Chapter 8

Constructed wetlands and other engineered natural treatment systems: *India status report*

Dinesh Kumar, Saroj Kumar Sharma and Shyam R. Asolekar

8.1 INTRODUCTION

India has one of the largest numbers of small and medium enterprises (SMEs) engaged in a variety of sectors including petrochemical, fertilizer, fine chemicals, pharmaceuticals and intermediates, dyes, paints, pigments as well as automobile and mechanical jobbing industry. Subsequent to the liberalization of economy and industry in the later part of last century, India has seen a tremendous growth in industry as well as urbanized population. As a result, the Government of India (GoI) has been investing in the expansion and strengthening of urban infrastructure sectors over the past three decades. In that context, there have been systematic efforts of up-scaling of facilities for treatment and distribution of drinking water as well as collection, treatment and disposal of wastewater (Arceivala & Asolekar, 2006; Asolekar *et al*. 2013).

The task of treatment and disposal of effluents generated by large-scale industries appear to be relatively under control when compared to the challenge posed by SMEs. Barring the few exceptions, the situations pertaining to collection, treatment and disposal of wastewater in cities and towns continue to be inadequate in most of the municipalities in India (Arceivala & Asolekar, 2012; Kalbar *et al*. 2013). Furthermore, the challenge of treating wastewater generated by rural communities has not even been addressed.

8.1.1 Significance of natural treatment systems in the context of India

As reported by Asolekar (2002), disposal of untreated or partially treated effluents into rivers and lakes as well as run-off from urban and agricultural areas are the two main reasons responsible for deterioration of drinking water resources in India. It is clear that less than 10% of the generated wastewater are treated effectively, while the rest of the wastewater find their ways into the natural ecosystems in the vicinity. In addition, excessive withdrawal of water for agricultural and municipal utilities as well as use of rivers and lakes for religious and social practices and perpetual droughts limit the capacity of natural water sources to provide adequate dilution (Asolekar, 2002; Asolekar *et al*. 2013; Starkl *et al*. 2013; Chaturvedi *et al*. 2014).

According to the statistics of year 2005, presented by Chaturvedi and Asolekar (2009) on wastewater management in India, about 26,000 MLD of wastewater was reportedly collected cumulatively in two mega cities (population above 5 million), 11 large metro cities (population from 2 to 5 million) and 26 small metro cities (population from 1 to 2 million), 384 class I cities (population from 100,000 to 1 million) and 498 class II cities (population between 50,000 and 100,000). These urban centres are inhabited by more than 70% of India's 500 million urban population. Overall, merely 27% of urban wastewater received some kind of treatment.

The statistics of year 2009 revealed a similar trend. In all, 38,254 MLD of wastewater were generated from class I cities and class II towns but only a treatment capacity of 12,000 MLD existed (Central Pollution Control Board (CPCB), 2009). The class I cities of India are contributing about 93% of total wastewater generated by class-I cities and class-II towns. The wastewater generated in class-I cities was estimated to be 35,558 MLD and treatment capacity exists for only 11,553 MLD in these cities, *i.e.*, only 32% of wastewater is being treated, whereas the rest is disposed untreated. In India, there are 35 metropolitan cities (with a population of more than 1 million) which are generating wastewater of 15,644 MLD but the existing treatment capacity is 8,040 MLD, which is only 51% of the total wastewater generated in these cities. The generated wastewater in class-II towns was estimated as 2,696 MLD and only 233 MLD treatment capacities exist in these cities, which show that only 8% of wastewater is being treated. Thus, there is a large gap between the amount of wastewater generation and treatment in India. Due to disposal of the untreated wastewater into water bodies, both surface and groundwater are being contaminated. The Central Pollution Control Board (CPCB) (2009) also reported unsatisfactory operation and maintenance (O&M) of existing wastewater treatment plants (WWTPs) and pumping stations, as nearly 39% WWTPs are not conforming to the minimum standards prescribed under the prevailing regulatory standards meant for disposal of treated wastewater into rivers and lakes (receiving water bodies).

The use of natural treatment systems (NTSs) for treatment of domestic wastewater was practiced in ancient India. The community tanks in villages, water bodies maintained by temples for performance of religious functions and crimination rites, irrigation systems installed and maintained in community-joint forests invariably received controlled flows of wastewater. These were some of the noteworthy examples of sustainable wastewater management in India's village ecosystems (Jana, 1998; Chaturvedi & Asolekar, 2009).

At the level of the Central Government, the Ministry of Rural Development, the Ministry of Urban Development, Ministry of Environment and Forests (MoEF) as well as Ministry of Water Resources (MoWR) and Ganga Rejuvenation have been incorporating the strategy of providing low-cost eco-centric treatment to wastewater for correcting the pollution of natural water courses in India. The Jawaharlal Nehru National Urban Renewal Mission and several programs have been implemented by the GoI over the past three decades. Similarly, the State Governments in the Union of India have also been complimenting efforts in the respective states and favouring the decentralized treatment technologies to address issues associated with disposal of wastewater.

8.1.2 Scope and objectives

Clearly, there exists a looming challenge of inadequate and insufficient infrastructure for treatment of wastewater throughout India, both in urban as well as rural communities. The Union of India has exhibited a serious commitment to fulfilling this basic necessity of rural and urban communities – responding to the political pressure exerted by them. For example, as reported by Asolekar (2013), in the context of rejuvenation and ecological up-gradation of the Ganga River, the entire North of India (almost 400 million people) has forged an alliance on political and social platforms.

Currently, the Honourable Supreme Court of India has ordered the responsible State Governments in the Union of India, including the MoEF, to ascertain that the untreated and partially treated wastewater shall not be disposed into the tributaries and main stream of Ganga River. Already, over the past two decades, there have been concerted efforts in the direction of up-scaling of infrastructure for wastewater treatment all over India. On one hand, there are several communities waiting eagerly to be included in the programme for improving sanitation, while on the other hand, the budgets allocated to wastewater treatment facilities are not adequate.

At such a crossroad, identification and adoption of so-called "appropriate technological solutions" will become more critical than ever – especially in a developing economy like India (Kalbar *et al.* 2012). As argued by Kumar and Asolekar (2015) the broad class of engineered NTSs- including horizontal sub-surface flow constructed wetlands (HSSF-CWs) – will continue to dominate the platform of favoured technologies for treatment and recycling of wastewater in warmer climates and increasing of the unmet demand for waters for irrigation and industry.

In this context, an attempt has been made to assess the status of engineered NTSs, including HSSF-CWs installed all over India, in order to manage wastewater and in some cases mixed with biodegradable industrial effluents. In this study, however, the other NTSs such as riverbank filtration (RBF), soil aquifer treatment (SAT), managed aquifer recharge (MAR) or some other riparian zone technologies to address agricultural and urban run-off have not been included and are addressed in other chapters.

Currently, in India, there are substantial efforts to incorporate NTSs into wastewater treatment facilities in smaller communities. However, not all the facilities are working satisfactorily nor meet the design and regulatory expectations. Typologies of the reasons behind their failure and success have also been articulated in this chapter. It is hoped that the assessment presented in this chapter may also be helpful for the planners and implementing agencies in developing countries like India in meeting the challenge of wastewater treatment in the years to come with the help of low-cost and eco-centric technological interventions.

