Chapter 10

Significance of incorporating constructed wetlands to enhance reuse of treated wastewater in India

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10.1 INTRODUCTION

Rural, semi-urban and urban communities in India have been looking for augmentation of their water supplies. Almost none of the communities have adequate water supply and infrastructure for collection and disposal of wastewater across the country. Reportedly, nearly every developing country worldwide has been facing water scarcity during the past four decades. The challenge of water shortage and its consequences remains a major point of discussion in all the key international water, environment and development related meetings and conferences. For example, the issues associated with drinking water, wastewater and contamination of rivers and oceans were debated to formulate a collective action plan in three recently held international conferences, namely: United Nations Conference on Environment and Development, 3rd to 14th June 1992, in Rio de Janeiro, Brazil; World Summit on Sustainable Development, 26th August to 4th September 2002, in Johannesburg, South Africa and United Nations Conference on Sustainable Development, 13th to 22th June 2012, in Rio de Janeiro, Brazil.

Several international platforms have been urging that the world will have to come together to address the challenge of pollution of our surface waters and marine coastal ecosystems. It has been recognised that urban and rural communities worldwide are contaminating water resources by disposing their domestic wastewater into nearby water bodies. The threat has reached such proportions, especially in developing countries, that the communities are now forcing local self-governments and national governments to solve the crises through social and political actions.

During the first four decades of urban development in free India (1947 to the early nineties) the emphasis was laid on fetching potable water from 50 to 100 km distances from pristine rural settings (water reservoirs of dams and lakes). Such water supply schemes cannot be planned and implemented anymore because they are not considered to be politically defensible. The Environmental Impact Assessment Regulation was passed in 1986 by the Ministry of Environment and Forests (MoEF) of the Government of India (GoI) and large development projects need to be categorically approved by the team of experts at the MoEF as well as scrutinised and cleared by the stakeholders in a public hearing. During the past two decades, it has become more complicated because government policies not only favour inclusive growth of rural and tribal communities, but also factor in environmental and ecological costs in the impact analyses and cost benefit analyses performed before approving any development projects.

Presently, the GoI does not support exploitation of tribal and remote rural locations and forests for the benefit of urban and peri-urban communities. Besides, as stated earlier, the tribal and rural communities have begun to exert their political pressure onto growth-related policies and programmes formulated and implemented by the Central and State Governments in the Union of India. Clearly, a time has come when alternate suitable technological solutions that are concurrent with the capabilities of local agricultural and natural ecosystems must be favoured.

India's commitment to global warming related actions and the Kyoto Protocol obviously has challenged the conventional approach of water supply and wastewater management in rural and urban communities. It is now expected that all municipal authorities will have to prepare their respective "resource consumption and environment management plan" and after deliberating on the short-term and long-term "sustainability" of their proposals funding would be released by the respective ministries.

For example, the recent guidelines of the Ministry of Rural Development, the Ministry of Urban Development, MoEF as well as the Ministry of Water Resources (MoWR) and the Ganga Rejuvenation for development of infrastructure for wastewater management in rural and urban communities lay emphasis on decentralized and low-energy consuming solutions. Clearly, greener eco-centric solutions will typically be favoured in the coming years. One more factor that is likely to influence the solutions implemented in the near future is the shortage of funds. These socio-economic and political realities are influencing the technological choices of municipalities. In this context, natural treatment systems (NTSs) are indeed emerging as the preferred solution – especially in rural and small communities in India.

10.1.1 The potential of constructed wetlands for treatment of wastewater

The engineered NTSs have been incorporated into wastewater treatment plants (WWTPs) to treat wastewater since the early seventies – especially in the developing countries of Asia and Africa. Several WWTPs employing a variety of NTSs have been studied and reported in literature (Arceivala & Asolekar, 2006, 2012; Chaturvedi & Asolekar, 2009; Starkl *et al.*, 2013; Asolekar *et al.*, 2013; Chaturvedi *et al.*, 2014). Chapter 8 of this Handbook presents the lessons learned from the national survey of engineered NTSs currently functioning in India – which was one of the outputs of the Saph Pani Project. Reportedly, there are108 sites across India where NTSs are used for treating mixtures of wastewater and in some cases biodegradable industrial effluents. Among those, the 41 WWTPs were studied in-depth by the authors during December 2011 to June 2014. The details of these 41 sites have been presented in the Report No. D3.1 of the Saph Pani Project (Asolekar, 2013).

As described in Chapter 8, 23 plants had waste stabilization ponds (WSPs), three plants had duckweed ponds (DPs), seven plants had polishing ponds (PPs) and 8 plants employed horizontal sub-surface flow constructed wetlands (HSSF-CWs) or Karnal-type constructed wetlands (KT-CWs). The constructed wetlands (CWs) were preferred by small rural and semi-urban communities, especially to treat wastewater and industrial biodegradable effluents to achieve removal of carbonaceous and nitrogenous organic pollutants. In some cases, the treated effluents from CWs were put to reuse for the irrigation and rejuvenation of lakes (Asolekar *et al.*, 2013; refer also to Chapter 8 of this Handbook). Vymazal and Brezinová (2014) also reported similar observations from Czech Republic. The CWs were also found to be favoured in situations wherein evaporation of treated effluents needed to be achieved. Several researchers, too, have reported the preference for CWs in several communities in the world (Burken & Schnoor, 1998; Mara & Pearson, 1998; Metcalf & Eddy Inc., 2003; Kamath *et al.*, 2004; Mara, 2004; Arceivala & Asolekar, 2006; Asolekar *et al.*, 2013; Chaturvedi *et al.*, 2014; Vymazal, & Brezinová, 2014; Starkl *et al.*, 2015).

