12 Improving Rural Wastewater Management

Aviraj Datta,* Mukund Patil and Suhas P. Wani

International Crops Research Institute for the Semi-Arid Tropics, Patancheru, India

Abstract

Improved sanitation and hygiene through proper wastewater management is critical for sustainable growth of rural communities. Traditional wastewater treatment technologies experience low penetration in the resource-poor semi-arid tropical villages with limited or no access to good quality electricity and skilled supervision. The substandard wastewater treatment efficiencies of traditional effluent treatment plants, even in the urban centres, are testimony of their unviability in rural India. Constructed wetland (CW) is an age-old, low-cost, decentralized wastewater treatment technology. The absence of heavy metal and other xenobiotics in rural grey water highlights their reuse potential for growing jute, flower, teak plantation, etc. Lack of field-scale study with real wastewater thus far has made policy makers and professionals working in the sanitation sector sceptic about the long-term reliability of CWs with respect to wastewater treatment efficiencies. This chapter is an attempt to present the potential and real-life challenges of CW implementation.

12.1 Significance of Decentralized Wastewater Treatment

Water, food and energy securities are emerging as increasingly important and vital issues for India and the world. Most of the river basins in India and elsewhere are experiencing moderate to severe water shortages due to the simultaneous effects of agricultural growth, industrialization and urbanization. One in every nine persons in the world today does not have access to safe and clean drinking water. There is a need to enhance the water use efficiency in the agricultural sector which consumes about 70% of the total anthropogenic withdrawal of 3928 km^3/year (WWAP, 2017). Research and resources are thus necessary to find a more efficient, productive, equitable and environmentally friendly way of using wastewater in agriculture, so that quality of crop, soil and human health is not compromised. There needs to be focused effort to maximize the potential of wastewater as a valuable and sustainable resource.

12.1.1 Rural wastewater as a sustainable resource

About 80% water supplied to a household comes out as wastewater; thus as long as households and human habitats exist, wastewater generation will take place. It is worth mentioning, as often the obsession with groundwater and rainwater statistics prompts us to declare cluster of

* Corresponding author: a.datta@cgiar.org

villages as 'dry' and hence no wastewater management activity is viable. Unfortunately the sheer number of such villages in the semi-arid tropics is large and the marginalized population living there is in need of wastewater management, at least for better health and hygiene. Often the wastewater generated from these resource-poor households is easily biodegradable and simple low-cost technology like constructed wetland (CW) can abate the environmental degradation. On a macro-scale, the effect of such small-scale scientific interventions cumulatively has the potential to influence major environmental degradation. Here it has to be mentioned that often local contractual engineers, and sanitation and rural health professionals do not prefer small-scale interventions for reasons pertaining to financial profit rather than environmental concern. Post-independence the focus of rural development in India has been on establishing schools, health care facilities, housing and drainage network. In the absence of a proper wastewater management scheme, however the health and hygiene of rural India has suffered. Pest- and vector-borne diseases such as malaria, chikungunya, etc. are impossible to eradicate in the absence of a proper wastewater treatment scheme. In recent years sanitation and cleanliness has received unprecedented attention of the Government of India through the Swachh Bharat mission. Good drainage network is the prerequisite of any rural wastewater management scheme. Moreover, maintaining proper slope of the drains and proper village-level maintenance of the drains are important and should be the starting point for any rural wastewater management scheme.

12.1.2 Impact of improper rural wastewater management on health and hygiene

The link between wastewater management and health is well documented. In developing countries as much as 80% of illness is linked to inaccessibility of good quality potable water. In 2012, an estimated 842,000 deaths in middle- and low-income countries were caused by contaminated drinking water, inadequate hand washing facilities and sanitation services (WHO, 2014). Additionally, 361,000 deaths among children aged below 5 years could have been prevented through reduction of risks related to inadequate hand hygiene, sanitation and water during the same year (Prüss-Üstün *et al.*, 2014). Raw wastewater discharge contributes towards water pollution and critically affects the actual availability of potable water and thus adversely impacts the ecosystem services (Corcoran *et al.*, 2010) through eutrophication, groundwater pollution, etc. Annual health cost per child in an untreated wastewater irrigated environment is estimated to be about ₹4000/annum (~US$60), which is 73% higher than for freshwater irrigated areas (Grangier *et al.*, 2012). Srikanth and Naik (2004) reported that the prevalence of giardiasis among farmers irrigating with wastewater in a suburb of Asmara, Eritrea was 45%. Based on hospital data they found that giardiasis prevalence was 7% among residents of the community who consumed only vegetables grown with untreated wastewater compared with 1% for residents in similar towns in Eritrea without wastewater irrigated crops. Melloul and Hassani (1999) found higher rates of salmonella infection in children living in wastewater-irrigated areas near Marrakesh, Morocco compared with those living in areas without wastewater irrigation (Chary *et al.*, 2008). Organic pollution which affects around one-seventh of all river stretches in Africa, Asia and Latin America (UNEP, 2016) can have severe impacts on the livelihoods of poor rural communities depending on fisheries or natural resources. For every US$1 invested in water and sanitation, there is an economic return of US$3 to US$4 (WHO, 2015). Planned and safe irrigation practices with wastewater will significantly help in nutrient recycling. For example, the phosphorus load of the wastewater when discharged in surface water bodies triggers eutrophication. Remarkably, the sources of extractable phosphorus are dwindling and is estimated to become scarce or exhausted in the next 50–100 years (Van Vuuren *et al.*, 2010). This makes phosphorus recovery from wastewater financially viable. Recycling human urine and faeces can provide steady supply chain for phosphorus for about 22% of the present anthropogenic demand (Mihelcic *et al.*, 2011). Phosphorus recycling to agriculture through decentralized wastewater treatment (DWAT) schemes is fairly straightforward. Moreover, such initiatives will reduce the input cost and chemical dependency of agriculture increasing the net income of farmers (Winblad and Simpson-Hébert, 2004). Treated grey water can be suitably utilized to produce bio-ethanol (both first and second generation) through sweet sorghum cultivation.