8.2 METHODOLOGY

The survey focused on HSSF-CWs and other NTSs currently employed in treatment of domestic wastewater in India. The prior experience of Asolekar and co-workers influenced this survey (Chaturvedi & Asolekar, 2009; Asolekar *et al.* 2013).

In all, five technologies practiced at various locations in India were selected for site assessment, namely: HSSF-CWs, duckweed ponds (DPs), waste stabilization ponds (WSPs), polishing ponds (PPs) and Karnal-type constructed wetlands (KT-CWs) for on-land disposal of wastewater.

8.2.1 Questionnaire for the survey and identification of the sites

Before starting the activities related to assessment of the potential of existing HSSF-CWs and other NTSs for wastewater treatment and reuse across India, a questionnaire was developed for collecting data from the field. The questionnaire was developed after a broad discussion with experts working in the area of natural treatment technologies as well as with the partners from the Saph Pani Project to incorporate various data requirements. Appendix 8.1 exhibits the questionnaire utilized during the field survey. As can be noticed the questionnaire includes three kinds of data about a given field site; *viz*. first, the technical data, second, the data on economics and finally, the social and consumer related data.

The primary aim of identification of prospective sites for field investigation was to identify and seek permission from the respective municipal authorities to investigate if the potential of the NTSs installed for treatment of the wastewater generated by the respective communities is met in reality. In addition, it was hoped that the choice of sites would be representative of the actuality of the technology practiced today in the context of municipal wastewater management. After all, the real proof of the utility of the survey proposed in the research lies in the fact that the concerned development and implementing agencies would find the learnings from the survey useful for development and monitoring of wastewater treatment facilities. Numerous sites of HSSF-CWs and other NTSs were found all over India (Appendix 8.2).

A closer look at the 108 sites listed in the Appendix 8.2 and in the light of information collected in the reconnaissance survey; it was decided to study around one third of the sites through a questionnaire survey so that the conclusions drawn from the survey would be of practical relevance. Thus, 41 sites were finally shortlisted for administering the questionnaire survey for this study.

8.2.2 Data collection and assessment

A tentative list of engineered HSSF-CWs and other NTSs was prepared after discussion with various water and wastewater practitioners as well as governing and regulatory bodies, including state pollution control boards, public health engineering departments of different states, and water and sewerage boards. A literature review was also carried out in order to select the most appropriate and representative sites for assessment. After identifying the potential representative sites of HSSF-CWs and other NTSs across the country, the identified sites were visited in order to obtain the relevant information mentioned in the questionnaire. The specifications and the data related with the identified sites of HSSF-CWs and other NTSs were cross-checked with plant operators onsite during the visit and were documented in the database. It aimed at understanding technical and management related facts as well as obtaining qualitative description of the issues faced while providing the treatment at the respective wastewater treatment facility.

The 41 identified sites of WWTPs were visited during the survey and secondary data were collected by interviewing the operating staff of the respective WWTPs as well as by utilizing the literature, log books, and progress reports supplied by the respective personnel. The data were logged into the questionnaires in the sections covering technical, physical, geographical as well as social aspects of the respective engineered systems. The assessment of selected WWTPs were planned and performed by visiting the shortlisted sites at least once (in some cases even twice or thrice). A two-step approach was adopted during the field work: first, the rapid national survey of identified engineered HSSF-CWs and other NTSs and second, the detailed assessment of selected representative sites.

In summary, 41 WWTPs based on engineered natural treatment technologies (WSPs, PPs, DPs, HSSF-CWs and KT-CWs) were surveyed between December 2011 and June 2014. In addition to collecting the technical data, views of the personnel related to the difficulties faced in routine and episodic O&M were also recorded. This assessment intends to highlight some of the more intricate and counter-intuitive lessons which can potentially be used for up-grading of technologies and effectiveness of NTSs in the Indian context as well as for articulation of policy and regulatory reforms in India.

8.3 RESULTS AND DISCUSSION

The data collected during the field survey was analysed from mainly three perspectives:

1) Performance of WWTPs based on engineered natural treatment technologies in India,
2) Problems associated with O&M of NTSs across India, and
3) Issues associated with management of wastewater in India

8.3.1 Performance of WWTPs based on engineered natural treatment technologies in India

Secondary data on performance of the WWTPs, reported by the respective operators of 41 shortlisted facilities across India, were collected through field visits over the period of 2.5 years. Table 8.1 summarizes the indicative statistics on efficacy of the technologies (values for Biological Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD) and Faecal Coliforms (FC)) expressed as the ratios of the typical outlet to inlet concentrations.

Table 8.1 Summary of the performance reported by the respective operators of 41 shortlisted NTS-based WWTPs across India. The values for BOD_5, COD and FCs, indicative of efficacy of the technologies, were expressed as the ratios of the typical outlet to inlet concentrations.

Types of NTSs	Number of Sites	Average Annual Performance (% Removal)		
		BOD_5	**COD**	**Cs**
WSPs	23	50–96	62–82	90–99.3
PPs	7	33–69	17–46	90–98.75
DPs	3	89–95	NA	94.5–99
HSSF-CWs	6	61–93	64–90	99–99.99
KT-CWs	2	NA	NA	NA
Total	41			

The national survey of HSSF-CWs and other NTSs indicates that nearly 76% of the WWTPs investigated were generally achieving the *Minimum National Standards* stipulated by the MoEF (GoI) for disposal of treated wastewater into legally permitted surface water bodies; or for the purposes of land irrigation as prescribed in the *Water (Prevention and Control of Pollution) Act*, 1974 and companion regulations.

It is to be noted that the *Minimum National Standards* stipulated by the MoEF for disposal of treated wastewater into ambient aquatic environment were meant to be the guideline for ensuring the “minimum” performance expected from a given municipality. There are several communities, however, who believe in achieving much higher performance with respect to the quality of their treated wastewater so as to minimize the impacts on surrounding aquatic bodies. The local self-governments as well as the regulatory authorities are fully empowered under the prevailing environmental regime to make such determinations and implement these stringent standards at local levels on a case-to-case basis in consultation with the community and the stakeholders. Also, several communities (especially the ones that are land-locked) have no receiving water bodies for disposal of their treated effluents. There are several other locations where farms and city-spaces have been facing acute shortages of water for irrigation. In such instances, the MoEF and MoWR have been permitting land irrigation with treated wastewater meeting certain norms acceptable to the regulatory framework and have judiciously monitored the crops and vegetation in agriculture and commercial agro-forests. Thus, the GoI has developed and implemented the *Minimum National Standards* for disposal of treated wastewater into ambient aquatic environment as well as for on-land application for irrigation (as shown in Table 8.2) in conjunction with several other standards and safe-guards built into the prevailing regulatory framework.

Table 8.2 The Minimum National Standards stipulated by the MoEF (GoI) for disposal of treated wastewater into legally permitted surface water bodies or for the purposes of land irrigation through the Water (Prevention and Control of Pollution) Act, 1974. (Information based on CPCB, 2005).