The WWTPs based on engineered CWs are found to be comparably or better performing than the conventional treatment technologies, which include activated sludge plants, sequential batch rectors, trickling filters, oxidation ditches or extended aeration basins–especially when compared to consumption of electrical energy and chemicals. Kumar and Asolekar (2014a and 2014b) have also highlighted the preferences of tribal communities settled in remote locations as well as rural and peri-urban communities surrounded by agricultural and commercial agro-forestry for NTSs in general and CWs in particular. In developed countries, CWs have been used for treating a variety of wastewater including domestic wastewater (Cooper *et al.*, 1997), acid mine drainages (Wenerick *et al.*, 1989), agricultural run-off, landfill leachates (Staubitz *et al.*, 1989), urban storm water run-off and for polishing treated effluents to be returned to freshwater resources.

The HSSF-CWs are typically employed for treatment and reuse of treated wastewater and sometimes even for treatment of industrial effluents. Such wetlands include 'Reed beds' and 'Root-zone' treatment methods devised to obtain environmental duty from the macrophytes cultivated in trenches or on beds having been saturated with wastewater. Wetlands have also been suggested as an alternate for treating nitrate bearing contaminated aquifers, denitrification of nitrified domestic effluents and irrigation return flows (Baker, 1998). Furthermore, the denitrification efficiency in the presence of low organic carbon was shown to depend on the C:N ratio (carbon:nitrogen ratio), with peak efficiencies occurring at a C:N ratio of 5:1.

CWs have also been used for treating the eutrophic water from Lake Taihuin China (Li *et al.*, 2008), and for providing make-up water for Lake Mansagar in Jaipur, the State of Rajasthan, India as well as for the conservation of ecosystems (Asolekar *et al.*, 2013). The habitat of endangered bird species was created on vegetated silt mounds in Lake Mansagar, which received treated effluents from the City of Jaipur (Asolekar *et al.*, 2013).

Mandi *et al.* (1998) reported a study on the treatment of domestic wastewater under semi-arid conditions in Morocco. At a hydraulic loading rate of 0.86–1.44 m^3/d to a reed bed planted with *Phragmites australi*s, organic removal of 48–62%, total suspended solids (TSS) removal of 58–67% and 71–95% removal of parasites were reported. In Egypt, Stott *et al.* (1999)

achieved a 100% removal of parasitic ova from domestic wastewater intended for agriculture use. In Iran, a subsurface flow reed bed (*Phragmites australis*) of 150 m^2 was reportedly employed for treating municipal wastewaters. At an organic loading rate of 200 kg/(ha∗d), which is higher than the previously recommended rate of 133 kg/(ha∗d), (Metcalf and Eddy Inc., 2003), removal efficiencies for Chemical oxygen Demand (COD) 86%, biological oxygen demand (BOD_5) 90%, TSS 89%, total nitrogen (TN) 34%, total phosphorous (TP) 56%, and faecal coliform (FC) bacteria 99%, were obtained.

Okurut *et al.* (1999) demonstrated the viability of CWs with indigenous *C. papyrus* and *Phragmites mauritianus* in Uganda for treating municipal wastewater. In the *C. papyrus* systems, average mass removal rates for COD, TSS, ammonium (NH_4-N), TN and o-phosphorus were 15.32, 6.62, 6.5, 1.06, 0.06 g/(m^2∗d), respectively. In *Phragmites mauritianus* systems, the rate for the same parameters was 2.25, 0.9, 0.66, 0.65, and 0.058 g/(m^2∗d), respectively. The level of BOD_5 and TSS in the effluents was below 20 and 25 mg/L. A higher degree of FC removal was reported for the CW planted with *C. papyrus*.

The potential of CWs for application by small communities for wastewater treatment was examined in Nepal (Laber *et al.*, 1999). A hybrid CW system comprised of horizontal flow and vertical flow beds (140 m^2 bed area for horizontal flow and 120 m^2 bed area for vertical flow) with *Phragmites karka* was tested for one year on full-scale for treatment of hospital wastewater. At a hydraulic loading rate of 107 mm/d, removal efficiencies for COD 93%, BOD_5 97%, ammonium 99.7%, TP 74%, total coliforms 99.99%, *Escherichia coli* 99.99%, *Streptococcus* 99.97% and TSS 98% were obtained.

10.1.2 Scope and objectives

The WWTPs based on engineered NTSs in general, and CWs in particular, have been adopted worldwide for treatment of wastewater and biodegradable industrial effluents – especially in developing countries. Among several variants of engineered CWs, the four varieties are typically practiced all over the world, which include HSSF-CWs, vertical flow constructed wetlands (VF-CWs), free floating constructed wetlands (FF-CWs) and hybrid systems (Hybrid-CWs). The HSSF-CWs are gaining increasing acceptance among rural, peri-urban and remotely located small communities to treat domestic wastewater and reuse it to augment irrigation water as well as conservation and sustenance of lakes and rivers in India – which is also the scope of the present chapter. The specific objectives pursued in the present analysis are:

- In-depth assessment of three significant CWs in the context of India
- Lessons from selected case studies for in-depth assessment
- Typologies of failure of CW and remedial measures

10.2 IN-DEPTH ASSESSMENT THROUGH CASE STUDIES

Based on the survey of engineered NTSs in India (described in Chapter 8), the following three HSSF-CWs that have been providing various kinds of services were selected for in-depth assessment:

1) HSSF-CW at Mansagar Lake, in the City of Jaipur, State of Rajasthan in northern India
2) HSSF-CW in Katchpua slum, City of Agra, State of Uttar Pradesh in northern India
3) HSSF-CW in Pipar Majra, a rural community in the District Ropar, State of Punjab in northern India

The focus for this in-depth assessment included some of the critical considerations regarding public health and sanitation, environmental sustainability, fulfilment of societal aspirations and implementation of certain out-of-box ideas on institutional arrangements.