12.1.3 Wastewater irrigation: prevailing practice, potential and risks

Use of wastewater in agriculture is not new as its fertilizer value is well recognized; however, reliable estimates of projected wastewater use in agriculture are scarce in literature (Qadir *et al.*, 2007). Moreover, these farming activities often remain informal and are not indicated in official statistics (Drechsel *et al.*, 2006). Globally about 800 million farmers are engaged in urban agriculture, of whom about 200 million practise market-oriented farming on small peri-urban plots using wastewater. Sometimes farmers use raw wastewater, as it provides nutrients or is more reliable or cheaper than other water sources (Keraita and Drechsel, 2004). For example, in rural Sri Lanka, use of sewage and wastewater for irrigation is common particularly among livestock farmers; as farm size in most cases is less than 1 ha, the extent of wastewater use in agriculture is difficult to estimate (Udagedara and Najim, 2009). There are past instances where farmers resisted the treatment of wastewater which is being used for agriculture, fearing that it will reduce its fertigation potential, for example, in the Tula Valley in Mexico (Jimenez, 2005). The potential of planned use of wastewater to increase the water-use efficiency and nutrient recycling is well demonstrated in countries such as Australia, Mexico, China and USA. In countries which suffer from acute water stress, such as Jordan, treated wastewater irrigation has been promoted since 1977 and today 90% of the treated wastewater is being used for irrigation in this country. Israel represents a similar example, where treated wastewater contributes about 40% of irrigation water demand (OECD, 2011). However, one has to make a distinction between safe and unsafe irrigation practices regarding wastewater irrigation. In India, the irrigation standards are prescribed for only a few parameters and not well implemented, particularly with regard to soil types, agro-climatic zone and nature of the agricultural produce. There is a huge lack of awareness about the risks or the potential environmental consequences of raw wastewater irrigation. Moreover, there is no proper labelling practice for farm produce grown on wastewater or freshwater making the consumer vulnerable. Consumers or stakeholders involved in the postharvest value chain (commonly termed 'farm to fork') often remain unaware of the health risk associated with raw wastewater-irrigated farm produce.

12.1.4 Economics of rapid spread of peri-urban vegetable farms

The surplus wastewater from the major Indian cities is utilized for irrigation in the peri-urban area to grow vegetables. Lack of infrastructure and unreliable electric supply has resulted in lack of refrigerated transport facility in India for perishable salad crops and vegetables, thus long-distance travel of these crops are often not economically viable. Growing vegetables utilizing urban wastewater (which is often the most cheap and reliable fertigation source for marginal farmers) in the vicinity of urban centres in the hot Indian climates thus reduces both input cost as well as transport cost and hence is economically lucrative. In most West African cities, 60–100% of the vegetables consumed are produced in urban and peri-urban areas (Drechsel *et al.*, 2006). In Accra (Ghana, Africa), for example, thousands of farmers produced contaminated lettuce grown on wastewater for the urban food sector. This supports livelihood and food supply for more than 200,000 urban dwellers every day but at the cost of health risk (Obuobie *et al.*, 2006; Amoah *et al.*, 2007). Apart from the health risk from pathogen contamination, the presence of xenobiotic, heavy metals and endocrine disrupting agents in urban wastewater increases the cost and capacity of treatment and thus restricts the scope of safe reuse. Risk of pathogen contamination compromises fitness of raw wastewater irrigated farm produce for human consumption. A survey along the Musi River in Hyderabad, India revealed the transfer of metal ions from wastewater to cow's milk through para grass fodder irrigated with wastewater. Milk samples were contaminated with different metal ions like cadmium, chromium, nickel, lead and iron ranging from 12 to 40 times the permissible levels (Minhas and Samra, 2004). Leafy vegetables and salad crops tend to bio-accumulate certain metals, namely cadmium. Generally, metal concentrations in plant tissue increase with metal concentrations in irrigation water, and concentrations in roots usually are higher than concentrations in leaves. This challenge can be addressed only through wastewater treatment.

12.1.5 Limitations of traditional wastewater treatment technologies

Despite the growing number of wastewater treatment units around the world, about 80% of the wastewater generated by anthropogenic activities returns to the ecosystem without any treatment (FAO, 2017). At present, of the 62,000 million litres per day wastewater generated in major Indian cities only 23,277 million litres per day are treated (CPCB, 2015). The explosion of population in urban centres of India has triggered higher water demand and greater wastewater generation over the past few decades. Unfortunately, the gap between wastewater generation capacity and treatment capacity is increasing. Untreated urban sewage is one of the biggest causes of environmental pollution in India. Wastewater treatment plants in Class I or Class II cities often do not function at their designed capacity or efficiency, and hence do not achieve standards prescribed under the environmental (protection) rules for discharge into streams. There is lack of awareness about the importance of separating storm water from sewerage networks or for that matter separation of municipal sewage from industrial effluents. Complex social, political, technical and financial challenges have impacted adequate and efficient management of these wastewater treatment plants. Nevertheless an increased capacity for sewage treatment is difficult yet attainable in urban area where necessary skill sets, human resource and other resources required for sophisticated wastewater treatment technologies are available. Considering the situation of wastewater treatment in urban India, a sustainable solution to wastewater management situation in rural areas is speculative. The facts and figures from rural India at a macro-level have rarely been reported or considered while planning solid and liquid waste management programmes. This track record of conventional wastewater treatment technologies such as activated sludge process, sequential batch reactors or membrane bioreactors, etc. makes their penetration in resource-poor rural India (where electricity is often unavailable or reliable) doubtful. Thus there is a need for low-cost wastewater treatment technologies which are feasible in rural India.

12.2 Sustainable Off-grid Technology for Rural Wastewater Treatment

12.2.1 Constructed wetland as a low-cost wastewater treatment technology

Constructed wetland (CW) is a proven age-old wastewater treatment system. Despite the apparent simplicity of CWs, these are complex ecosystems driven by many physical, chemical and biological processes. The CWs involve basic biogeochemical processes such as filtration, sedimentation, plant uptake, phytoremediation and microbial degradation in removing contaminants from wastewater. Common gardening skills are sufficient to take care of such a wastewater treatment system. The CWs present a feasible solution to the wastewater menace for small rural communities with limited resources and power supply. The various types of CWs used over the past four decades can be grouped into two broad categories, namely free water surface (FWS) wetlands or subsurface flow (SSF) wetlands. In a nutshell, the former involves a pond whereas the latter involves a dry surface (as their names suggest). The SSF CWs, though slightly more expensive than FWS CWs owing to the filter media (made of sand and aggregates), are preferred to avoid mosquito and odour menace. The SSF wetlands provide a path through which wastewater can move, and surfaces on which microorganisms can live (Fig. 12.1). As wastewater flows through the porous media, the microbial biofilm developed on the media constituents feed on the waste materials, removing them from the water. The top layer of sand provides support for the plants growing in the wetlands.