Parameters	pH	BOD_5 [mg/L]	COD [mg/L]	TSS* [mg/L]	TDS** [mg/L]
Standards for discharge in streams	5.5–9	30	100	100	2100
Standards for land irrigation	5.5–9	100	–	200	–

* Total Suspended Solids (TSS)
** Total Dissolved Solids (TDS)

Local standards and guidelines, as discussed above, play a crucial role in making decisions with respect to the extent of treatment to be adopted as well as in determining the type of technology to be implemented for treatment of wastewater in a given community. It was clear after the national survey that nearly all the administrators and decision makers in the respective communities had thoughtfully gravitated to “engineered natural treatment systems” for treatment of wastewater generated by their communities. Responding to the local requirements, a variety of NTSs have apparently been chosen by the 41 communities investigated in the present survey. The relative distribution of numbers of facilities based on technologies employed by them is depicted in Figure 8.1. Out of the 41 selected WWTPs based on engineered natural treatment technologies, 23 plants had WSPs, three plants had DPs, seven plants had PPs and eight plants employed HSSF-CWs or KT-CWs.

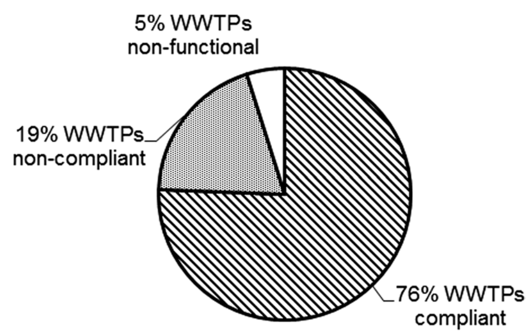

Figure 8.1 Distribution of cumulative number of WWTPs in various compliance categories among the 41 WWTPs surveyed during December 2011 and June 2014.

The relative distribution of numbers of WWTPs in various compliance categories among the 41 facilities surveyed during December 2011 and June 2014 is displayed in Figure 8.1. Similarly, Figure 8.2 presents the relative distribution of WWTPs in various compliance categories among the 41 facilities surveyed all over India. Typically, technologies like HSSF-CWs, KT-CWs as well as DPs seem to cater to the communities, generating relatively smaller flow rates of wastewater compared to technologies including WSPs and PPs. These data clearly suggest that size of a given community has a lot to do with selecting centralized versus decentralized technology for management of their wastewater.

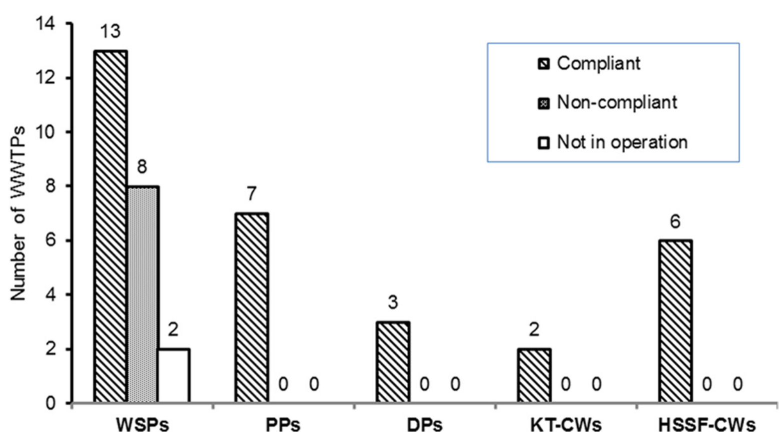

Figure 8.2 Compliance status of individual technologies among the 41 WWTPs.

8.3.2 Natural treatment technologies practiced in India

A detailed review of a variety of NTSs practiced in Asia in general, and India in particular, is presented in various chapters of this Handbook and also by Arceivala and Asolekar (2006). Most of the NTSs consist of a train of individual unit processes, set-up in series, with the output of one process becoming the input of the next process. The first stage usually comprises physical processes that take out pollutants in a physico-chemical manner. After this, biological processes generally further treat the remaining pollutants. These may 1) convert dissolved or colloidal impurities into a solid or gaseous form, so that they can be removed physically, or 2) convert them into dissolved materials, which remain in solution and typically are not as undesirable as the original organic pollutants. The solids (residuals or sludge) which result from these processes form a side-stream and are typically treated for further stabilization and desirably converted into manure or soil conditioners and disposed of into the farms and commercial agro-forests and green city-spaces in the vicinity. These practices, however, are customarily regulated by the empowered agencies so that the stabilized sludge does not introduce trace toxic metals and other pollutants typically emitted by industrial activities into farms and soils and thereby contaminate food.

Typically, WWTPs based on WSPs consist of a cascade of ponds. These ponds can be classified into three classes: 1) anaerobic ponds, 2) facultative ponds and 3) aerobic ponds. Alternately, on the basis of water depths, ponds may also be divided into two classes: a) shallow ponds and b) deep ponds. Shallow ponds (typical water depths <2.5 m) include conventional aerobic ponds as well as polishing or maturation ponds with marginal facultative conditions near the sediment-zone. The deep ponds (typical water depths >2.5 m) include facultative ponds having aerobic, facultative and anaerobic layers. The ponds are also at times anaerobic owing to their greater depths of 5 to 10 m. The generalized treatment processes adopted at most of the NTSs surveyed in this study (based on WSPs) are shown in Figure 8.3(a).

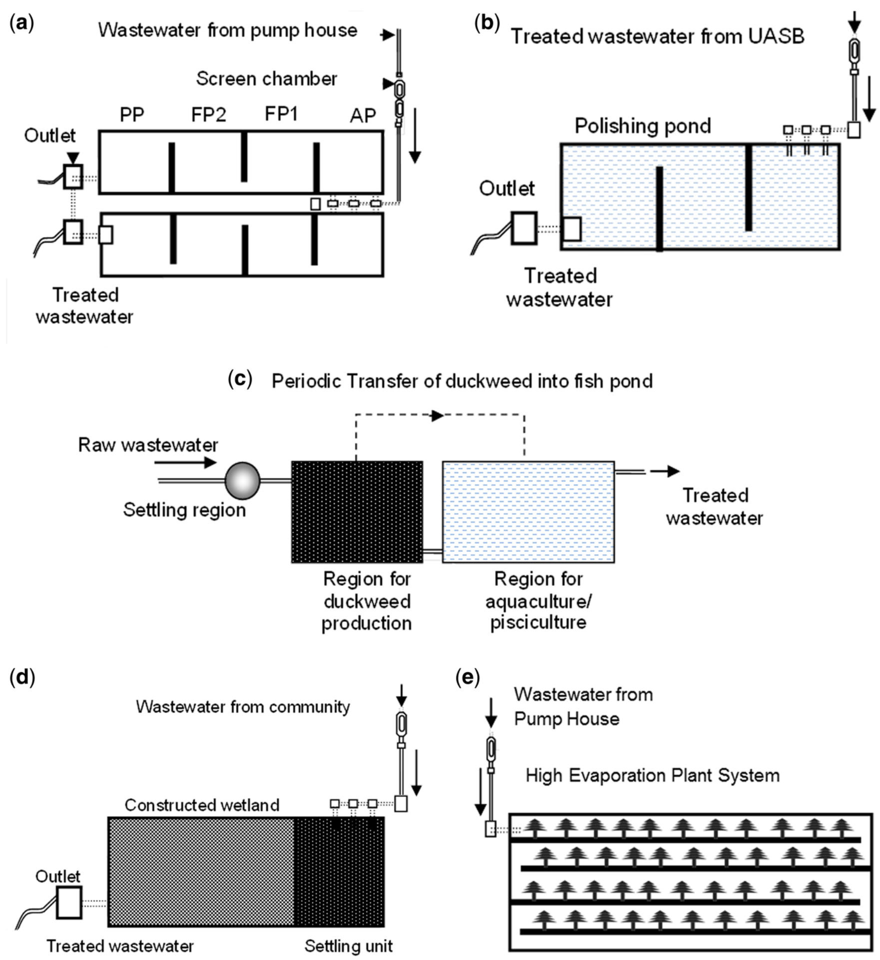

Figure 8.3 Schematic representation of the five natural treatment technologies typically installed in the 41 WWTPs surveyed across India: (a) Waste stabilization pond, (b) Polishing pond, (c) Duckweed pond, (d) Horizontal sub-surface constructed wetland and (e) Karnal-type constructed wetland.

