Constructed Wetlands for the Treatment of Domestic Grey Water: An Instrument of the Green Economy to Realize the Millennium Development Goals

Gopalsamy Poyyamoli, Golda Arpudhalin Edwin, and Nandhivarman Muthu

Abstract In rapidly developing countries like India, wastewater generation has increased manifold due to an increasing population, industrialization and urbanization. This in turn has led to the deterioration of several urban water bodies and aquifers. Transition to a green economy in the water sector requires a paradigm shift from the current practices by adopting innovative technologies that provide environmental as well economic benefits. In this context, constructed wetland systems (CWs) for domestic water treatment and reuse promise to be a cost-effective alternative to conventional systems and can contribute to improved water security. This chapter discusses the potential of CWs to contribute to a green economy, the various costs and benefits associated with it, along with a case study. The case study conducted shows removal efficiency between 65 and 99% for various pollutants, which complies with established reuse standards set by the Central Pollution Control Board (CPCB). In the process, it helps to save around 47% of the overall water requirement of the household. This chapter concludes that CWs proves to be an effective instrument of a green economy.

Keywords Constructed wetlands • Water treatment • Green economy • Sustainable water management

1 Introduction

The vast majority of people in India, as in many other developing countries, still do not have access to a safe drinking water supply. In recent years, rapidly expanding population, industrial development and urbanization have exerted immense

---

G. Poyyamoli • G.A. Edwin (✉) • N. Muthu
Pondicherry University, Puducherry, India
e-mail: gpoyya9@gmail.com; edwingolda@gmail.com; m.nandhivarman@gmail.com

R. Simpson and M. Zimmermann (eds.), *The Economy of Green Cities: A World Compendium on the Green Urban Economy*, Local Sustainability 3,
DOI 10.1007/978-94-007-1969-9_27, © Springer Science+Business Media Dordrecht 2013

environmental pressures on freshwater sources. Discharging wastewater effluents rich in nitrogen and other nutrients into receiving water bodies has a number of problems including eutrophication in the receiving water bodies, and impact on human health and marine ecology. Therefore, the pollutants must be removed/remediated in order to preserve the water environment, protect the aquatic life and health of water users downstream. In turn, efficient wastewater treatment and reuse is critical for sustainable development (Al-Jayyousih 2003).

Although conventional wastewater treatment technologies have been used by municipalities and industries for over three decades, they are rather expensive for use in small communities or households of developing countries. The use of the constructed wetlands systems (CWs) in urban areas at both small and large scale is now being recognized across the world due to their good treatment performances and low construction and operating costs (Kadlec et al. 2000; Sonavane et al. 2008). It has been accepted as a low cost eco-technology alternative to conventional treatment methods (especially beneficial to small communities that cannot afford expensive treatment systems) and been increasingly accepted by the general public for reuse purposes (Green and Upton 1995; White 1995; Billore et al. 1999; Fenxia and Ying 2009; Friedler 2008). Some of the most prominent benefits of small scale CWs include water reuse and cost saving, while the large scale implementation can include additional benefits such as nutrient harvesting, habitat creation, recreational and other human use, protection of aquatic life and the health of marine ecology.

However, successful implementation of CWs in India at a small scale (either at household/community/institutional level) is still in its primitive stage because it is hindered by three principle factors: (a) lack of available investment capital, (b) insufficient knowledge about the local wetland plant species, and (c) the cost of water supplied by the local municipality is too low due to heavy subsidies which fail to motivate the users to conserve/reuse water (Edwin and Poyyamoli 2012).

Designing a standard modular system for developing countries that can be easily installed and maintained can support the creation of more green jobs, improve the environment and backup the crumbling centralized wastewater treatment infrastructure, while providing economic and social benefits (Yang et al. 2008).

2 Green Economy

A green economy is one that results in improved human well-being and social equity, while significantly reducing environmental risks and ecological scarcities. According to United Nations Environment Programme, “A green urban economy realizes opportunities to enhance human well-being and local natural resources, while reducing future costs, ecological scarcities and environmental risks.” Water reclamation and greywater treatment are the two main aspects of sustainable water management and essential to realize a green urban economy. The economics of wastewater management and treatment are crucial topics in developing countries because:

- Wastewater is a significant and growing problem in many urban areas of both the developed and developing world.
- The available fresh water sources are dwindling and getting scarcer.
- Increase in fresh water pollution from human activity.
- Uncontrolled discharge of wastewater into streams and oceans, which causes a range of external costs, including cost to human health and ecosystems.
- Current wastewater treatment systems are at a rudimentary stage in developing countries and are grossly inefficient or ineffective, at a time of rapid growth.