12.2.2 Overview of the constructed wetland-based wastewater schemes

Land-based treatment systems such as CW are well suited to agricultural applications given

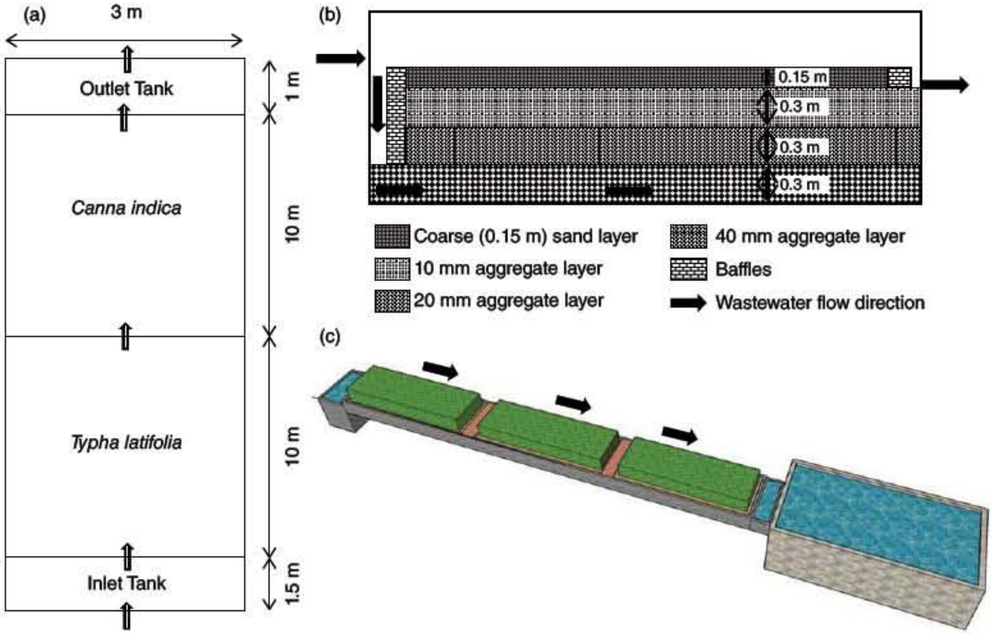

Fig. 12.1. General design of subsurface flow constructed wetland: (a) layout; (b) media constituents and flow regimen; (c) three-dimensional view of a typical DWAT unit.

their low cost and farmland availability (Carreau *et al.*, 2012). They are commonly used for the treatment of wastewater from on-farm slaughterhouses, dairies, piggeries, etc. (Bosak *et al.*, 2016). Despite the potential (Dunne *et al.*, 2015) application of full-scale FWS wetlands, these have been limited for community wastewater as these are notorious for mosquito and odour nuisance (Datta *et al.*, 2015). The SSF CWs are designed to minimize exposure of the wastewater to the ambient environment. Constructed wetlands reported in literature are predominantly horizontal SSF or vertical SSF types (Vymazal and Kropfelova, 2008). The technology is predominantly used to treat wastewater from small communities and is known for excellent removal efficiency for organic matter and total suspended solids. The removal of total nitrogen and total phosphorus as required to meet surface water discharge norms through CW is a land intensive option (Vymazal, 2010). Studies reported from Spain where horizontal SSF type CWs are widely used highlighted the limitations to removal of some pollutants such as nitrogen, organic matter and phosphorus (Puigagut *et al.*, 2007). The reason for poor removal efficiency for nitrogen and phosphorus is because SSF-type CWs are anoxic systems with insufficient amount of dissolved oxygen in water (Vymazal, 2014); moreover, the traditional bed materials are not suitable enough to abate phosphorus as they lack sufficient calcium, magnesium, iron and aluminium ions (Vohla *et al.*, 2011). Energy-intensive solutions such as bed aeration (Fan *et al.*, 2013) or influent wastewater aeration (Rossmann *et al.*, 2013) using solar-powered aerators though will compromise the intrinsic operational simplicity of these systems. Such modifications should be limited to sites where skilled supervision is available at a reasonable cost. Specific bed materials to augment the natural bioremediation processes in a SSF type CW, such as blast-furnace slags or heated opoka (natural material from southeastern Poland composed of 50% of calcium carbonate, 40% of silicon dioxide and 10% of aluminium, iron and other oxides) may be utilized in a specific manner. In developed nations such as Spain, although CWs are listed in the Spanish reuse law (BOE, 2007) as adequate systems to maintain the quality of reclaimed wastewater during storage, they are not considered as suitable systems for secondary or tertiary treatment for further reuse. However, in the national guidelines of developing countries such as China and Mexico, the reuse of municipal wastewater treated with CWs for crop irrigation (Belmont *et al.*, 2004; Wang *et al.*, 2005) is allowed. In scarcely reported studies from the developed nations reuse of CW-treated urban wastewater by a hybrid CW system showed the reuse potential of the effluents (Ávila *et al.*, 2013). Nitrogen and phosphate recycling potential of CWs complements the irrigation potential for the treated water (Akratos and Tsihrintzis, 2007). The use of CWs to help recovering eutrophic water bodies has been reported in Europe and the numbers of such installations are increasing. The study carried out by Li *et al.* (2008) with three types of pilot-scale CWs (FWS, horizontal SSF and vertical SSF) in China gives a comparison of their nutrient removal potential. The difference of scale used in cited studies make sketching-up a general life cycle assessment difficult. Operation and maintenance of pump, pipe and overall functioning required for vertical SSF-type CWs makes them difficult to operate for the long term in rural environment. Bed media in SSF-type CWs are mostly made of gravel and sand (Zidan *et al.*, 2013). However, the use of shredded tyres (Collaço and Roston, 2006) and plastic pieces (Cordesius and Hedström, 2009) may be good media.

12.2.3 ICRISAT in-house research on constructed wetland

Performance of CW is being evaluated at field scale as part of ongoing Indo-European Union project named Water4Crops funded by the Department of Biotechnology, Government of India under the Seventh Framework Program (FP7). The project involved 22 European and 12 Indian partners. The field-scale experimental facility at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, India provided the scope to compare the phytoremediation potential of several macrophytes in different combinations over a period of three years for the grey water generated by a nearby urban household.