The WWTPs based on the eco-centric technology of the DP has typically three treatment units, namely: 1) settling tank, 2) DP and 3) fishponds. After settling, the primary treated wastewater is subjected to a DP, where major reduction in carbon, nitrogen and phosphorus from the wastewater take place. The DPs are known for their combined action of phytoplankton, zooplankton and bacteria. Thus, the secondary treated wastewater from the DP finally is let into a fishpond to provide further polishing. The fishponds typically perform two functions. First, they provide some kind of polishing to the secondary treated wastewater. Second and more importantly, they consume the duckweed and algae and in response produce more fish – which could be harvested and sold in the market to make a profit and earn a livelihood. It is interesting to note that the duckweed generated in response to treatment in the DPs need to be routinely harvested and transferred into the associated fishponds to feed the fishes. The duckweed typically doubles its mass in two to three days under supportive conditions of nutrients, sunlight and temperature. The algae, however, are developed in fishponds in response to algal-bacterial "polishing" of secondary treated wastewater. Thus, treated wastewater emerging from DPs can be safely used for irrigation. Sizes of different treatment units in such systems are customarily estimated on the basis of biological kinetics of degradation of duckweed pond and fishpond, life cycle of fishes, climatic conditions and feasibility of land available.

The typical flow sheet for duckweed-fed aquaculture for wastewater treatment adopted at most of the places is depicted in Figure 8.3(c). At many places in India, DP systems have been found to be quite effective for treatment and reuse of rural wastewater. Also, they seem to perform well in various climatic conditions across India as well as meeting the prescribed regulatory standards.

One of the most commonly encountered systems for treatment of wastewater in rural areas and small urban communities across India is the so-called "constructed wetland" (CW). There are, by and large, two variants of CWs encountered among the present installations in India. As a part of the shortlisted WWTPs investigated in this survey, six HSSF-CWs and two KT-CWs were studied.

CWs, first developed in 1960s by Dr K. Seidel in Germany, are now accepted to be the low-cost, eco-centric technology especially beneficial for small towns that typically cannot afford expensive conventional treatment systems (Billore *et al.* 1999; Billore *et al.* 2001; Vymazal, 2010). A CW is a simple and effective wastewater treatment approach, which consists of a shallow depression in the ground with a levelled bottom. With incorporation of sophisticated flow controls and monitoring devices, it is possible to build the WWTPs with CW-technology to exercise a higher degree of control over the process and performance (Brix, 1997; Vymazal, 2013a). CWs seem to cater for nearly any combination of wastewater and biodegradable industrial effluent.

The CWs appear to perform all of the biochemical transformations related to the degradation of a variety of pollutants present in domestic and industrial wastewater including carbonaceous, nitrogenous and pathogenic constituents (Vymazal, 2013a; Vymazal, 2013b). The CWs can be employed in place of the commonly practiced conventional wastewater treatment strategy – which is not favoured on account of it being energy intensive and ineffective in removing pathogens. In a typical rural setting, CWs appear to treat wastewater to a higher degree when compared with the more conventional rural alternatives including septic tanks, drain fields and other forms of land treatment.

The HSSF-CW requires a primary treatment to raw wastewater before treating it into the wetland-bed. A primary treatment unit is normally installed in most of the treatment systems incorporating CWs to minimise the complications normally arising due to larger debris, garbage, floating polymeric wastes and fragments of packaging materials carried with the raw wastewater. It has become clear to the operators of the CW-systems that the life of wetland-beds would prolong if the superior primary treatment units are installed to remove even fine suspended solids in the influents to the WWTPs. Three plant species were most commonly found in CWs across India, namely: *Canna indica*, *Phragmites karka* and *Typha latifolia* .The typical flow sheet for HSSF-CW for wastewater treatment adopted at most of the places is depicted in Figure 8.3(d).

It is interesting to note here that HSSF-CW-systems have been found to be quite effective for treatment and reuse of wastewater generated by rural and town communities. The engineered wetland systems seem to be quite robust and versatile in a variety of climatic conditions across India as well as meet the prescribed regulatory standards. Communities seem to prefer them even more in the recent time owing to the innate advantage offered by HSSF-CWs in the context of minimizing mosquito breeding and thereby minimizing the threat of cerebral malaria, dengue and several vector-based diseases.

The other variant of CWs, KT-CWs have been installed in some places in India – especially in land-lock regions where there was typically no option for disposal of treated effluents. These systems were found to be quite effective for achieving complete evapotranspiration of wastewater subjected to them. In addition, the KT-CWs generate fuel-wood as well as feedstock for pulp and paper industry and thus provide an opportunity to engage in commercial agro-forestry to the community. The nutrients as well as the buffer capacity typically present in wastewater can potentially create a novel opportunity of application onto acidified and infertile wastelands. Thus, KT-CWs could probably become the most appropriate and economically viable proposition for the rural areas interested in restoring wastelands as well as generate biomass.

Those tree species which are fast growing and can transpire high amounts of moisture through evapotranspiration processes and are typically able to withstand high moisture contents in their root-zones are the most suitable for KT-CWs. For example, *Eucalyptus* is one such species. It has the capacity to transpire large amounts of water, and grows rather fast – thereby giving high yield of timber and green biomass. Raw wastewater is normally applied through furrow sand trees are planted on the ridges. The typical flow sheet for KT-CWs for wastewater treatment adopted in the systems investigated in this study is shown in Figure 8.3(e).

8.3.3 Problems associated with operation and maintenance of NTSs across India

Results of the national survey of HSSF-CWs and other NTSs across India indicated that at some places NTSs have failed in achieving the prescribed standards of treated wastewater. During the field visits, many reasons responsible for failures of NTSs were identified – which are summarized in this section.

It appears that there are several problems associated with mixing of industrial toxic effluents with domestic wastewater before subjecting into the treatment facility (Figures 8.4 and 8.5). For example, as shown in Figure 8.4, the KT-CW facility, in the City of Ujjain in central India, failed due to mixing of the industrial effluent generated by dyeing industry of cotton fabrics with urban wastewater. Reportedly, the colour of the mixture of domestic wastewater and textile effluents flowing into the KT-CW was visible frequently. Clearly, as seen from Figure 8.5, the trees (especially the foliage) were found to be wilting due to the toxic effects of industrial effluents. Reportedly, among the two KT-CW systems catering to the City of Ujjain, one KT-CW received only domestic wastewater (about half of the flow of wastewater from the City). The other KT-CW received wastewater flow that was mixed with textile industry wastewater. The operator of the facilities showed the difference in vitality of vegetation in the two KT-CWs. Similar observations were also made during field visits to WSPs wherein very poor performance was found (indicated by lower average% BOD_5 removal) due the mixing of industrial effluents with domestic wastewater entering the WWTPs.