2.1 The Potential of CWs for a Green Economy

CWs are natural systems in which wastewater is treated with wetland plants using natural processes (e.g. sedimentation, filtration, adsorption, biological degradation, volatilization, photolysis, biotic/abiotic degradation, nitrification/denitrification, microbial uptake, plant uptake, volatilization, etc.) to treat the wastewater in a controlled environment (Reed et al. 1995; Cooper et al. 1996; Constructed Wetlands Manual 1998; Gray 1999; Rai 2009). Hammer and Bastian (1989) puts it as "man-made complexes of saturated substrate, emergent and submerged vegetation, animal life and water that simulate natural wetlands for human use and benefits".

There have been several attempts by various authors to develop a vertical flow CWs that will comply with the most stringent effluent standard (i.e. 95% removal of biological oxygen demand, BOD, 90% removal of total-P and 90% nitrification) (Laber et al. 1997; Brix and Arias 2005). These and several other studies conducted in various parts of the world clearly demonstrate that such systems would be able to meet the effluent standards (e.g. Platzer 1996; Laber et al. 1997; Weedon 2003). Treating only the greywater (water from showers, laundry and kitchen) has an economic advantage over treating combined wastewater (includes blackwater from toilets) as greywater represent 70% of the total wastewater generated and has only about 10% of the nitrogen load that one would expect in the combined wastewater (Müllegger et al. 2003; Friedler et al. 2005). CWs for greywater treatment designed for single households or small communities can reclaim 70% of their wastewater and use them for various purposes including flushing toilets, for cleaning purposes, landscaping, etc. (Friedler 2008). The major disadvantages of these systems are that they require more space than conventional systems and site selection is almost always an issue due to availability of adequate land area and accessibility of the site (Sundaravadivel and Vigneswaran 2010).

CWs are especially applicable to urban areas where the collection and transport of wastewater cause 70–80% of the total costs of centralized wastewater treatment. Small scale decentralized systems can become economical if they are mass-produced using a standardized approach. In terms of the flow of investments, the centralized approach requires investment flow in building large sewerage systems whereas the decentralized approach directs investments towards production and maintenance of plants leading to more jobs (Otterpohl et al. 2003).

2.2 Costs

Using a CWs for greywater treatment proves to be more economically advantageous than treating the combined wastewater. This is mainly because treating only segregated greywater is more efficient at removing virtually all of the suspended solids and BOD, and about 80% of the Chemical Oxygen Demand (COD) after only 8 h of treatment. In general, the overall costs for wastewater treatment using natural methods can be subdivided into capital/investment costs and operational/maintenance costs. However, several of the monetary factors depend on the local situation, regulatory standards, and partly unquantifiable factors (Starkl et al. 2002).

2.2.1 Capital Costs

Major capital costs for a pilot scale CWs include land acquisition, earth moving, plastic liners to prevent groundwater contamination or infiltration, and the filter media in case of Subsurface Flow. The small scale CWs designed for single households can in most cases eliminate land costs by utilizing the free space available in the backyard or the terrace (as vertical flow CWs requires an area of 1–2 m^2 per person). The designs are usually oversized to comply with the regulatory standards and thus the costs reported in literature are usually quite large (Rousseau et al. 2008). Capital costs are highly dependent on the local situation, space availability and the decommissioning cost of the system after its life period, and cleaning/disposing cost of the filter media that remain uncertain (Rousseau et al. 2008).

2.2.2 Operational Costs

Operational costs include the costs for sampling, lab analysis, maintenance, energy, sludge disposal, cleaning, plant harvesting/weed control and labor. The maintenance costs of the CWs will be lower compared to the conventional treatment due to its low complexity, which does not require specialized skills for maintenance. It also has low consumption of energy that is often limited to pumping and disinfection of treated water.

2.2.3 Benefits

Using CWs has several advantages. It is a low cost and an eco-friendly method in treating water, which makes it a potential alternative to costly conventional techniques (Billore et al. 1999; Otterpohl et al. 2003; Trivedy 2007). Various studies have established that greywater reuse is economically, environmentally and technologically feasible for various purposes including the most common ones such as toilet flushing and landscape irrigation. There are examples of CWs that are aesthetically designed to reclaim domestic sewage for toilet flushing, landscape irrigation and aesthetic water features in Chatham County, NC (House et al. 1999). They are also designed indoors in some cases to flush the toilets in a hotel (March et al. 2004). Another case from an urban example shows how on-site greywater reuse in Israel is both acceptable to the public and is also an economically feasible solution for reducing urban water demand (Friedler 2008).