A total of 12 CWs vegetated with different plant species, namely *Typha latifolia*, *Canna indica*, lemongrass (*Cymbopogon* sp.), napier grass (*Pennisetum purpureum*), hybrid napier grass (*P. purpureum* × *P. americanum*), bamboo, para grass (*Brachiaria mutica*), and floating macrophytes such as water hyacinth (*Eichhornea crassipes*) and water lettuce (*Pistia stratiotes*) were evaluated (Table 12.1). The CWs were operated under identical hydraulic loading to evaluate the phytoremediation potential of these plant species at a field scale. Wastewater flow in each CW was about 3 m^3 per day which resulted in a hydraulic retention time of 4 days for each CW. The in-house research highlighted the tremendous potential of CWs in treating grey water (Tilak *et al.*, 2017). These studies also found plant nutrient uptake as well as plant growth rate combined is an effective measure to estimate the phytoremediation potential of these macrophytes (Datta *et al.*, 2015). The study found that the resilience of *Typha latifolia* and *Canna indica* combined with their high plant growth rate makes them superior in terms of their phytoremediation capacity and consistent performance compared to other plant species tested. The growth rate of both *Typha latifolia* and *Canna indica* showed very little seasonal variation in the semi-arid tropics which ensured minimal seasonal variation in the wastewater treatment efficiency of the CW vegetated with these two plant species. A weed species *Ageratum conyzoides* demonstrated higher nitrogen removal efficiency compared to *Typha latifolia* and *Canna indica* (Tilak *et al.*, 2017). However, their lower growth rate and long lag phase of growth following transplantation in CW sand media makes their field-scale application limited. Floating macrophytes showed tremendous wastewater treatment potential; however, their high moisture content severely restricts the dry biomass generation rate compared to terrestrial macrophytes limiting their overall phytoremediation potential.

As real wastewater was used for the evaluation of phytoremediation capacity, the inlet wastewater characteristics varied during the study period, hence removal efficiencies are better represented by range rather than any specific value (Tilak *et al.*, 2017). The study identified key wastewater parameters which are affected by CW; these are total suspended solids concentration (84–97%), chemical oxygen demand (56–70%), inorganic nitrogen (35–59%), sulphate (12–37%) and coliform count (72–88%). Low removal of phosphate was observed in the CWs. Virtually no removal of

Table 12.1. Average tissue concentration observed for nitrogen, phosphorus and potassium of different macrophyte species grown in the constructed wetlands at ICRISAT, Patancheru campus.

	Tissue concentrations (mg/kg)		
Plant species	Nitrogen	Phosphorus	Potassium
Ageratum conyzoides	26,958	3,251	15,398
Typha latifolia	21,219	3,520	22,370
Canna indica	21,633	3,558	25,786
Brachiaria mutica	24,761	6,498	19,266
Cymbopogon sp.	14,917	2,354	11,166
Bambuseae sp.	22,848	1,808	9,317
Pennisetum purpureum × *P. americanum*	20,324	2,999	14,828
P. purpureum	16,189	2,481	16,528
Pistia stratiotes	31,276	6,509	25,325
Eichhornea crassipes	25,378	6,238	20,621

sodium, potassium, calcium, magnesium, chloride and fluoride was observed in the CWs.

12.2.4 Impact indicators, advantages and disadvantages of DWAT

Based on the field-scale research on CW carried out as part of Water4Crops, a few key advantages and limitations of the technology were identified along with key impact indicators. Facilitating effective treatment of the wastewater flow has been selected as one of the key performance indicators for the DWAT systems implemented in different watersheds. However, wastewater treatment is only one of the impact indicators. Other impact indicators are self-sufficiency of villagers about the DWAT system maintenance activity. Sustainability of the DWAT system in terms of maintenance by its prime beneficiaries through work for treated wastewater or biomass access is also a key indicator which affects the longevity of the units implemented. Reuse of treated wastewater (at feasible locations), the final indicator of the utility of the DWAT system in terms of increased water- and nutrient-use efficiency is another key impact indicator. Making revenue out of treated wastewater reuse through energy or cash crop cultivation is the final impact indicator for this intervention. It is worth mentioning that some of these indicators are beyond technological provisions and involve considerable social engineering which often requires a systematic and patient approach as it takes longer to materialize on the ground. Probably inculcating a sense of pride and ownership among the villagers for the DWAT system implemented in their neighbourhood is the most important social-level intervention required for faster assimilation of the scientific intervention.

Advantages of DWAT system

- Devoid of chemicals or electricity; maintenance can be done by rural communities.
- Facilitates increased water-use efficiency of resource-poor rural communities.
- Income source during the construction, operation and maintenance activities.
- Enables recycling nitrogen, phosphates and other nutrients.
- Biomass generated in CW can be used for composting, biogas or ethanol production.

Limitations of constructed wetlands

- Requires lined drainage network.
- Incomplete removal of nutrients or coliforms.

12.2.5 Salient features of DWAT unit in ICRISAT watersheds in India

The DWAT system implemented by ICRISAT team utilizing funds available through various corporate social responsibility (CSR) initiatives typically consists of four components, namely an inlet tank, an SSF CW, an outlet tank and a storage pond (may or may not be lined). The inlet tank acts as flow equalization tank, whereas specific plants known for their phytoremediation potential such as *Canna indica* and *Typha latifolia* are grown on the sand layer of the SSF CW. The plant roots take up nutrients from the subsurface wastewater stream passing through their root zones to facilitate phytoremediation. Once the plants get established, the bulk of the pollutant removal takes place in the root zone by the biofilms present in the rhizosphere of these plants. The inlet tank and outlet tank help to maintain the SSF regimen by suitably placing the inlet and outlet pipes while utilizing the gravity flow. For sites where scope of reuse is restricted or the wastewater flow is not expected to irrigate 1 acre of land, the storage tank component may be omitted. The cost of the DWAT system varies from site to site based on the geometry, which in turn depends on the wastewater flow. A minimum 3-day hydraulic retention time is required to treat the wastewater effectively in DWAT system. The cost of filter media constituents, such as sand and aggregates, differ from place to place, thus affecting the cost. A typical DWAT system treating wastewater generated from rural communities costs ₹7–10 lakhs (US$10,000–15,000).

12.3 Field-scale Performance of Constructed Wetlands

12.3.1 Performance of DWAT units commissioned utilizing CSR funds

The scaling-up of CW outside ICRISAT campus in different village locations across the country was carried out as part of various developmental projects supported by the government and CSR projects. The DWAT units thus implemented range from 50 to 250 households in terms of their designed capacity for wastewater treatment. The field-scale installation involved site selection, design and implementation by ICRISAT team, in partnership with local non-governmental organizations (NGOs) (e.g. Backward Integrated Rural Development Society (BIRD), Development Alternative (DA), Bharatiya Agro Industries Foundation (BAIF)) as well as through the government Panchayat Raj Engineering Department (PRED) in Karnataka. This critical next step generated further knowledge about challenges of scaling-up. To share the learnings about the diverse set of social, local and perceptional challenges, these were described as general learnings and site-specific learnings for the eight locations where DWAT units were established to treat rural wastewater, utilizing the CSR fund as a watershed development activity (Tables 12.2, 12.3 and 12.4).