Figure 8.4 Effluent from the textile industry was mixed with domestic wastewater at the inlet of KT-CW in the City of Ujjain, central India.

Figure 8.5 Wilting of vegetation resulting from toxicity of industrial pollutants was observed.

By and large, poor O&M of primary treatment units (or absence of it) was found to be one of the major causes of failure of NTSs based on CW-technology. Figures 8.6 and 8.7 exhibit two examples of such lapses found while visiting the *Ekant Park* HSSF-CW and the HSSF-CW installed at *City WWTP*, respectively (both located in the City of Bhopal, State of Madhya Pradesh in Central India). It was evident during the site visit that there was no periodic cleaning of sludge accumulated in primary treatment unit.

Figure 8.6 Poor maintenance of the primary treatment unit prior to HSSF-CW in Ekant Park, City of Bhopal, central India.

Figure 8.7 Chocking of wetland bed was observed in the CW at Ekant Park.

Even the CW-beds faced similar negligence on part of the respective civic authorities and the failure of NTSs based on HSSF-CW was feared by the operators of the facility of CW-bed (located in the City of Bhopal) and in the outskirts of the City of Ropar, State of Punjab (in northern India), respectively, as depicted in Figures 8.8 and 8.9. At both sites, the CW-beds were chocked with weeds and unwanted growth of planted vegetation was evident. Though both WWTPs were giving satisfactory quality of treated effluents at the time of the survey, the need for systematic and disciplined harvesting of biomass as well as implementing de-weeding programme thoroughly from time-to-time cannot be overemphasized.

Similarly, in Figures 8.10 and 8.11, the poor maintenance of primary treatment units carries forward the unsettled and floating debris to the first pond (anaerobic pond) in the WSP-system installed in the *Municipal WWTP* of the City of Vrindavan, State of Uttar Pradesh in northern India. Figures 8.12 and 8.13 exhibit extremely poor maintenance of the primary treatment units in the *Municipal WWTP* of the City of Agra, State of Uttar Pradesh and in the *Municipal WWTP* of the City of Miraj, State of Maharashtra in western India. Clearly, in the case of WSPs there too is a need for sedimentation and removals of particulate matter in primary treatment unit before wastewater are subjected to WSPs. In the absence of adequate primary treatment the ponds in WSPs could not perform properly. Such WSPs were found to develop short-circuiting and bypassed untreated or partially treated wastewater through channels in sludge beds – thereby reaching the final outlets and thus resulting in non-compliance.

Figure 8.8 No primary treatment unit was provided prior to the HSSF-CW in the City of Bhopal, central India.

Figure 8.9 Poor maintenance of primary treatment unit lead to carry-forward of garbage and solids in the wetland bed of HSSF-CW in the City of Ropar, northern India.

Figure 8.10 Poor maintenance of the primary treatment unit prior to WSP in the *Municipal WWTP* of the City of Vrindavan, northern India.

8.3.4 Issues associated with management of NTSs in India

In the Indian context, water, wastewater and the associated utility services is the "state subject" *i.e.* the funding for development of sanitation projects, O&M of the facilities, monitoring of performance, general administration and revenue collection related to the utility. The important agencies involved in these functions can typically be divided into four groups, namely: 1. Urban

Local Bodies (ULBs; comprising of Municipal Corporation, Nagar Palika and Parishad and Village Council), 2. State and Central Governments (comprising of respective state governments, the Government of India, National River Conservation Directorate in the MoEF, Yamuna Action Plan and Public Health Engineering Departments in various states and in GoI), 3. Water Boards (comprising of State Jal Boards and Water Authorities, Water and Sewerage Boards and Environmental Planning & Coordination Organization) and 4. United Nations Development Programme (UNDP). Table 8.3 summarizes the number of WWTPs which received capital costs as well as number of WWTPs which are being operated by the respective agencies corresponding to the above-mentioned four groups of agencies. A detailed account of the reasons for failure (or success) has been presented in the last column of Table 8.3. Clearly, it appears that the agencies that built, commissioned and transferred the WWTPs to the ULBs for O&M were the glaring success stories. If the operating agencies plan and allocate adequate funds for O&M, the chances of success were even greater. In summary, providing capital investments to the community is as important as helping them in planning to provide adequate O&M costs.

Figure 8.11 Poor maintenance of primary treatment unit lead to carry-forward of garbage and solids in WSP in the *Municipal WWTP* of the City of Vrindavan.

Figure 8.12 Poor maintenance of the primary treatment unit prior to WSP in the *Municipal WWTP* in City of Agra.

8.3.5 Post-treatment and reuse of effluents from NTSs in India

Out of 41 NTSs investigated across India, very few (only two WWTPs) have the post-treatment facility (disinfection using chlorine gas). The summary of available post-treatments and reuse in the context of different eco-centric technologies surveyed in the present study are presented in Table 8.4. The two WWTPs employing UASB followed by PPs were found practicing chlorination, namely: in the *Municipal WWTP* in City of Kapoorthala, State of Punjab and *Municipal WWTP* in City of Agra, State of Utter Pradesh. These WWTPs reused their treated effluents for irrigation and the leftover excess treated effluents were disposed into the Yamuna River. Typically, 1–2 mg/L doses of dissolved molecular chlorine were applied at the outlet of PPs before the effluents were reused (or disposed of). The downstream reuse options practiced by various communities among the 41 WWTPs surveyed in this study were also summarized in Table 8.4. It appeared that the most commonly practiced reuse option was irrigation and leftover treated effluent is disposed of into nearby rivers or lakes.

Figure 8.13 Poor maintenance of the primary treatment unit prior to WSP in the *Municipal WWTP* in City of Miraj, western India.

8.4 CONCLUSIONS AND LESSONS LEARNT

Over the past three decades, the GoI has made several efforts to supply drinking water to communities in urban as well as rural India. Though there was a large investment concurrently made in creating infrastructure for wastewater across India, the shortfall between water supply and wastewater treatment continues to grow at steep rates. Thus, there exists a large gap between the amount of wastewater generated and treated in urban and peri-urban communities. It is alarming that the water bodies of both surface and groundwater are currently found to be severely contaminated by untreated or partially treated wastewater.

Clearly, there exists a looming challenge of inadequate and insufficient infrastructure for treatment of wastewater throughout India, both in 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 for correcting the pollution of natural water courses in India.