Treated water from CWs can also be used for restricted or unrestricted agricultural irrigation of crops depending on its effluent standard, and it can also serve as a tool for recharging groundwater (Emmett et al. 1996; Rousseau et al. 2008). Certain plant species have commercial value: some as ornamental plants (Belmont and Metcalfe 2003; Konnerup et al. 2009), others as raw material for various purposes including biomass fuel (Ciria et al. 2005) since the plants sequester carbon during their growth that can be used for energy production and for obtaining carbon credits. Harvested plant material can provide fibers, fodder for livestock and also can be composted for use as manure (Knight 1997).

Large scale CWs can serve as a new habitat for the local species of flora and fauna (Knight et al. 2001). Although most CWs are not designed with habitat functions in mind, they can be designed to achieve optimal wildlife potential if approached from an ecological viewpoint (Worrall et al. 1997). Large scale CWs designed from both ecological and engineering perspective can add further value for recreational and various other human use such as nature watching, walking, jogging, fishing, picnicking, relaxing and art (photography, painting) (Gearheart and Higley 1993; Knight 1997; Knight et al. 2001).

2.3 *Case Study*

To illustrate this, a case of a single house with five persons is considered in Puducherry, India. Here, greywater is being treated using vertical sub-surface flow CWs and the treated water is reused for toilet flushing and gardening purposes before releasing to the sewer. The complete flow diagram of the system is shown in Fig. 1.

The quantity and quality of the effluent water will in part determine how it can be reused. In general, the reuse of greywater serves three purposes:

- It reduces the fresh water requirement
- It reduces the sewage generation
- It helps close the water and nutrient cycle to a great degree at source

The system treats 350 l per day of greywater generated from showers, kitchen and laundry, while the remaining is sent to the sewer directly. The composition of the greywater generated from various source is shown in Table 1.

In primary treatment, screening and sedimentation process is used to remove the suspended solids that can be easily filtered or settled at the bottom. This is followed

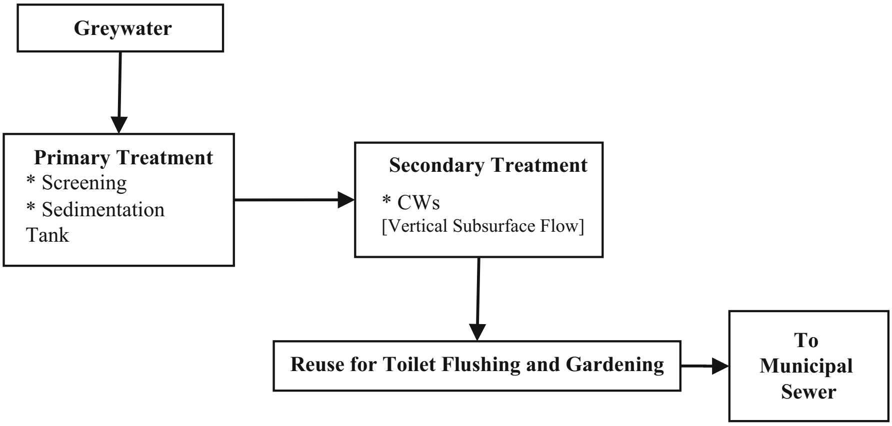

Fig. 1 Flow diagram of the greywater treatment system

Table 1 Composition of the greywater generated from various sources

Description	Percentage generated (%)	Composition
Bathroom	50–60	Soap, shampoo, hair dye, toothpaste and cleaning products
Washing	25–35	Detergents and associated chemical agents
Kitchen	10	Detergents, cleaning agents, food particles, oils, fats and other wastes

by a vertical subsurface flow CW planted with *Arundo donax* which is a freely available, fast growing indigenous plant with efficient biomass to treat the greywater through root zone treatment techniques. A collection tank of 500 l capacity is utilized to hold the treated greywater, which is then pumped to a storage tank of 500 l capacity from where it is directed to toilet flushing and gardening purpose.