12.3.2 Few general learnings from scale-up

The journey from proof of concept to field-scale installations, often referred as the 'science of delivery', gave abundant lessons of which the key learnings are listed below.

- The SSF CW is preferred over FWS CW despite the additional cost of media for the former as it avoids mosquito, pest and foul odour nuisance in the absence of free wastewater surface.
- Both *Canna indica* and *Typha latifolia* are suitable for field-scale units because of their short stabilization phase post-transplantation, tolerance to both water stress and abundance conditions, as well as high phytoremediation potential.

Table 12.2. Location of field-scale DWAT systems in India implemented through CSR fund.

Village	District	State	Capacity (m^3/day)	Collaboration work[a]
Pendakal	Kurnool	Andhra Pradesh	51	ICRISAT, NGO, Power Grid Corp
Mentapalle	Wanaparthy	Telangana	20	ICRISAT, RECL, NGO
Rajapeta	Wanaparthy	Telangana	25	ICRISAT, RECL, NGO
Dhikoli	Jhansi	Uttar Pradesh	10	ICRISAT, CAFRI, NGO
Dandiganahalli	Kolar	Karnataka	10	ICRISAT, NGO, Coca Cola
Doddanthapur	Bellary	Karnataka	12	ICRISAT, NGO, JSW Foundation
Ukkali	Bijapur	Karnataka	90	ICRISAT, NGO, Power Grid Corp
Bhanoor	Medak	Telangana	56	ICRISAT, NGO, Asian Paints

[a]RECL = Rural Electrification Corporation Limited; CAFRI = Central Agroforestry Research Institute.

Table 12.3. Average inlet wastewater characteristics of different field-scale DWAT units in eight villages.[a]

Parameters[b]	Pendakal	Mentepalle	Rajapeta	Dhikoli	Dandiganahalli	Doddanthapur	Ukkali	Bhanoor
Alkalinity (mg/l as $CaCO_3$)	1044	440.00	196.00	634	168.00	153.00	567.00	197.00
Arsenic (mg/l)	0.02	0.01	0.01	BDL	0.01	BDL	0.01	BDL
Boron (mg/l)	3.45	0.14	0.12	2.13	0.06	0.03	0.31	0.09
Calcium (mg/l)	121	148.00	47.00	154	102	24.5	78	77
COD (mg/l)	121	400.00	160.00	216	88	89	456	720
Chlorides (mg/l)	1280	214.22	141.94	149	120	78	487.3	286.5
Chromium (mg/l)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Detergents (mg/l)	0.206	0.79	0.57	0.62	0.18	0.22	BDL	BDL
EC (mS/cm)	6.183	2.96	1.7	2.19	0.98	1.12	1.32	3.55
Fluorides (mg/l)	1.884	1.56	1.43	1.31	1.294	290	1.68	2.13
Faecal coliform (per 100 ml)	712	139	234	923	109	349	203	323
Hardness (mg/l as $CaCO_3$)	640	1000.00	490.00	530	320	56.8	360	360
Magnesium (mg/l)	90	126.00	82.00	32	43	11.6	22.3	113
N as ammonia (mg/l)	64.68	55.96	15.06	65	27	21.9	58.13	103.57
N as nitrate (mg/l)	3.086	3.84	12.01	3	2	1.8	1.9	16.68
pH at 25°C	8.47	8.30	8.47	7.98	8.14	7.67	6.81	8.62
Phosphates (mg/l)	1.38	0.96	BDL	1.88	0.7	0.72	1.86	1.32
Potassium (mg/l)	569	34.05	14.69	31	24	15	27.5	12.3
Sodium (mg/l)	844	218.22	148.05	102	67	107	112.3	49.8
Sulphate (mg/l)	2.55	121.17	84.04	6.2	8.5	4.1	234.36	17.2
Sulfur (mg/l)	1.62	35.00	26.00	3.8	4.9	2.3	73	9.42
TDS (mg/l)	4216	1774.00	1023.00	1123	57.9	892.3	2131	770
Total iron (mg/l)	BDL	0.02	BDL	0.02	0.04	0.01	0.17	0.16
TSS (mg/l)	40	80.00	138.00	67	32.3	8	2395	43.7
Zinc (mg/l)	BDL	0.07	0.05	BDL	BDL	BDL	0.07	0.01

[a]Concentrations for lead, manganese, nickel, cobalt, cadmium and copper were below detectable limit (BDL) for all samples. [b]COD = chemical oxygen demand; TDS = total dissolved solids; TSS = total suspended solids.

Table 12.4. Average removal efficiency of constructed wetlands (July 2014 to March 2017).[a]

Key parameters Parameter	Inlet (mg/l)	Removal efficiency (%)
Chemical oxygen demand	88–456	58–82
Inorganic nitrogen	27–120	43–67
Phosphate	BDL–1.88	19–48
Sulphate	1.6–73	37–72
Total suspended solids	8–2395	84–97
Faecal coliform	109–923[b]	72–88

[a]BDL = Below detectable unit. [b]No. per 100 ml

- Exact wastewater flow calculation in a village drain is a futile approach because of wide diurnal, seasonal and occasional variations. A better approach would be to estimate the flow based on the household number or total supplied water. Often, supply water is supplemented with innumerable village bore wells, so the former leads to better flow approximation.
- Information regarding household number, volume and frequency of water supply and length of cemented drainage network data is often available at the panchayat level. Updating and utilizing such data can help to approximate the wastewater flow.
- Rainwater data, terrain topography and land registration data can help not only to estimate storm water volume but also to check the availability of public land and its suitability for this activity.
- The number of households in the village may not be useful for deciding the design treatment capacity of CW as the village wastewater often flows in different directions through multiple drains, as per the terrain. A better approach would be to identify village drains which receive wastewater from at least 100 households for this activity.

12.3.3 Site-specific learnings from scale-up

Pendakal

At this site the seasonal variation of flow is quite high; hence during peak summer the unit experiences at least one week of dry period with no inflow. However, the SSF regimen as depicted in Figure 12.1b ensures that the root zone remains moist so that plants survive this period. The site also receives runoff from the nearby area during monsoon as lateral flow. Hence, to prevent ponding on the wetland sand surface, siltation and loss of top layer sand the side walls were raised and side drains were provided after initial months of operation.

Mentapalle

In Mentapalle village of Wanaparthy, Telangana, villagers were very accommodative of scientific interventions and their sincerity was evident through the clean and well-maintained village drains. The wastewater generated in the village is distributed in three main village drains. These three drains were joined with subsurface cemented pipe to channel the wastewater flow towards the inlet tank of the DWAT unit. Moreover, the required length of 23 m for the DWAT unit for all the components (as shown in Figure 12.2) was not available. Hence the design was modified and a storage tank was constructed on the side of the CW as shown in Figure 12.2. This is an example of the flexibility of the design for DWAT units. The general stepwise process of DWAT implementation is depicted in Figure 12.3.