10.2.1 HSSF-CW at Mansagar lake, in the city of Jaipur, state of Rajasthan in Northern India: Case study 1

The City of Jaipur, popularly known as the *Pink City*, with a population of ≈ 3.1 million, is situated in the State of Rajasthan on the north western frontier of India in the midst of the *Thar Desert*. The City is placed in the "golden quadrilateral highway network" because of its popularity as a tourist destination. Historically, it has been the hub for arts and crafts including bandhani, block printing, stone carving and sculpture; tarkashi, zari, gota, kinari and zardozi, silver jewellery, gems, *kundan*, *meenakari*, miniature paintings; blue pottery; ivory carving; shellac work and leatherwear (The World Public Library Association, 2015).

Among the many archaeological and cultural monuments in the City of Jaipur, Lake Mansagar, a 300-acre man-made water body surrounded by the Nahargarh Hills, attracts visitors. The artificial lake was created behind the dam on River Darbhawati in the 18th century. Today it is the only significant water body in the City of Jaipur. The *Jalmahal* (literally means "palace in water"), an architectural monument, is situated in the midst of Lake Mansagar – which served as the summer palace for the Royal Family since the 18th century (Jal Mahal Innovation Report, 2005).

Historically, the Lake served the Royal Family in the summers and the residents of Jaipur throughout the year for recreation. An even more important attraction of the Lake has been its outflow for the benefits of farmers downstream. The cultural and economic uses of the Lake, however, came into conflict with rather exploitative usage of the water by the residents of the City of Jaipur and surrounding communities. Much of the untreated wastewater (and some partially treated wastewater) was disposed of into the Lake year-round. The problem was aggravated further by letting the storm water run-off into the Lake – which carried municipal solid wastes, silt and other urban pollutants. As a result, the Lake witnessed a steady decline of its health during the past three decades and reached apathetic extent of deterioration. At any point during the year, if the Lake had any water, it was due to the deposited wastewater. Not surprisingly then, the surrounding community and the City of Jaipur had endemic malaria and water borne diseases owing to the menace of mosquitoes and contamination of water in dug-wells and river.

Asolekar *et al.* (2013) has reported a brief account of the flagship project aimed at rejuvenating Lake Mansagar, which was conceived, planned, designed and executed by Asolekar and co-workers under the supervision of Prof. Soli J. Arceivala. This project has significance because it has three relatively uncommon features. First, it employed eco-centric technology to create make-up water for the Lake from treated wastewater of the City of Jaipur. Second, it aspired to up-grade the lake ecosystem to create favourable conditions for thriving biodiversity, habitats for fishes and nesting sites and hideouts for various species of birds. Third, this project experimented with a novel approach of the so-called public-private partnership (PPP) to attract capital investments and involvement of commercial implementing agencies. A four-step plan devised and implemented before implementing the ecosystem-related intervention was as follows:

1) A settling zone was created at the mouth of the storm water drain entering the Lake. Mechanical devices and operators were devised to skim off the floating plastic and any municipal garbage carried through the storm water. Also, arrangements were made to dredge out the settled sludge in the settling zone.
2) The wastewater generated northward of the ridge, dividing the City of Jaipur, was treated in the late nineties with the help of activated sludge treatment facility. Over the years, the WWTP received larger flows of wastewater. Therefore, the WWTP was modernized and expanded to give adequate primary treatment followed by conventional activated sludge process (ASP)-based secondary treatment, as depicted in Figure 10.1 and Figure 10.2–10.5.
3) A detailed hydro-geological study of the lake bed and the peripheral land was done and the mathematical model was developed by Prof G. C. Mishra from the National Institute of Hydrology (NIH), Roorkee. Based on the results, a water balance of Lake Mansagar was developed. It was concluded that at least 7 MLD of water would be needed as a daily make-up flow. Accordingly, 7.8 MLD flow was tapped from the outlet of the "WWTP-North at Brahampuri", which was situated nearly 3 km south of Lake Mansagar at a slightly higher altitude. As seen in Figures 10.1 and 10.2–10.5, the tapped flow was further subjected to tertiary treatment comprised of phosphorus removal and HSSF-CWs and the resulting tertiary treated effluent was sent to Lake Mansagar. In order to get an adequate area for CWs, three separate patches of land at different locations were used (location 1, 2 & 3).
4) The balance-treated wastewater from the modernized WWTP facility was diverted (nearly two-thirds flow) through an under-ground sewer and disposed into the Darbhavati River. The treated wastewater meets the regulatory standards to be disposed safely into river.

Over a period of eight years of sustained efforts, the aquatic ecosystem and the terrestrial vegetation on the periphery have reached a stage where these now survive without any special protection or interventions. For example, the surface feeders and bottom grazing fishes have been thriving in a sustainable manner so that the water body seems to have a balance between fishes and plants. Needless to emphasize the additional advantages Lake Mansagar continuously derives from the presence of various life forms. It is well known that such aquatic life polishes organic micro-pollutants from a given water body. Another benefit from the efforts of rejuvenation of Lake Mansagar resulted in the creation of a conductive aquatic environment for breeding of endemic and migratory species of birds. Reportedly, more than 20 species of birds have been residing on the various islands designed to support the habitats of the respective species.

One such experiment on sustainable development and business generation has been completed in Jaipur. This unique project involved environment conservation, heritage restoration and business promotion all rolled into one. To achieve a good quality of Lake water, a water budget study was carried out and the quantity of water required as make-up water estimated was 7.8 MLD. This amount of water requirement was being fulfilled by the tertiary treated wastewater from HSSF-CW installed in the vicinity of Jalmahal. The secondary treated wastewater first undergoes phosphorus removal followed by tertiary treatment in the HSSF-CW (total 40,000 m^2). The tertiary treated wastewater is then led into Lake Mansagar, its BOD_5 has come down from 150 mg/L to 10–15 mg/L.