The annual saving in water is calculated to be 10,500 l or about 47% as indicated in Table 2. The pollution removal efficiency of the system increased in the first 3 months before stabilizing and the laboratory analysis clearly indicate the removal efficiency of 95.2% for BOD_5, 79.2% for suspended solids, 74% total alkalinity, 81.1% for COD, 80% for turbidity, 73.2% for nitrate nitrogen, 65% for ammonium nitrogen and 99.1% for coliform bacteria.

3 Conclusion

Grey water reclamation and reuse is an alternate source of non-potable water that directly reduces the sewage flow rates and indirectly reduces the cost of treating sewage at a centralized facility. Besides the water saving advantages these systems

Table 2 Annual water saving by using treated greywater

Parameter	Before treatment and reuse	After treatment and reuse
Water source	Municipal tap water [750 lpd]	Municipal tap water [400 lpd] Greywater reuse [350 l]
Water requirement for toilet flushing and gardening	Municipal tap water [350 lpd]	Greywater reuse [350 l]
Annual cost of water	Annual expenditure on purchase of water INR 1,200/- (after subsidy from government)	Capital expenditure for greywater treatment INR 10,000/- O & M cost is ~ INR 400/- Annual expenditure on purchase of water INR 636/-
Annual water saving		10,500 l or ~ 47%

offer, they also close the water and nutrient cycles at greywater generation source itself on a local scale. The study concluded that around 47% of the water requirement can be reduced by utilizing a small scale CWs to treat and reuse greywater. For small wastewater treatment plants especially the operational costs are essential and when greywater is reused, the health/hygiene aspects also have to be considered. Frequent laboratory tests needs to be performed to ensure that the system is performing as per the guidelines set by the regulatory bodies. These systems may not be a preferable option among the urban users as long as the government provides drinking water at a huge subsidy. Though water subsidy should be used as a tool for poverty alleviation for poor families, it should not make the affordable users to underestimate the value of this precious resource and encourage wasteful use of water. As an alternative, the government should subsidize the installation of these treatment systems and make it mandatory for all group housing projects to facilitate sustainable development and help achieve the Millennium Development Goals.

References

Al-Jayyousih OR (2003) Greywater reuse: towards sustainable water management. Desalination 156(1–3):181–192

Belmont MA, Metcalfe CD (2003) Feasibility of using ornamental plants (*Zantedeschia aethiopica*) in subsurface flow treatment wetlands to remove nitrogen, chemical oxygen demand and nonylphenol ethoxylate surfactants – a laboratory-scale study. Ecol Eng 21(4–5):233–247

Billore SK, Singh N, Sharma JK, Dass P, Nelson RM (1999) Horizontal subsurface flow gravel bed constructed wetland with Phragmites karka in Central India. Wat Sci Technol 40(3):163–171

Brix H, Arias CA (2005) The use of vertical flow constructed wetlands for onsite treatment of domestic wastewater: new Danish guidelines. Ecol Eng 25:491–500

Ciria MP, Solano ML, Soriano P (2005) Role of macrophyte Typha latifolia in a constructed wetland for wastewater treatment and assessment of its potential as a biomass fuel. Biosyst Eng 92(4):535–544

Constructed Wetlands Manual (1998) Department of Land and Water Conservation, New South Wales, Vols 1 and 2, National Library of Australia

Cooper PF, Job GD, Green MB, Shutes RBE (1996) Reed beds and constructed wetland for wastewater treatment. WRC, Swindon

Edwin GA, Poyyamoli G (2012) Climate change and sustainable management of water resources. In: Leal Filho W (ed) Climate change and the sustainable use of water resources. Climate change management. Springer, Heidelberg/New York, pp 431–447

Emmett AJ, Clarke S, Howles S (1996) Conjunctive wetland treatment/aquifer storage and recovery at Regent Gardens residential development, North Field, South Australia. Desalination 106:407–410

Fenxia Y, Ying L (2009) Enhancement of nitrogen removal in towery hybrid constructed wetland to treat domestic wastewater for small rural communities. Ecol Eng 35(7):1043–1050

Friedler E (2008) The water saving potential and the socio-economic feasibility of greywater reuse within the urban sector – Israel as a case study. Int J Environ Stud 65(1):57–69

Friedler E, Kovalio R, Galil NI (2005) On-site greywater treatment and reuse in multi-storey buildings. Wat Sci Technol 51(10):187–194

Gearheart RA, Higley M (1993) Constructed open surface wetlands: the water quality benefits and wildlife benefits – City of Arcata, California. In: Moshiri G (ed) Constructed wetlands for water quality improvement. Lewis Publishers, Boca Raton, pp 561–567, Chap. 62