Rajapeta

The wastewater from the nearby households was stagnated as a small wastewater sump (14 × 13 m). Because of the small available area the DWAT system was implemented as a circular unit with the storage tank at the centre (Fig. 12.4). The slope of the CW was adjusted to distribute the wastewater flow evenly.

Dhikoli

The village population was caste-sensitive and certain sections declined to do anything with wastewater. Also in the past, members of certain marginal classes did not have easy access to community tube wells. In subsequent years, through various government initiatives these lower-caste households were provided with individual tube wells at each household. This higher

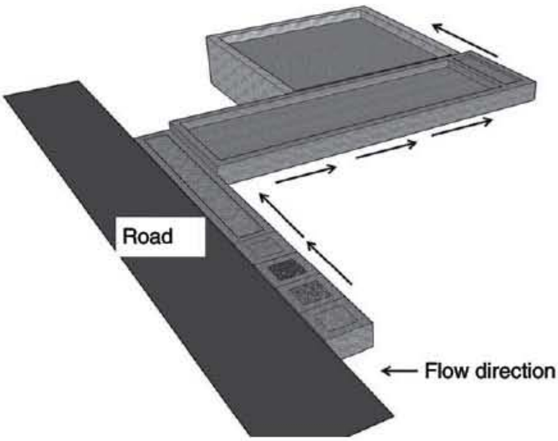

Fig. 12.2. Schematic diagram of the DWAT unit implemented at Mentapalle, Wanaparthy.

Fig. 12.3. Different phases of construction of the DWAT unit: (a) excavation; (b) concrete liner; (c) brick-masonry work; (d) plastering and curing; (e) fencing; (f) plantation.

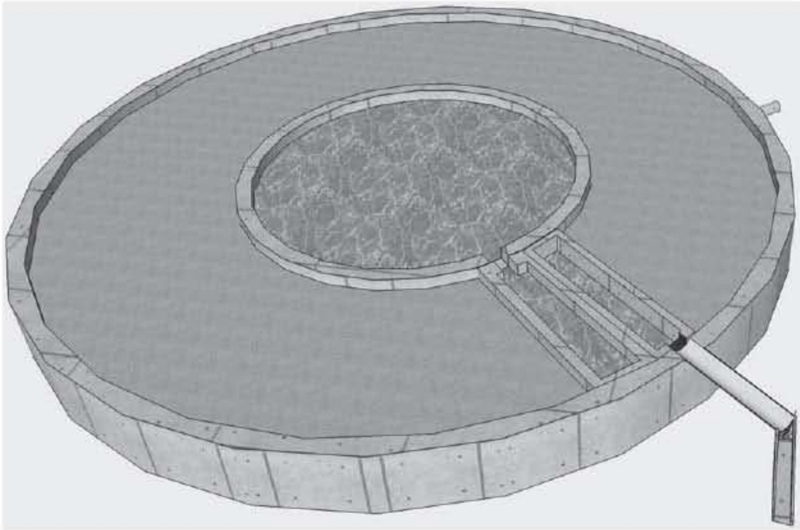

Fig. 12.4. Schematic diagram of the DWAT unit implemented at Rajapeta, Wanaparthy.

per capita water availability was probably the reason for higher wastewater flow in the drains which were in the proximity of these households. The members of these households were accommodative and receptive to the idea of improved wastewater management practices. Subsequently a village wastewater sump in Dhikoli was identified which receives wastewater from about 50 households (mostly belonging to the lower castes). The wastewater flow was about 2–3 m^3/day. The wastewater samples collected by ICRISAT team from these drains were devoid of any heavy metal. Local NGO officials offered to help in monitoring the wastewater treatment efficiency for a few parameters based on water test-kit method. The land adjacent to the wastewater sump belongs to Mr Haricharan Paul with a plot size of 1.15 acre. He used to irrigate occasionally with the raw wastewater from the sump nearby. He had some school education (10th Pass) and could grasp the perils of raw wastewater irrigation during the team's interaction with him. As there was no public land available ICRISAT requested him to give a small patch (as the flow was very low) of land for the wastewater unit highlighting the prospect of a treated wastewater pond nearby his agricultural field. It took long hours of reasoning to convince him to give a portion of his land which was uncultivable because of stone blocks. As the flow was very low, a small CW followed by a storage tank with 45 m^3 capacity was finalized. The ICRISAT team got generous help from local officials of Development Alternative (Dr S.N. Pandey) and National Research Centre for Agroforestry (Dr Ramesh Singh and Mr Anand Kumar). The construction work was carried out in a short span (9 June 2015–6 August 2015). Good-quality construction practices were ensured through proper supervision and the unit cost was ₹172,000 (approximately US$2500). The expected minimum life of the unit is 7 years. Replacement of the filter media (gravel and sand) should rejuvenate the unit after this period. Establishing a demo-site for DWAT was the main motivation for the ICRISAT team in an attempt to gain the trust of the locals. In the subsequent summer, the village experienced severe water scarcity and the treated water available to Mr Haricharan Paul enabled him to irrigate his 1.15 acre land for fodder crop with an additional dry-season income of ₹8000. It also helped to mitigate the fodder crisis in the village and the small DWAT unit got increased attention. The farmer got approximately 230–260 kg (fresh weight) *Canna indica* biomass every 45 days throughout the year and used this nutrient-rich biomass as soil conditioner directly after sun-drying. The unit being small has been easy to construct and manage thus far by the locals. The site is an example of how even a limited quantity of treated wastewater can significantly influence the livelihood of marginalized small communities. Moreover, such small interventions even as demo-sites may lead to greater acceptance and faster assimilation of technological interventions.

Dandiganahalli

The CW in this location was commissioned in farmers' fields as no suitable public land was available. However, in subsequent years access to the DWAT site as well as equitable distribution of the treated wastewater became disputed among the local villagers. This site was a learning experience of the need to prepare proper documentation pertaining to transfer of the selected private land (with consent of the legal owner) to panchayat before the commissioning of the DWAT unit.

Doddanthapur

The local farmers here objected to the DWAT unit as they were utilizing raw wastewater irrigation as the pressure drop across the CW required pumping of the treated wastewater, whereas the raw wastewater flow was sufficient to irrigate the adjacent 2–3 acres of land. The farmers were made aware about the environmental and health impact of raw wastewater irrigation to resolve the problem. The problem could have been resolved by providing solar pumping system for the treated wastewater through panchayat. However, the farmer involved being a chronic alcohol addict made it difficult for the panchayat committee to place such expensive equipment in his custody. At present the farmer here is using the treated wastewater for cotton cultivation.