In India, engineered NTSs are currently installed at 108 sites for treatment of mixtures of wastewater (biodegradable industrial effluents were also mixed in some situations). Through questionnaire surveys, one third of those sites (41 WWTPs) were shortlisted and visited during December 2011 to June 2014. The salient conclusions and learnings from the national survey are summarized below:

1) Out of the 41 selected WWTPs based on engineered natural treatment technologies, 23 plants had WSPs, three plants had DPs, seven plants had PPs and eight plants employed HSSF-CWs or KT-CWs.
2) Nearly 75% of the WWTPs investigated in this study were generally achieving the *Minimum National Standards* stipulated by the MoEF (GoI), for disposal of treated wastewater into legally permitted surface water bodies or for the purposes of land irrigation as prescribed in the *Water (Prevention and Control of Pollution) Act*, 1974 and companion regulations.
3) Technologies like HSSF-CWs, KT-CWs as well as DPs seemed to cater to the communities which generated relative smaller flows of wastewater when compared with other technologies including WSPs and PPs.
4) Local standards and guidelines play a crucial role in making the decisions with respect to the extent of treatment to be adopted as well as in determining the type of technology to be implemented for treatment of wastewater in a given community.
5) The FC removal is normally the slowest process and for that reason it becomes the main design criterion for a PP. In India depth of UASB PP has been kept at 1–1.5 meter with an average HRT of 24 hrs. In most of the places, such short HRT is insufficient to remove FCs to a desirable extent.

6) The DP systems were found to be quite effective for treatment and reuse of rural wastewater. Sizes of different treatment units of DP systems are customarily estimated on the basis of biological kinetics of degradation of pollutants and extinction of pathogens in DP and fishpond, life cycle of fishes, climatic conditions and land availability.
7) The most commonly encountered problems during successful operation of NTSs across India include mixing of industrial effluents and poor O&M of the treatment facilities, which cause malfunctioning. The agencies that financed, built and commissioned the WWTPs and subsequently transferred the WWTPs to the respective ULBs for O&M are the successful examples. If the operating agencies planned and allocated adequate funds for O&M, the chances of success would be even higher.
8) The engineered wetland systems were found to be quite robust and versatile in a variety of climatic conditions across India and met the prescribed regulatory standards.
9) Communities seem to prefer HSSF-CWs even more in recent times owing to the innate advantages offered by them in the context of minimizing mosquito breeding and thereby minimizing the threat of cerebral malaria, dengue and several vector-based diseases.

Table 8.3 Agencies responsible for providing capital investments for the communities to establish the WWTPs based on the eco-centric technologies as well as O&M of the facilities.

Sr. No.	Empowered Agencies	Number of WWTPs Funded (Capital and O&M Costs)	Number WWTPs Operated and Maintained	Observations and Comments
1	ULB[a]	5	22	At most of the places, ULBs are operating the facilities rather well. In some cases, however, the village councils did not have funds to perform adequate O&M and as result, the systems were not functioning well.
2	State or Central Government[b]	19	4	The four WWTPs, which were funded and operated by the same agencies, seemed to be operating satisfactorily. However, the WWTPs which were transferred to ULBs for O&M were facing difficulties on account of perpetual delays in releasing funds for O&M year-after-year.
3	Water Boards[c]	16	15	In context of the Indian administrative setup, the Water Boards were supposed to fund the capital costs, build those WWTPs and then transfer to the respective ULBs for O&M. However, the Water Boards do not have rapport with the respective urban and rural communities. As a result, they would fail in transferring the WWTPs after building and commissioning to the respective ULBs. Thus, Water Boards in different states in India are in possession of such WWTPs that were not transferred to ULBs and end up running them with no or minimal allocation of O&M funds. Obviously, all such WWTPs have been chronically facing problems with respect to O&M.
4	UNDP	1	0	The WWTP based CW-technology was found working well after the UNDP built and commissioned it for the Agra Municipal Corporation, City of Agra, State of Uttar Pradesh. In due course, the WWTP was transferred to the Agra Municipal Corporation; who were found to be operating it satisfactorily. The UNDP had provided for the O&M costs to cover the initial years. Subsequently, the Agra Municipal Corporation was supposed to allocate own funds through their revenue collection.

[a] comprising of Municipal Corporation, Nagar Palika and Parishad and Village Council.
[b] comprising of respective state governments, the Government of India, National River Conservation Directorate in the MoEF, Yamuna Action Plan and Public Health Engineering Departments in various states and in GoI.
[c] comprising of State Jal Boards and Water Authorities, Water and Sewerage Boards and Environmental Planning & Coordination Organization.

Table 8.4 Summary of the post-treatment and downstream reuse of treated effluent practiced in the 41 shortlisted NTS-based WWTPs across India.

S. No.	Technology	Number of WWTPs	Capacity Range [MLD]	Post-treatment (after NTS before Disposal or Reuse)	Downstream Reuse of Treated Effluent
1	WSPs	23	0.5–52.7	None	Irrigation of agricultural fields, river and lake discharge
2	DPs	3	0.5–1.0	None	Irrigation of agricultural fields
3	PPs	7	14–78	Two WWTPs perform chlorination (1–2 mg/L doses of dissolved molecular chlorine) at the outlet of PP before the effluent is reused	Irrigation of agricultural fields, river and lake discharge
4	HSSF-CWs + KT-CWs	8	0.05–7.8	None	Lake discharge

In summary, the broad class of engineered NTSs, including CWs, will continue to dominate the platform of "favoured technologies" for treating and recycling wastewater, taking advantage of the warm climate in India and thereby satisfying (at least partially) the unmet demand for waters for irrigation and industry. The CWs can potentially be the alternative to the commonly practiced conventional wastewater treatment strategy – which is not favoured on account of it being energy intensive and ineffective in removing pathogens. In a typical rural setting, CWs appear to treat wastewater to a greater degree when compared with more conventional rural alternatives like septic tanks, drain fields and other forms of land treatment.

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8.6 APPENDIX

Appendix 8.1 Questionnaire utilized during the field survey of 41 shortlisted NTS-based WWTPs across India during December 2011 and June 2014.

1 General information				
Contact Details	Contact person: Name and Address of WWTP: Phone no: Fax: E-mail:			
Legal Status				
Type of wastewater treated				
Mode of conveyance				
Year of WWTP's commissioning.				
Treatment technology				
Treatment chain/mode of operation				
Type of plant/Fish species				
2 Financial details				
Capital cost of the WWTP (Rs. 100,000 (hundred thousand))				
Cost of treatment (O&M Cost /month)				
Funding agency for wastewater treatment cost				
Revenue generated per month				
Agency bearing wastewater collection costs				
3 Design details				
Primary treatment units				
Screen chamber	Type of screen	Number of screen	Unit size	Other details
Grit chamber	Unit size	Number of units	Hydraulic Retention Time (HRT)	Other details
Secondary treatment units	Unit 1 (LxBxD)	Unit 2 (LxBxD)	Unit 3 (LxBxD)	Unit 4 (LxBxD)
Design basis				
BOD_5 (mg/L)	BOD_{inlet} BOD_{outlet}			
COD (mg/L)	COD_{inlet} COD_{outlet}			
pH	pH_{inlet} pH_{outlet}			
TKN (mg/L)	TKN_{inlet} TKN_{outlet}			
TP (mg/L)	TP_{inlet} TP_{outlet}			
TSS (mg/L)	TSS_{inlet} TSS_{outlet}			

Appendix 8.1 Questionnaire utilized during the field survey of 41 shortlisted NTS-based WWTPs across India during December 2011 and June 2014 (*Continued*).