The Rejuvenation of Lake Mansagar through application of 7.8 MLD was designed to give a secondary treatment consisting of a conventional ASP followed by chemical phosphorus removal units, as depicted in Figure 10.2 and 10.3. The tertiary treated effluent was led to HSSF-CW as seen from Figure 10.4 and the treated wastewater from CW-bed was used for rejuvenation Lake Mansagar as evidenced in Figure 10.5.

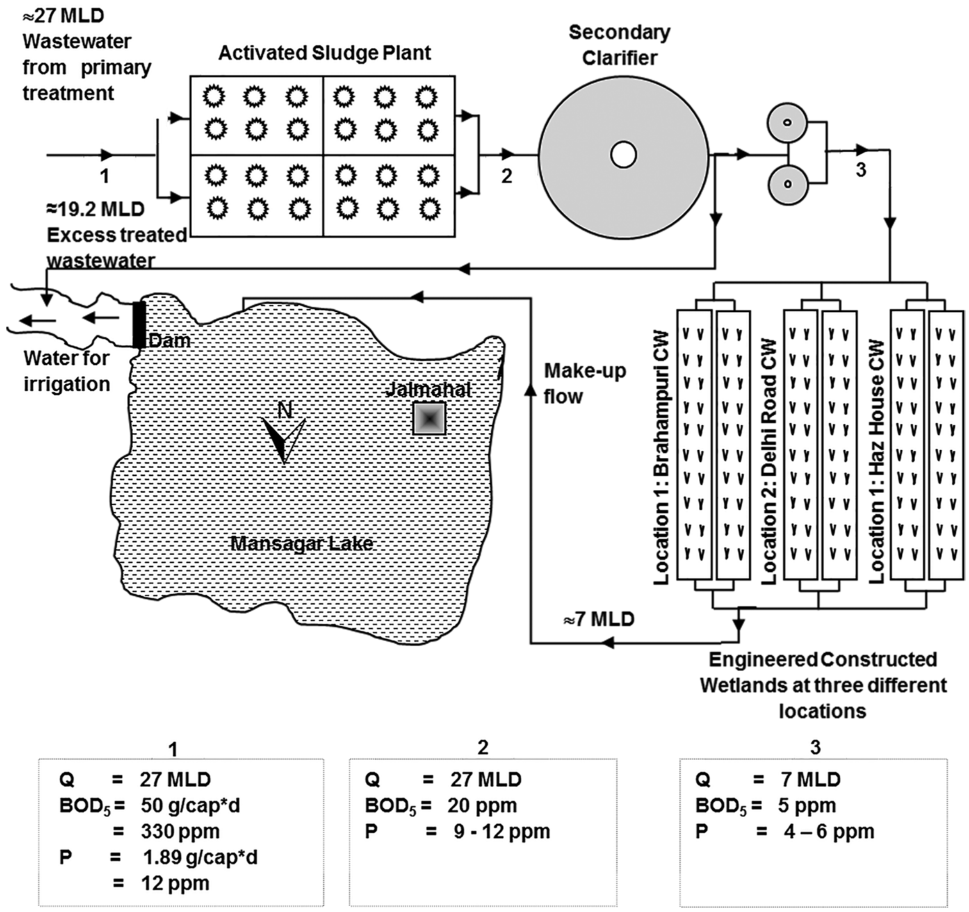

Figure 10.1 Flow diagram of the secondary WWTP of approximately 27 MLD capacity followed by two-stage tertiary treatment to generate 7 MLD make-up water for Lake Mansagar, City of Jaipur and the salient design objectives.

Figure 10.2 Conventional ASP to treat wastewater from the City of Jaipur (≈ 27 MLD).

Figure 10.3 Removal of phosphorus using lime precipitation technology (first step in tertiary treatment).

Figure 10.4 HSSF-CW (second step in tertiary treatment.

Figure 10.5 Rejuvenated Mansagar Lake that receives approximately 7 MLD of tertiary treated wastewater.

Prior to this rejuvenation work, the lake had received the untreated or partially treated wastewater from the City – which caused threats of several vector borne diseases in the surroundings of the Lake. Also, the accumulated untreated or partially treated wastewater posed a problem of ground water contamination. Rejuvenation of Mansagar Lake involved the private sector in sustainable development of the project area, and created a PPP of the State Government and Jalmahal Resorts Pvt. Ltd. (JMRPL). A grant of INR 24.72 crores (INR 247.2 million; ≈EUR 3.04 million[1]) was allocated for the restoration under the National River Conservation Program in 2002. Jaipur Development Authority was appointed as the nodal agency for the Lake Restoration part of the project. In 2007, JMRPL took the whole area of the Lake (310 acres) and its surrounding (totalling 432 acres) on a 99-year lease from the Government of Rajasthan for restoration.

10.2.2 HSSF-CW in katchpura slum, city of Agra, state of Uttar Pradesh in Northern India: Case study 2

The City of Agra in the State of Uttar Pradesh (population ≈ 1.8 million) is the most famous tourist attraction in India. Another interesting fact about the City of Agra and its peri-urban and sub-urban communities is that the region hosts one of the largest agglomerations of cottage and small-scale industries in India. Traditionally, Agra and the surrounding villages have a workforce engaged in artistic handicraft, *zarizardozi,* stone carving and in lay work as well as glass-blowing, bangle-work, foundry and brick kilns.

The City of Agra has several wastewater treatment facilities. One of the interesting WWTPs is the engineered CW in Kachpura slum. It was established in 2010 by the *Crosscutting Agra Program* intended for low-income communities with financial assistance from the *Water Trust UK* and *London Metropolitan University* and technical support from the *Vijay Vigyan Foundation*. This decentralized WWTP is operated by the Agra Municipal Corporation. The WWTP was designed to receive domestic wastewater from the five clusters of Kachpura slum *via* gutters. A part of the flow of wastewater (approximately 0.05MLD) was subjected to the CW created in the slum – right behind the *Taj Mahal*. The treated wastewater was typically utilized by the surrounding communities for irrigation. To balance untreated wastewater was led through gutters to the Yamuna River. The flow diagram adopted for treatment of wastewater is shown in Figure 10.6.