Ukkali

Local farmers who were irrigating with raw wastewater from the village main drain objected to its treatment through CW. Initially they dug up a sump inside the main drain at a location upstream to the DWAT unit, depriving it of any wastewater flow. The main objection was that extra pumping power was required to fetch the treated water from the storage tank at the end of the CW. It took a three-month-long negotiation involving local villagers, school teachers and NGO to convince the upstream farmer to allow the wastewater flow to the DWAT unit. The local panchayat helped to resolve the issue by making the farmers understand the long-term adverse effect of such practice to human and soil health. This is an example why follow-up after the establishment of wastewater treatment unit is needed to ensure the longevity and sustainability of the scientific interventions. In this case the actual construction of the wastewater unit took less than 30 days, whereas convincing the local farmers took more than three months through multiple panchayat-level meetings. Sometimes, the sincerity and diligence of the people in the implementation of the project to convince the farmers gives them the confidence.

Bhanoor

Here the local villagers were unaware of the importance of wastewater treatment; in fact, the locals dump solid waste randomly at the DWAT site, severely impacting its performance. The awareness campaign and panchayat-level vigil to prevent waste dumping had proved inadequate to stop the solid waste dumping at this site. At present, fencing is being provided to this DWAT site to protect the unit. Moreover, construction of a proper waste-dumping site has started through panchayat in the vicinity to improve the situation.

12.4 Challenges and Way Forward

Despite the high wastewater treatment efficiency demonstrated by the DWAT installed (Fig. 12.5) there is a sense of apprehension among the villagers about the reuse of the treated wastewater in agriculture. After long deliberations in multiple locations about this perceptional issue, it seems utilizing the treated water for cash crop (namely jute, flowers, lemon grass or cotton) cultivation or orchard maintenance may be an easier option.

Fig. 12.5. The DWAT unit installed at Mentepalle, Wanaparthy in 2016.

References

Akratos, C.S. and Tsihrintzis, V.A. (2007) Effect of temperature, HRT, vegetation and porous media on removal efficiency of pilot-scale horizontal subsurface flow constructed wetlands. *Ecological Engineering* 29(2), 173–191.

Amoah, P., Drechsel, P., Abaidoo, R.C. and Henseler, M. (2007) Irrigated urban vegetable production in Ghana: microbiological contamination in farms and markets and associated consumer risk groups. *Journal of Water Health* 5, 455–466.

Ávila, C., Salas, J.J., Martín, I., Aragón, C. and García, J. (2013) Integrated treatment of combined sewer wastewater and stormwater in a hybrid constructed wetland system in southern Spain and its further reuse. *Ecological Engineering* 50, 13–20.

Belmont, M.A., Cantellano, E., Thompson, S., Williamson, M., Sánchez, A. and Metcalfe, C.D. (2004) Treatment of domestic wastewater in a pilot-scale natural treatment system in central Mexico. *Ecological Engineering* 23(4–5), 299–311.

BOE (2007) *Royal Decree 1620/2007*, of 7 December, that establishes the juridical regime of the reuse of treated waters. BOE No. 294 (in Spanish). Boletín Oficial del Estado (Official State Gazette), Madrid, Spain.

Bosak, V., VanderZaag, A., Crolla, A., Kinsley, C. and Gordon, R. (2016) Performance of a constructed wetland and pretreatment system receiving potato farm wash water. *Water* 8, 183.

Carreau, R., VanAcker, S., VanderZaag, A., Madani, A., Drizo, A. *et al.* (2012) Evaluation of a surface flow constructed wetland treating abattoir wastewater. *Applied Engineering in Agriculture* 28, 757–766.

Chary, S.N., Kamala, C.T. and Raj, D.S.S. (2008) Assessing risk of heavy metals from consuming food grown on sewage irrigated soils and food chain transfer. *Ecotoxicology and Environmental Safety* 69, 513–524.

Collaço, A.B. and Roston, D.M. (2006) Use of shredded tires as support medium for subsurface flow constructed wetland. *Engenharia Ambiental – Espírito Santo do Pinhal* 3(1), 21–31.

Corcoran, E., Nellemann, C., Baker, E., Bos, R., Osborn, D. and Savelli, H. (eds) (2010) *Sick Water? The Central Role of Wastewater Management in Sustainable Development*. UNEP, UN–Habitat, GRID–Arendal, Arendal, Norway.

Cordesius, H. and Hedström, S. (2009) *A Feasibility Study on Sustainable Wastewater Treatment Using Constructed Wetlands – An Example from Cochabamba, Bolivia*. MSc thesis. Division of Water Resources Engineering, Department of Building and Environmental Technology, Lund University, Sweden.

CPCB (2015) CPCB directs municipal bodies not to discharge untreated sewage into rivers. Available at: https://www.livemint.com/Politics/vqQbrfuwjhv7cHEaZ3dy7J/CPCB-directs-municipal-bodies-not-to-discharge-untreated-sew.html (accessed 26 April 2018).

Datta, A., Wani, S.P., Tilak, A.S., Patil, M.D. and Kaushal, M. (2015) Assessing the performance of free water surface constructed wetlands in treating domestic wastewater: a potential alternative for irrigation. Presented at the International Conference ICID2015 (26th ERC and 66th IEC) held during 11th–16th October 2015. Montpellier, France.

Drechsel, P., Graefe, S., Sonou, M. and Cofie, O.O. (2006) *Informal Irrigation in Urban West Africa: An Overview*. IWMI Research Report 102. International Water Management Institute, Colombo, Sri Lanka.

Dunne, E.J., Coveney, M.F., Hoge, V.R., Conrow, R., Naleway, R. *et al*. (2015) Phosphorus removal performance of a large-scale constructed treatment wetland receiving eutrophic lake water. *Ecological Engineering* 79, 132–142.

Fan, J., Zhang, B., Zhang, J., Ngo, H.H., Guo, W. *et al*. (2013) Intermittent aeration strategy to enhance organics and nitrogen removal in subsurface flow constructed wetlands. *Bioresource Technology* 141, 117–122. DOI: 10.1016/j.biortech.2013.03.077.

FAO (2017) Wastewater an opportunity being flushed away. Food and Agriculture Organization, 22 March 2017. Available at: http://www.fao.org/news/story/en/item/853565/icode/?platform=hootsuite (accessed 23 March 2017).