Total Coliform (Count/100 mL)	Inlet				
	Outlet				
Faecal Coliform (Count/100 mL)	Inlet				
	Outlet				
HRT					
4 Actual performance					
Unit name		Unit 1	Unit 2	Unit 3	Unit 4
BOD_5 (mg/L)	BOD_{inlet}				
	BOD_{outlet}				
COD (mg/L)	COD_{inlet}				
	COD_{outlet}				
pH	pH_{inlet}				
	pH_{outlet}				
TKN (mg/L)	TKN_{inlet}				
	TKN_{outlet}				
TP (mg/L)	TP_{inlet}				
	TP_{outlet}				
TSS (mg/L)	TSS_{inlet}				
	TSS_{outlet}				
Total coliform (Count/100 mL)	Inlet				
	Outlet				
Faecal coliform (Count/100 mL)	Inlet				
	Outlet				
HRT					
5 Downstream destination of treated wastewater					
Downstream reuse		Agriculture	Landscape irrigation	Groundwater recharge	Others
Downstream disposal		River	Open drain	Estuary	Others
6 Post treatment before reuse					
Type of treatment given					
		pH			
		DO			
		Electric Conductivity			
		TOC			
		Ammonium			
		Nitrate			
		Phosphate			
		Turbidity			
		Total coliform			
Water quality before post treatment		Faecal coliform			
		DO			
		Electric Conductivity			
		TOC			
		Ammonium			
		Nitrate			
		Phosphate			

(*Continued*)

Appendix 8.1 Questionnaire utilized during the field survey of 41 shortlisted NTS-based WWTPs across India during December 2011 and June 2014 (*Continued*).

	Turbidity
	Total coliform
	Faecal coliform
	Others
	pH
	DO
	Electric Conductivity
	TOC
Water quality after post treatment	Ammonium
	Nitrate
	Phosphate
	Turbidity
	Total coliform
	Faecal coliform
	Others
Cost of post treatment in Rs./m^3	
If effluent not being reused now, is there any potential for reuse? If yes, for which purpose	
7 Health and environmental risks	
Are there any incidences of source pollution, which occurred in the past?	
Is there any risk for the person operating the system?	
Is there any risk for people involved in the disposal handling?	
Is there any risk for people living in the surrounding area of the system?	
For which purposes is the water used?	
If water is used for irrigation, what plants are irrigated?	
If vegetables are planted, are they eaten raw?	
How many people are exposed to the wastewater before treatment and after treatment?	
Are there any wells near the area where the treated water is reused?	
Are there any other possible risks to the environment	
Additional remarks	
8 Flow sheet of WWTP	

Appendix 8.2 List of known existing sites of engineered constructed wetlands and other NTS-based WWTPs across India (information based on the present field survey as well as from CPCB, 2009).

SN	Types of NTSs	Capacity (MLD)	Year of Commissioning	Type of Post-treatment	Down Streams Use of Treated Effluent	Location
1	WSP	14	2003	No Post-treatment	Godavari River	Ramagundam I, Andhra Pradesh
2	WSP	4	2003	No Post-treatment	Godavari River	Ramagundam II, Andhra Pradesh
3	WSP	4	2003	No Post-treatment	NA	Bhadrachalam, Andhra Pradesh
4	WSP	14	2004	No Post-treatment	Godavari River	Ramagundam IV, Andhra Pradesh
5	WSP	4	1988	No Post-treatment	Punpun, Ganga	Kermallichak, Bihar
6	WSP	2	1988	No Post-treatment	Ganga River	Chapra, Bihar
7	WSP	46	1965	No Post-treatment	Seonath River	Kutelabhatavill, Bhilai Nagar, Chhatisgarh
8	WSP	14	1965	No Post-treatment	NA	Risalivillage, Bhilai Nagar, Chhatisgarh
9	WSP	9	1965	No Post-treatment	NA	Bhilai House, Bhilai Nagar, Chhatisgarh
10	WSP	27.27	2003	No Post-treatment	Yamuna River	Timarpur, Delhi
11	PP	20	2000	No Post-treatment	Yamuna River	Faridabad I, Haryana
12	PP	45	2000	No Post-treatment	Yamuna River	Faridabad II, Haryana
13	PP	50	2000	No Post-treatment	Yamuna River	Faridabad III, Haryana
14	WSP	8	2000	No Post-treatment	Yamuna River	Karnal II, Haryana
15	WSP	1	2001	No Post-treatment	NA	Chhchhrauli, Haryana
16	WSP	1.5	2001	No Post-treatment	NA	Indri, Haryana
17	WSP	1	2001	No Post-treatment	NA	Radaur, Haryana
18	WSP	9	2003	No Post-treatment	Agricultural Field	Palwal, Haryana
19	WSP	3	2004	No Post-treatment	NA	Gharaunda, Haryana
20	WSP	3.5	2004	No Post-treatment	NA	Gohana, Haryana
21	WSP	19.45	2001	No Post-treatment	Tungabhadra	Davanagere, Karnataka
22	WSP	5.83	2001	No Post-treatment	Bhadra River	Bhadravati, Karnataka
23	WSP	1.47	2001	No Post-treatment	NA	Nanjagud, Karnataka
24	WSP	1.36	2001	No Post-treatment	NA	Sri Rangapatna , Karnataka
25	WSP	18.16	2003	No Post-treatment	Tunga River	Shimoga, Karnataka
26	WSP	1.45	2004	No Post-treatment	NA	K R Nagar, Karnataka
27	WSP	4.5	2007	No Post-treatment	NA	Pamba, Kerla
28	WSP	8	NA	No Post-treatment	NA	Bherkheda, Bhopal, Madhya Pradesh
29	WSP	52	2001	No Post-treatment	Shipra River	Ujjain, Madhya Pradesh
30	KT	1.67	2001	No Post-treatment	Shipra River	Barogarh, Ujjain, Madhya Pradesh
31	KT	1.67	2001	No Post-treatment	Shipra River	Barogarh, Ujjain, Madhya Pradesh
32	KT	1.2	2001	No Post-treatment	NA	Chapara, Madhya Pradesh
33	KT	0.75	2001	No Post-treatment	NA	Keolari, Madhya Pradesh

(*Continued*)

Appendix 8.2 List of known existing sites of engineered constructed wetlands and other NTS-based WWTPs across India (information based on the present field survey as well as from CPCB, 2009) (*Continued*).