Gray NF (1999) Water technology: an introduction for scientists and engineers. Arnold/Wiley, London/New York, ISBN 0 340 67645 0 (pb)

Green MB, Uptown J (1995) Constructed reed beds: an appropriate technology for small communities. Water Sci Technol 32:339–348

Hammer DA, Bastian RK (1989) Wetlands ecosystems: natural water purifiers? In: Hammer DA (ed) Constructed wetlands for wastewater treatment. Lewis Publications, Chelsea, MI, pp 5–21

House CH, Bergmann BA, Stomp AM, Frederick DJ (1999) Combining constructed wet-lands and aquatic and soil filters for reclamation and reuse of water. Ecol Eng 12(1–2):27–38

Kadlec RH, Knight RL, Vymazal J, Brix H, Cooper P, Haberl R (2000) Constructed wetlands for pollution control. Process, performance, design and operation. IWA Scientific and Technical Report No.8, ISBN: 1-900222-05-1

Knight RL (1997) Wildlife habitat and public use benefits of treatment wetlands. Wat Sci Technol 35(5):35–43

Knight RL, Clarke RA, Bastian RK (2001) Surface flow (SF) treatment wetlands as a habitat for wildlife and humans. Wat Sci Technol 44(11–12):27–37

Konnerup D, Koottatep T, Brix H (2009) Treatment of domestic wastewater in tropical, subsurface flow constructed wetlands planted with Canna and Heliconia. Ecol Eng 35(2):248–257

Laber J, Perfler R, Haberl R (1997) Two strategies for advanced nitrogen elimination in vertical flow constructed wetlands. Wat Sci Technol 35(5):71–77

March JG, Gual M, Orozco F (2004) Experiences on greywater re-use for toilet flushing in a hotel (Mallorca Island, Spain). Desalination 164:241–247

Müllegger E, Langergraber G, Jung H, Starkl M, Laber J (2003) Potentials for greywater treatment and reuse in rural areas. 2nd international symposium on ecological sanitation, Lübeck

Otterpohl R, Braun U, Oldenburg M (2003) Innovative technologies for decentralised water-, wastewater and biowaste management in urban and peri-urban areas. Wat Sci Technol 48(11–12):23–32

Platzer C (1996) Enhanced nitrogen elimination in subsurface flow artificial wetlands – a multi stage concept. In: Proceedings of the fifth international conference on wetland systems for water pollution control, Universität für Bodenkultur Wien, Vienna, Austria

Rai PK (2009) Heavy metal phytoremediation from aquatic ecosystems with special reference to macrophytes. Crit Rev Environ Sci Technol 39:697–753

Reed SC, Crites RW, Middlebrooks EJ (1995) Natural systems for wastewater management and treatment. McGraw-Hill, San Francisco, ISBN 0-07-060982-9

Rousseau DPL, Lesage E, Story A, Vanrolleghem PA, De Pauw N (2008) Constructed wetlands for water reclamation. Desalination 218:181–189

Sonavane PG, Munavalli GR, Ranade SV (2008) Nutrient removal by root zone treatment systems: a review. J Environ Sci Eng 50(3):241–248

Starkl M, Ertl T, Haberl R (2002) Experiences with benchmarking of sewerage systems with a special focus on investment costs. In: University of Bradford (ed) Proceedings of the international conference on sewer operation and maintenance (CD), 26–28 Nov 2002, Bradford

Sundaravadivel M, Vigneswaran S (2010) Constructed wetlands for wastewater treatment. Crit Rev Environ Sci Technol 31(4):351–409

Trivedy RK (2007) Low cost and energy saving technologies for water and wastewater treatment. J Ind Pollut Contr 23(2):403

Weedon CM (2003) Compact vertical flow constructed wetland systems – first two years' performance. Wat Sci Technol 48(5):15–23

White KD (1995) Enhancement of nitrogen removal in subsurface flow constructed wetlands employing a 2-stage configuration, an unsaturated zone, and recirculation. Wat Sci Technol 32(3):59–67

Worrall P, Peberdy KJ, Millet MC (1997) Constructed wetlands and nature conservation. Wat Sci Technol 35(5):205–213

Yang W, Chang J, Xu B, Peng C, Ge Y (2008) Ecosystem service value assessment for constructed wetlands: a case study in Hangzhou, China. Ecol Econ 68(1–2):116–125