Grangier, C., Qadir, M. and Singh, M. (2012) Health implications for children in wastewater-irrigated peri-urban Aleppo, Syria. *Water Quality Exposure and Health* 4(4), 187–195.

Jimenez, B. (2005) Treatment technology and standards for agricultural wastewater reuse: a case study in Mexico. *Irrigation and Drainage* 54 (Supplement 1), S22–S33.

Keraita, B.N. and Drechsel, P. (2004) Agricultural use of untreated urban wastewater in Ghana. In: Scott, C.A., Faruqui, N.I. and Raschid-Sally, L. (eds) *Wastewater Use in Irrigated Agriculture*. CAB International, Wallingford, Oxfordshire, pp. 101–112.

Li, L., Li, Y., Biswas, D.K., Nian, Y. and Jiang, G. (2008) Potential of constructed wetlands in treating the eutrophic water: evidence from Taihu Lake of China. *Bioresource Technology* 99, 1656–1663.

Melloul, A.A. and Hassani, L. (1999) Salmonella infection in children from the wastewater-spreading zone of Marrakesh city (Morocco). *Journal of Applied Microbiology* 87(4), 536–539.

Mihelcic, J.R., Fry, L.M. and Shaw, R. (2011) Global potential of phosphorus recovery from human urine and feces. *Chemosphere* 84(6), 832–839. DOI: 10.1016/j.chemosphere.2011.02.046.

Minhas, P.S. and Samra, J.S. (2004) *Wastewater Use in Peri-urban Agriculture: Impacts and Opportunities*. Central Soil Salinity Research Institute, Karnal, India.

Obuobie, E., Keraita, B., Danso, G., Amoah, P., Cofie, O.O., Raschid-Sally, L. and Drechsel, P. (2006) *Irrigated Urban Vegetable Production in Ghana: Characteristics, Benefits and Risks*. IWMI-RUAF-IDRCCPWF, Accra, Ghana. Available at: http://www.cityfarmer.org/GhanaIrrigateVegis.html (accessed 25 March 2017).

OECD (2011) *OECD Environmental Performance Reviews: Israel 2011*. Organisation for Economic Co-operation and Development Publishing, Paris. Available at: http://www.oecd.org/env/oecd-environmental-performance-reviews-israel-2011-9789264117563-en.htm (accessed 5 April 2017).

Prüss-Üstün, A., Bartram, J., Clasen, T., Colford Jr, J.M., Cumming, O. *et al*. (2014) Burden of disease from inadequate water, sanitation and hygiene in low- and middle-income settings: a retrospective analysis of data from 145 countries. *Tropical Medicine and International Health* 19(8), 894–905.

Puigagut, J., Villaseñor, J., Salas, J.J., Bécares, E. and García, J. (2007) Subsurface-flow constructed wetlands in Spain for the sanitation of small communities: a comparative study. *Ecological Engineering* 30(4), 312–319.

Qadir, M., Wichelns, D., Raschid-Sally, L., Minhas, P.S., Drechsel, P. *et al*. (2007) Agricultural use of marginal-quality water – opportunities and challenges. In: Molden, D. (ed.) *Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture*. Earthscan, London and International Water Management Institute, Colombo, Sri Lanka, pp. 425–457.

Rossmann, M., Matos, A.T., Abreu, E.C., Silva, F.F. and Borges, A.C. (2013) Effect of influent aeration on removal of organic matter from coffee processing wastewater in constructed wetlands. *Journal of Environmental Management* 128, 912–919.

Srikanth, R. and Naik, D. (2004) Health effects of wastewater reuse for agriculture in the suburbs of Asmara City, Eritrea. *International Journal of Occupational Environment and Health* 10(3), 284–288.

Tilak, A., Wani, S.P., Datta, A., Patil, M., Kaushal, M. and Reddy, K.R. (2017) Evaluation of *Ageratum conyzoides* in field scale constructed wetlands (CWs) for domestic wastewater treatment. *Water Science & Technology* 75(10), 2268–2280. DOI: 10.2166/wst.2017.119.

Udagedara, U.S.C. and Najim, M.M.M. (2009) Potential to enhance the extent of paddy cultivation using domestic and municipal wastewater harvesting – a case study from the dry zone of Sri Lanka. *Journal of Applied Irrigation Science* 44(2), 239–248.

UNEP (2016) *A Snapshot of the World's Water Quality: Towards A Global Assessment*. United Nations Environment Programme, Nairobi.

Van Vuuren, D.P., Bouwman, A.F. and Beusen, A.H.W. (2010) Phosphorus demand for the 1970–2100 period: a scenario analysis of resource depletion. *Global Environmental Change* 20(3), 428–439. DOI: 10.1016/j.gloenvcha.2010.04.004.

Vohla, C., Kõiv, M., Bavor, H.J., Chazarenc, F. and Mander, Ü. (2011) Filter materials for phosphorus removal from wastewater in treatment wetlands – A review. *Ecological Engineering* 37(1), 70–89.

Vymazal, J. (2010) Constructed wetlands for wastewater treatment: five decades of experience. *Environmental Science and Technology* 45(1), 61–69.

Vymazal, J. (2014) Constructed wetlands for treatment of industrial wastewaters: a review. *Ecological Engineering* 73, 724–751.

Vymazal, J. and Kropfelova, L. (2008) *Wastewater Treatment in Constructed Wetlands with Horizontal Sub-Surface Flow*. Springer Verlag, Heidelberg, Germany.

Wang, X., Bai, X., Qiu, J. and Wang, B. (2005) Municipal wastewater treatment with pond-constructed wetland system: a case study. *Water Science and Technology* 51(12), 325–329.

WHO (2014) *Preventing Diarrhoea through Better Water, Sanitation and Hygiene: Exposures and Impacts in Low- and Middle-income Countries*. World Health Organization, Geneva.

WHO (2015) *UN-Water GLAAS TrackFin Initiative: Tracking Financing to Sanitation, Hygiene and Drinking-water at the National Level*. Guidance document summary for decision-makers. World Health Organization, Geneva.

Winblad, U. and Simpson-Hébert, M. (eds) (2004) *Ecological Sanitation*. Revised and enlarged edition. Stockholm Environment Institute, Stockholm.

WWAP (2017) *The United Nations World Water Development Report 2016: Water and Jobs*. World Water Assessment Programme. United Nations Educational, Scientific and Cultural Organization (UNESCO), Paris.

Zidan, A.A., El-Gamal, M.A., Rashed, A.A. and Abd El-Hady, M.A. (2013) BOD treatment in HSSF constructed wetlands using different media (set-up stage). *Mansoura Engineering Journal* 38(3), 36–42.