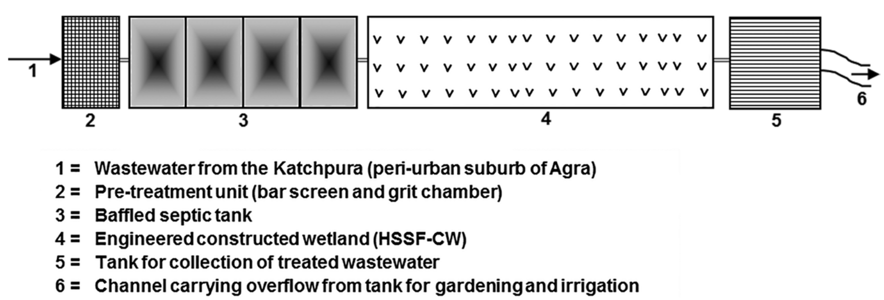

Figure 10.6 Flow diagram of the pre-treatment followed by septic tank and HSSF-CW of approximately 0.05 MLD capacity in Katchpura slum, City of Agra, State of Uttar Pradesh in northern India.

The CW in Katchpura slum was designed to give a first-rate primary treatment consisting of the settling chamber followed by a baffled septic tank, as depicted in Figure 10.7 and 10.8. The primary treated effluent was led to HSSF-CW as seen from Figure 10.9 and the treated wastewater from the sump was used to irrigate the garden as evidenced in Figure 10.10.

The primary treatment is comprised of a grit chamber, bar-screen and a baffled septic tank. The bar-screen prevents the floating solids from entering the septic tank. After pre-treatment, the wastewater is led to the baffled septic tank (nine baffles). The CW bed is filled with three layers of media, namely white river pebbles at the bottom, red stones in the middle and gravel of size 30 to 50 mm nominal diameter on the top. The bed is planted with locally abundant *Canna indica* plants. The overall operation and maintenance (O&M) of the system was found to be satisfactory. Reportedly, the capital cost incurred for establishing this WWTP was ≈EUR 15,000 and the O&M costs are currently of the order of ≈EUR 3,500 per year. The local residents reported that prior to the establishment of CW, the canal was wider carrying untreated wastewater, which created a number of problems including mosquito breeding and foul odour. The CW system has noticeably improved the sanitation in the community.

[1]Average currency exchange rate year 2014: INR EUR = 0.0123 (Online Currency Converter).

Figure 10.7 Pre-treatment unit comprising of bar-screen and grit removal.

Figure 10.8 Primary treatment unit (baffled septic tank).

Figure 10.9 HSSF-CW having *Canna indica*.

Figure 10.10 Tank for collection of treated wastewater to be sent for gardening and irrigation.

10.2.3 HSSF-CW in Pipar Majra, a rural community in the district Ropar, state of Punjab in northern India: Case study 3

Ropar (also called as Rupar), is a small city and a municipal council in Rupnagar district, the State of Punjab, in northern India. The City of Ropar has several wastewater treatment facilities. One of the interesting WWTPs is the engineered HSSF-CWs in the outskirts of the City (≈50 km away from the city) with a capacity of 0.5 MLD.

It was established in 2006 by the *Ropar Municipal Corporation* to improve the sanitation in the village community (Pipar Majra), with financial assistance from the Water and Sewerage Board as well as from the National Rural Employment Guarantee Act (MGNREGA) 2005. The respective village council has been operating this decentralized WWTP. The WWTP was designed to receive domestic wastewater from the village community *via* gutters.

The primary treatment is comprised of a grit chamber, bar-screen and aseptic tank. The bar-screen prevents the floating solids from entering the septic tank. After the pre-treatment, the wastewater is led to the septic tank. The process used for treatment of wastewater at the treatment site is depicted in Figure 10.11. The CW bed is filled with locally available river sand. The bed is planted with locally abundant *Typha latifolia* plants (i.e. common cattail) (Figure 10.12). The primary treated wastewater from the septic tank further undergoes secondary treatment through HSSF-CW. The treated effluent from the CW bed is discharged into the adjacent fishpond for pisciculture (Figure 10.13).

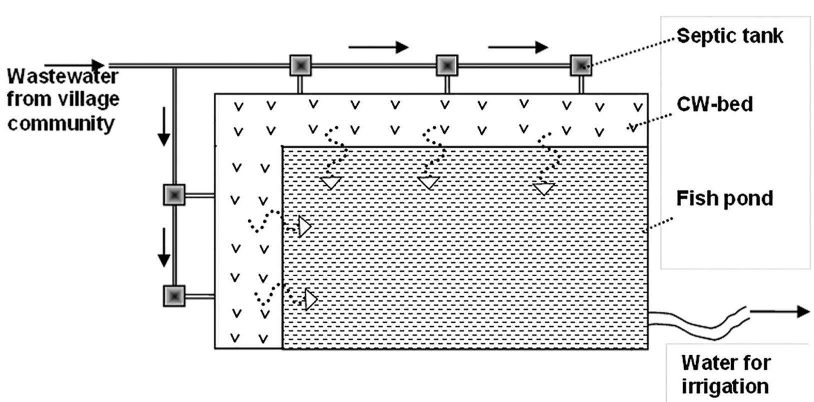

Figure 10.11 Flow diagram of the septic tanks overflowing into the HSSF-CW of approximately 0.5 MLD capacity percolating treated wastewater into a fish pond for further polishing in Pipar Majra, a rural community in the District Ropar, State of Punjab in northern India.