SN	Types of NTSs	Capacity (MLD)	Year of Commissioning	Type of Post-treatment	Down Streams Use of Treated Effluent	Location
34	KT	9	2004	No Post-treatment	Betwa River	Vidisha, Madhya Pradesh
35	WSP	6	2005	No Post-treatment	Tapi River	Burhanpur, Madhya Pradesh
36	WSP	2.5	1995	No Post-treatment	Sina, Bhima River	Aurangabad, Maharashtra
37	WSP	5	NA	No Post-treatment	Salim Ali Lake	JNEC, Aurangabad, Maharashtra
38	OP	18.9	1995	No Post-treatment	Gima River	Jalgaon, Maharashtra
39	OP	12.87	Pre 95	No Post-treatment	Manjeera River	Latur , Maharashtra
40	WSP	26/8.9	2000	No Post-treatment	Godavari River	Nanded-Waghala, Maharashtra
41	WSP	1	2003	No Post-treatment	NA	Trimbakeshwar, Maharashtra
42	WSP	23.82	2004	No Post-treatment	Krishna River	Sangli-Miraj and Kupwad, Maharashtra
43	WSP	33	2003	No Post-treatment	Mahanadi River	Cuttak, Orissa
44	WSP	2	2005	No Post-treatment	NA	Talcher, Orissa
45	WSP	2.6	2003	No Post-treatment	NA	SultanpurLodhi, Punjab
46	WSP	2.56	2004	No Post-treatment	Satluz river	Phillaur, Punjab
47	PP	25	NA	Chlorination	Agricultural Field	Kapoorthala, Punjab
48	PP	22.73	2005	Information Not Available	NA	Raipur Kalan,Chandigarh,
49	DP	0.5	NA	No Post-treatment	Agricultural Field	Bais Village, Ludhiana, Punjab
50	DP	0.5	NA	No Post-treatment	Agricultural Field	Village Saidpur, Ludhiana, Punjab
51	DP	0.5	NA	No Post-treatment	Agricultural Field	Village Sandhuan, Roop Nagar, Punjab
52	WSP	0.5	NA	No Post-treatment	Agricultural Field	Village Dedwal, Ludhiana, Punjab
53	WSP	0.5	NA	No Post-treatment	Agricultural Field	Village Sandhuan, Roop Nagar, Punjab
54	DP	1	NA	No Post-treatment	Agricultural Field	Village Uncha, Roop Nagar, Punjab
55	WSP	20	2007	No Post-treatment	Agricultural Field	Village Nanded, Jodhpur, Rajasthan
56	WSP	20	2007	No Post-treatment	Agricultural Field	Vallabh Garden Bikaner, Rajasthan
57	PP	111	2004	No Post-treatment	Agricultural Field	Ludhiana, Zone B, Punjab
58	PP	152	2004	Information Not Available	Agricultural Field	Ballok, Ludhiana
59	PP	48	2005	Information Not Available	Agricultural Field	Jmalpur, Ludhiana
60	WSP	28	2003	No Post-treatment	Kaveri	Tiruchirappalli II, Tamil Nadu
61	WSP	3.94	2003	No Post-treatment	NA	Bhawani, Tamil Nadu
62	WSP	58	2004	No Post-treatment	Kaveri	Tiruchirappalli, Tamil Nadu
63	WSP	20	2004	No Post-treatment	Kaveri	Erode I, Tamil Nadu
64	WSP	3.96	1988	No Post-treatment	NA	Farrukhabad, Uttar Pradesh
65	WSP	9	1999	No Post-treatment	Yamuna River	Noida III, Uttar Pradesh
66	WSP	10	2001	No Post-treatment	Yamuna River	PeelaKhar, Agra, Uttar Pradesh
67	PP	14	NA	Chlorination	Yamuna River	Dayal Bag, Agra, Utter Pradesh

68	PP	78	NA	No Post-treatment	Agricultural Field	Dhandpur, Agra, Utter Pradesh
69	WSP	2.5	2001	No Post-treatment	Yamuna River	BurhikaNagla, Agra, Uttar Pradesh
70	WSP	32	2001	No Post-treatment	Kali River	Muzaffarnagar, Uttar Pradesh
71	PP	70	2001	Information Not Available	NA	Hindone I, Ghaziabad, Uttar Pradesh
72	PP	56	2001	Information Not Available	NA	Hindone II, Ghaziabad, Uttar Pradesh
73	PP	34	NA	Information Not Available	NA	Noida I, Uttar Pradesh
74	PP	27	NA	Information Not Available	NA	Noida II, Uttar Pradesh
75	PP	27.5	NA	No Post-treatment	NA	Mirzapur, Uttar Pradesh
76	WSP	14.5	2001	No Post-treatment	Agricultural Field / Yamuna River	Bangalighat dairy farm, Mathura, Uttar Pradesh
77	WSP	4	NA	No Post-treatment	Agricultural Field	Baba Temple, Vrindavan, Uttar Pradesh
78	WSP	12.5	2001	No Post-treatment	Agricultural Field / Yamuna River	Masani, Mathura, Uttar Pradesh
79	WSP	0.5	NA	No Post-treatment	Agricultural Field	Kali Deh, Vrindavan, Uttar Pradesh
80	WSP	10.45	2001	No Post-treatment	Yamuna River	Etawah Uttar Pradesh
81	WSP	10	1987	No Post-treatment	Ganga River	E (Madrail),Bhatpara, West Bengal
82	WSP	30	1987	No Post-treatment	Ganga River	S.Sub-E, Kolkata, West Bengal
83	WSP	4.54	1987	No Post-treatment	Ganga River	Chandannagar II, West Bengal
84	WSP	8	1987	No Post-treatment	Beel	Baharampur, West Bengal
85	WSP	16.5	1988	No Post-treatment	Irrigation, Pissiculture	Panihati, West Bengal
86	WSP	45	1988	No Post-treatment	Irrigation, Pissiculture	Bally, West Bengal
87	WSP	14.1	1988	No Post-treatment	Irrigation, Pissiculture	Bandipur, West Bengal
88	WSP	4.54	1988	No Post-treatment	Irrigation, Pissiculture	Titagarh, West Bengal
89	WSP	10	1988	No Post-treatment	Ganga River	Nabadwip, West Bengal
90	WSP	3	2003	No Post-treatment	Ganga River	Khardaha, West Bengal
91	WSP	3.93	2003	No Post-treatment	Ganga River	Maheshtala, West Bengal
92	WSP	5.9	2003	No Post-treatment	Ganga River	Barrackpur, West Bengal
93	WSP	1	2003	No Post-treatment	Ganga River	Barrackpur, West Bengal
94	WSP	10.9	2003	No Post-treatment	Ganga River	Barrackpur, West Bengal
95	WSP	4.35	2003	No Post-treatment	Ganga River	Barrackpur, West Bengal
96	WSP	1.9	2005	No Post-treatment	NA	Murshidabad, West Bengal
97	WSP	0.52	2005	No Post-treatment	NA	Diamond Harbour, West Bengal
98	WSP	1.39	2006	No Post-treatment	NA	JiaganiAjimganj, West Bengal
99	CWs	21.25m × 5.5m	NA	No Post-treatment	NA	Kakatiya Musical Garden of Warangal City, Andhra Pradesh
100	CWs	NA	NA	No Post-treatment	NA	Mahindra Mahindra, Igatpuri, Nashik.
101	CWs	NA	NA	No Post-treatment	NA	Presidency Kid Leather Ltd. Kannivakkam Tamil Nadu

(*Continued*)

Appendix 8.2 List of known existing sites of engineered constructed wetlands and other NTS-based WWTPs across India (information based on the present field survey as well as from CPCB, 2009) (*Continued*).

SN	Types of NTSs	Capacity (MLD)	Year of Commissioning	Type of Post-treatment	Down Streams Use of Treated Effluent	Location
102	CWs	NA	NA	No Post-treatment	NA	Guru govindsingh Park (Ekant Park) Southern area Bhopal
103	CWs	1	NA	No Post-treatment	NA	Kankhal, Haridwar, UttaraKhand
104	CWs	NA	NA	No Post-treatment	NA	Sainik School Bhuneshwar, Orissa
105	CWs	0.5	NA	No Post-treatment	NA	village PipalMajra, District Ropar, Pumjab
106	CWs	2.5 acres	NA	No Post-treatment	NA	village Shekhupur in District Patiala, Punjab
107	CW	7.8	2008	No Post-treatment	Mansagar Lake (Recreational)	Mansagar Lake, Jaipur, Rajasthan
108	CW	NA	NA	No Post-treatment	NA	Ujjain