog formation arising with rise in temperature (Kuchelmeister 1991). Carbon dioxide, a major component of air pollution and greenhouse effect, can also be reduced through photosynthesis and reducing heat island effect with urban greening and plantations.

Urban plantations influence climate in two distinct manners, depending on the size, spacing, and design of plantations and green areas, first directly through effect on human comfort and second indirect effect on the energy budget of buildings in cities where air-conditioning is used. Plantations increase human comfort by influencing the degree of solar radiation, air movement, humidity, and air temperature and providing protection from heavy rains. Plantations and other vegetated areas also have an important impact on the energy budgets of buildings and, in turn, of entire cities. Plantations have been found to reduce the average air temperature in buildings by as much as 5 °C (Akbari et al. 1992). Studies in Chicago suggest that an increase of 10 % plantation cover can reduce the total energy requirements of the city by an equal extent (McPherson et al. 1994). Urban plantations also supply renewable energy in the form of fuel wood and other substitutes of fossil fuels. Treating wastewater in plantations eliminates the need for major sewage treatment plants that need fuel for their operation. Similarly, organic municipal solid waste serves as composted fertilizer, mulch for green areas, and animal feed, thereby reducing the energy and transport.

Social Benefits

Although difficult to quantify, the benefits of urban plantations and greening to human health are considerable. Urban plantations and green parks improve air quality, contribute toward aesthetically pleasing and relaxing environment, and thus have positive impacts on health in terms of decrease in respiratory illnesses and reduction in stress. Urban forests provide a connection between people and their natural environment that would otherwise be missing in a city. This connection is important for everyday enjoyment, productivity, and general mental health of workers (Nowak et al. 1996). Plantations also reduce ultraviolet light exposure thereby lowering the risks of harmful health effects such as skin cancer and cataracts (Heisler et al. 1995).

Green areas provide recreational sites, especially for lower-income residents who tend to frequent city parks more than wealthier citizens because of financial constraints and restrictions on leisure time. The urban poor generally have few affordable options for recreation and thus place a high value on green areas. Parks and other green areas also provide educational opportunities to learn about the environment and natural processes.

The aesthetic value of plantations and green areas, though not considered as important as food and shelter, is also very meaningful to urban residents. Vegetation reduces sun glare and reflection, complements architectural features, and tones down the harshness of large expanses of concrete. Rehabilitating lands with vegetation are often more attractive and cost effective than constructing buildings. Aesthetically pleasing green areas help in enhancing the properties values. For example, the vegetated beautification of Singapore and Kuala Lumpur has been adjudged as a major factor in attracting huge foreign investment and their rapid economic growth (Braatz 1993). Similarly, focused urban greening along roadways and railway lines in the Black Country district of England, a region of polluted lands, helped to attract huge investments (Jones 1995). The range of benefits that urban greening provides is both practical and comprehensive and addresses many of the social, environmental, and economic problems most cities face. Though urban plantations and green park areas are not the panacea for every urban problem, nonetheless these can significantly improve many of them and create a much more desirable environment to live.

Conclusions

Wastewater has enormous irrigation, nutrient, and labor employment potential, which is likely to increase with urbanization. Therefore, the wastewater needs to be considered as a resource rather than a menace by the urban planners and policy makers, especially in freshwater-scarce urban situations. However, wastewater also contains salts, pathogens, heavy metals, and other pollutants. Therefore, the benefits of wastewater use can be offset by the associated adverse health and environmental impacts in the long run, especially in developing countries where large volumes of raw or diluted wastewater are used in high-value vegetables, food grains, and fodder crops in peri-urban agriculture.

To overcome the hazards associated with wastewater use in agriculture, the chapter emphasizes on low-cost appropriate alternative measures like urban plantations and green park areas and some guidelines for selection of suitable species. Urban plantations and green areas should be designed on the basis of needs and desires of local populations so that these can serve maximum possible benefits to all residents. Plantations have the potential to improve air, water, and land resource quality, moderate the extreme high and low temperatures, and control floods and erosion with additional advantages such as creating habitats for wildlife, recreational activities, soothing environment, and above all aesthetic value of the cities.

To make the urban plantations and green park areas a safer and viable alternative for wastewater use, the plantation species should include fast-growing, high-rate transpiration multipurpose trees tolerant to salts and waterlogging and generate regular income. Tree plantations such as *Eucalyptus*, poplar (*Populus* spp.), pine (*Pinus* spp.), *Melaleuca* spp., bamboo (*Bambusa arundinacea*), acacia (*Acacia mangium*), neem (*Azadirachta indica*), and Indian rose wood (*Dalbergia sissoo*) which have high-rate transpiration system can be effectively utilized as safer alternative for beneficial disposal of wastewater. But to avoid contamination of natural resources, wastewater disposal rate needs to be regulated depending upon the plantation transpiration rate, tolerance to salts, and uptake of toxic substances.

Since the plantation transpiration capacity and their water requirement also decrease due to low evaporative demand during winter and rainy seasons, therefore, the provision of alternative storage and soil aquifer treatment needs to be developed in integration with constructed wetland with urban plantations and green park areas. But as a caution, regulatory mechanisms are required to be evoked to control loading rates since these are not as profligate consumers of water.

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