Figure 10.12 Outflow of septic tank connected to the HSSF-CW having *Typha latifolia*.

Figure 10.13 Treated wastewater percolated from wetland bed into the fish pond.

The overall O&M of the system was found to be satisfactory. Reportedly, the capital cost incurred for establishing this WWTP was ≈EUR 25,000. Presently, the WWTP is under stress clearly reflected by the obvious sign of clogging in the bed. The problem of bed clogging arises because of improper functioning of the primary treatment unit. The improper functioning of the septic tank arises due to negligence of operating agencies, because de-slugging of the septic tank is not performed regularly. Due to the improper functioning of the settling unit, the floating sludge from septic tank continues to enter the CW bed which results in clogging. The system may degrade beyond possible recovery if proper action, particularly immediate cleaning of septic tank is not given.

The local residents reported that prior to the establishment of CW, the untreated wastewater from the village accumulated in many ponds around the village – which created a number of problems including mosquito breeding and foul odour. The CW system has noticeably improved the sanitation in the community.

10.3 RESULTS AND DISCUSSION

There is high potential to (re)use the treated effluent from CW systems. For that, infrastructure should be in place for transferring the treated effluents from the treatment plants to the site. The effluent from CWs could also be used in some industrial processes after suitable post-treatment. Finally, artificial recharge of the treated effluent from NTSs is another attractive option to polish the effluent quality and to replenish the depleting groundwater levels in different places of India if groundwater quality is not endangered by the infiltration. However, there exists a potential danger of infiltrating persistent toxic organic pollutants, trace metals, pathogenic bacteria and viruses into the receiving aquifer. Therefore, it could be desirable to take a balance view in the context of adequate scientific information before such steps are implemented on large scale.

In most of the cases, properly operated systems of wastewater treatment based on CWs are able to achieve up to 3–4 log reduction in pathogenic bacteria count. In some cases, complete removal of pathogenic bacteria has also been reported. More importantly, natural die-off of pathogenic bacteria may be the best way because it does not require adding any potentially harmful substances like chlorine into the wastewater (the conventional practices used for disinfection). Most chemical and physical methods used to disinfect the wastewater (except chlorine) are either costly or ineffective for long-term practice, therefore CWs provide one of the most appropriate ways of reducing the pathogenic count without adding any harmful by-products to the wastewater.

There are different lessons that could be articulated based on the three case studies presented in Section 10.2. It must be noted that the three locations were deliberately chosen for developing a deeper understanding of strength and weaknesses of establishing engineered CW as the "technology of choice" for addressing the issues associated with management of wastewater in the context of a variety of situations. For example, it was recognized at the outset that the challenges faced by an urban local body (ULB), while restoring and rejuvenating a lake or a river subjected to the input of wastewater in the respective city or town, are completely different when compared with the challenges faced while treating domestic wastewaters generated by any peri-urban or sub-urban community. Likewise, both the techno-economical and the socio-cultural considerations play a crucial role when wastewater generated in a rural community need to be managed successfully.

There are two aspects to consider when assessing the effectiveness of CW as a technology during planning and designing a WWTP for a given community. First, the techno-economic evaluation of CW – especially if the technology is capable of delivering suitable quality of treated wastewater acceptable to the regulatory agency and the municipal administration. Second, the equally pertinent consideration should be the affordability and manageability of the technology. Arceivala and Asolekar (2006) have emphasized these two aspects as the most relevant and critical for determining if a specified technology is "appropriate" in a given technological and socio-economic context.

10.3.1 Highlights of the performance of selected case studies

Kumar and Asolekar (2014a, 2014b) have described the detailed results of nation-wide survey of NTSs in general and CWs in particular. The summary of the performance of the three CWs selected for in-depth study across India, as described in the prior section, is depicted in Table 10.1.

Table 10.1 Summary of the performance of the three shortlisted HSSF-CW across India based on analyses of the data reported by the respective operators. The values for BOD_5, COD and Faecal coliforms (FC), indicative of efficacy of treatment of the respective WWTPs (expressed as the ratios of the typical outlet to inlet concentrations).

Location of WWTP	Capacity	% Removal (Average Annual Performance)		
		BOD_5	COD	FC
HSSF-CW at Mansagar Lake, City of Jaipur,State of Rajasthan, India	7.8 MLD	50–96%	75–87%	99.99%
HSSF-CW in Katchpua slum, City of Agra, State of Uttar Pradesh, India	0.05 MLD	61%	64%	90 to 99%
HSSF-CW in Pipar Majra, a rural community in the District Ropar, State of Punjab, India	0.5 MLD	85–87%	Not available	99.90%

The values for BOD_5, COD and FC, which are indicative of the efficacy of HSSF-CWs, were expressed as the ratios of the typical outlet to inlet concentrations in the respective locations. It can be concluded from Table 10.1 that the engineered CWs are apparently relatively more effective in removing the biodegradable organic pollutants in wastewater (indicated by BOD_5 and COD). However, the systems are not as effective in removing of FC (3–4 log-reduction) as was observed for WWTPs. It was argued by Kumar and Asolekar (2014a, 2014b) that the NTSs (particularly CWs) are known for removing pathogenic entities relatively more effective when compared with the technologies typically employed in conventional WWTPs (e.g. ASP, trickling filters, extended aeration, sequential bio-reactor etc.).

The performance of CWs with respect to the removal of FC (Table 10.1) is typically better by one to two orders of magnitude than conventional wastewater treatment technologies. However, there is, as pointed out by Kumar and Asolekar (2014c) and Kumar *et al.* (2014), still room for further development of techniques to enhance the performance of CWs through targeted research and development. Some of the details of those strategies and the lessons learned from pilot-scale experimentation were also highlighted in Chapter 9. Clearly, the need for effective post-treatment is vital if one intends to reuse treated wastewater for irrigation applications involving physical contact and for other higher end-uses.

10.3.2 Lessons learnt from rejuvenation of Lake in the city of Jaipur

In case of the Mansagar Lake, the City of Jaipur was disposing nearly half of the wastewater generated by the metropolis into the lake. It continued for over two decades and the lake deteriorated to a condition of a big cesspool. The surrounding peri-urban community and the visitors of Jalmahal monument were troubled by stench, ugly sight and mosquito menace. As described earlier, droughts and excessive abstraction from the lake for irrigation had converted the lake in a sludge bed. It was in this context, the engineered CW (of HSSF-CW type) was devised to provide a first-rate tertiary treatment providing daily make-up flow of 7.8 MLD to the lake.

Interesting to note that the original ecosystem of the lake and the surroundings had been completely destroyed as a result of the long-term onslaught of untreated wastewater and urban run-off into the lake. Therefore, the real challenge was to revive the aquatic ecosystem in the desert environment. This was achieved through implementing the two kinds of interventions. The first challenge was to bring make-up water of suitable quality and quantity to the lake, desirably every day, so as to maintain the adequate depth of water in the lake throughout the year. The second challenge was the propagation of the aquatic and terrestrial ecosystem within the water-body and on its periphery. Both these challenges were, in fact, interdependent.

It was not practical to hope that the community would support the ecosystem in the lake without ensuring the sustained outflow for benefit of their farms downstream. Thus, the survival of lake as well as rejuvenation of the ecosystem had to be engineered with the help of “appropriate technology” that was capable of providing adequate quantity and quality of water (acceptable levels of BOD_5, TSS, nitrogen and phosphorus). Incorporation of the engineered CW for providing the tertiary treatment to upgrade the output from the adjoining WWTP, worked-out to be the practical solution.

Clearly, the efforts directed to up-gradation of the Lake ecology has been one of the most spectacular benefits – both, for the ecosystem as well as tourism. The downstream community of the farmers was probably the other spectacular beneficiary. Before the rejuvenation of Lake, the farmers were using untreated or partially treated wastewater intermittently available somehow to satisfy their irrigation needs. The lake now is capable of discharging adequate quantity and quality of water for irrigation throughout the year.

10.3.3 Lessons learnt from decentralized treatment of wastewater from a peri-urban community in Agra

Resulting from rapid industrialization over the past three decades in India, the workforce has been migrating to urban centres in an unprecedented manner. Concurrently, the number of peri-urban and slum communities situated on the periphery of such industrialized urban centres is escalating exponentially across India (Asolekar *et al.*, 2013). The inadequate infrastructure for providing sanitation in such highly populated peri-urban and slum communities have typically worked synergistically to aggravate the public health-related challenges. The Katchpura Slum, a peri-urban community within the limits of Agra Municipal Corporation, is a typical community facing challenges arising from its location, population density and status of sanitation.

Nearly 7,500 cities in India are struggling to manage resource consumption and sanitation-related challenges. Clearly, ULBs that provide sustainable solutions and that are successful in motivating local communities to get involved while addressing these challenges are thriving. In that sense, the intervention in Katchpura Slum may be seen as a winning example of achieving integrated development through adoption of inclusive approaches. Kumar and Asolekar (2014c) have emphasized the significance of the decentralized approach adopted in the Katchpura Slum as one of the valuable examples of bringing about the so-called “integrated development” of a slum community with the help of an inclusive management approach.

10.3.4 Lessons learnt from decentralized treatment of wastewater from a rural community

Yet another interesting application of engineered CW was found in the village of Pipar Majra in the district of Ropar, State of Punjab. The HSSF-CW was employed to treat the wastewater generated by the rural community in Pipar Majra. The WWTP has been treating domestic wastewater to such an extent that nearly every drop of the treated wastewater is put to some gainful economic as well as ecological use. In that sense, the WWTPs can be termed as so-called "zero liquid discharge" facilities.

The treated wastewater at the outlet of HSSF-CW is collected in a pond having a natural clay liner installed at the bottom to minimize percolation losses. Interestingly, the pond also serves as a flood protection installation by virtue of its location within the rural community and special care was taken in designing the facility to ensure that the surface water run-off could easily be drained into the pond in the event of flash floods. A lift-irrigation facility has also been devised for the benefit of the agricultural community. There are three noteworthy features of this pond, namely:

1) The storm water run-off collection into the pond brings a lot of water to the pond providing dilution to the pond water as well as flood protection for the surrounding community.
2) The daily addition of treated wastewater ensures an adequate make-up of the water, both in terms of quality and quantity.
3) The abstraction of water through the lift-irrigation system provides blow-down of the residual water of the pond – thereby minimizing salinity, suspended solids, total phosphorus and any toxic micro-pollutants.

In addition to the special features described above, the pond has been serving the community by harbouring a sustained population of fishes, which has in fact become an income source for fishermen. The Ministry of Rural Development, Government of India has been encouraging the creation of ponds in rural communalities through the "MGNREGA Schemes"–especially in land-locked settings (like village Pipar Majra) to ensure increased flood protection and to provide water for irrigation. Arguably, as highlighted by Kumar and Asolekar (2014, 2014b), the WWTP facility in Pipar Majra combines some of the most desirable features, including use of eco-centric technology, production of a better quality of treated wastewater and creation of a pond within the village which provides irrigation water and flood protection for the surrounding community.

10.3.5 Typologies of failures of constructed wetlands and remedial measures

Based on the survey of NTSs in general and CWs in particular (especially those from sites visited for in-depth study) several insights into the typologies of failure of engineered CWs were articulated. As depicted in Table 10.2, the three sites investigated for the in-depth study formed the basis of the analyses presented in the table. However, the lessons learned should not be viewed as restricted to the respective sites because the case studies have addressed a diverse variety of institutional situations and technology related issues. It is hoped that the lessons learned in this analyses will prove to be significant and helpful during future efforts of implementation and replication.

As summarized in Table 10.2, the poor O&M of the eco-centric technology typically results from inadequate primary treatment in almost all cases. Clogging of the porous media can have a domino effect on the efficacy of all the unit operations included in the treatment train. Another common challenge has been insufficient funds for O&M. One of the cardinal principles used in India's environmental jurisprudence is: "the polluter pays!" Unfortunately, the institutional arrangements are either too weak or non-existent when it comes to collecting and utilizing the fees from the "users or polluters" who are sending their wastewater to the WWTP (Arceivala & Asolekar, 2012).

In that sense, the CWs at Lake Mansagar, as described in sections 10.2.1 and 10.3.2, did not face any financial crises because the quality of secondary treated wastewater is ensured by the Jaipur Municipal Corporation and the O&M of the phosphorus precipitation plant and CWs has been taken care of through the PPP arrangements.

As regards to the social challenges, it is now clear that the modalities of access to the harvested biomass and entitlement of the community owning the WWTP based on CWs will need to be worked out in more detail and mutually agreed upon. In absence of such systematic efforts, it has been observed that communities feel alienated from the wetland beds. Such negative impression discourages the operators of the WWTP even further to the extent that no user fees are charged at all and O&M deteriorates further.

Finally, the success of the WWTP largely depends on the balance between the realistic inlet quality and quantity of wastewater and the expectation of the community to treat it for certain kinds of reuse applications. The three selected case studies presented have categorically underscored these facts. Over the years, the demography, land-use pattern, economic activity and the extent of industrialisation has been transformed to a new state of equilibrium. Thus, the proportion of domestic and industrial effluents will vary and the WWTP may become relatively obsolete or redundant. This, however, is not only true for WWTPs based on CWs but also for other wastewater treatment technologies.

Table 10.2 The typologies of failure based on the analyses of data and experiences collected from site visits to the three shortlisted HSSF-CW across India.

Sr. No.	Typology of Failure	Jaipur	Agra	Ropar
1	Poor O&M	No issue was observed	No issue was observed	Poor maintenance of primary treatment unit leads to carry-forward of garbage and solids in the wetland bed and system experiences clogging. Harvesting of vegetation is not done. This has led to the dead plants falling on the wetland bed.
2	Financial crises	No issue was observed	It is well known that the system performance can be improved by ensuring release of sufficient funds for the O&M periodically.	It is well known that the system performance can be improved by ensuring that adequate work-force is employed and sufficient funds are provided for the O&M.
3	Social issues	Due to lack of fencing around the CW-bed, domestic animals usually eat the biomass which affects the performance of the systems.	No issue was observed	No issue was observed
4	Mixing of industrial toxic effluents with wastewater	The facility is suffering with the mixed type of industrial toxic wastewater from dyestuff industry, which has toxic effects.	No issue was observed	No issue was observed

10.4 CONCLUSIONS AND LEASSONS LEARNT

Over the past two decades municipalities have been making efforts to address the challenge posed by inadequate and insufficient infrastructure for treatment of wastewater throughout India, both, of urban as well as rural communities. The Ministry of Urban Development, the MoEF as well as the MoWR and Ganga Rejuvenation have been incorporating the strategy of providing low-cost eco-centric treatment to wastewater to counteract the pollution of natural watercourses in India. In the recent past, many states in the Union of India have been taking steps to develop and implement plans for strengthening systems to provide sanitation in sub-urban, peri-urban and small communities. As reported in Chapter 8, it was observed that the shortfall between the quantities of wastewater generated *versus* quantity treated has been increasing. It is in this context, municipalities serving small communities are looking for alternatives that are eco-friendly and inexpensive when it comes to capital and O&M costs. Several CWs were surveyed during the national survey from December 2011 to June 2014. Three WWTPs based on CWs were studied in more detail. The salient conclusions and learnings from these case studies are summarized below:

1) HSSF-CWs have been adopted worldwide for treatment of wastewater and biodegradable industrial effluents, especially in developing countries.
2) The WWTPs based on CW technology have been found to be quite effective for the treatment and reuse of wastewater generated by rural and town communities across India.
3) The engineered CW systems seem to be quite robust and versatile in a variety of climatic conditions across India and meet the prescribed regulatory standards.
4) Communities seem to prefer them even more in the recent times due to the CWs' innate advantages of minimizing mosquito breeding and thereby minimizing the threat of cerebral malaria, dengue and several vector-borne diseases.

5) Several CW-based WWTPs have been designed and implemented for wastewater treatment and reuse across India including the remarkably successful system in the City of Jaipur, which has transformed Lake Mansagar and rejuvenated its ecosystem, the CW in Katchpura Slum of City of Agra and the CW-pond in the rural setting of Pipar Majra of the Ropar District.
6) Primary treatment plays an important role in trouble-free O&M of HSSF-CWs. Therefore, adequate primary treatment should be designed, installed as well as operated in any WWTP based on CW.

In summary, the engineered CWs, in conjunction with adequate primary treatment and suitable tertiary treatment, present the possibility of producing treated effluents of rather high quality. Such treated effluents can be used for irrigation, gardening and even for recharging into contaminated urban lakes and ponds. In addition, the CWs are simple to operate and can be easily combined with cultivation of fodder, production of recyclable water, production of fuel, production of timber for the pulp and paper industry as well as up-gradation of lake or river ecosystem and to create habitats for fishes and birds. Strengthening institutional arrangements and financial provisions, which is conducive for incorporating engineered CWs in WWTPs as well as for motivating communities to own and operate decentralized systems, is going to be a vital task to be addressed by the municipalities in the years to come.

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