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Qualitative evaluation of small scale municipal Wastewater Treatment Plants (WWTPs) in South India

S. Suneethi*, G. Keerthiga, R. Soundhar, M. Kanmani, T. Boobalan, D. Krithika and Ligy Philip

EWRE Division, Indian Institute of Technology Madras, Chennai, 600 036, India

*Corresponding author. E-mail: sundar.suneethi@gmail.com

Abstract

Decentralized wastewater treatment system (DEWATS) are widely used for the treatment of wastewater originating from residences, institutes and municipalities, specifically in South India. Most of these STPs are denounced owing to failures on several fronts including design, operation and maintenance, installation and monitoring. A comprehensive review and evaluation of STPs was timely, in order to derive sound conclusions and recommendations for future wastewater management strategies. The objective of the present study was to conduct an independent evaluation of already existing decentralized STPs in South India. The technologies assessed were Aerated lagoon (AL), Extended aeration (EA), Anaerobic filter/Vortex put forward by Centre for Scientific Research (CSR VORTEX), Constructed Wetland (DEWATS others), Membrane bioreactor (MBR) and Moving bed Biofilm reactor (MBBR). Among the various technologies evaluated, MBR exhibited the highest total COD, BOD and solids removal efficiency. Pathogen count was lowest in MBR, followed by MBBR and AL. Nutrient removal in terms of ammoniacal nitrogen and nitrate nitrogen was highest in DEWATS. Effective hours of continuous operation enabled improved plant performance. In case of natural treatment technology such as DEWATS, energy requirement is quite low, whereas conventional treatment technologies such as EA necessitate considerably high demand of energy, requiring few personnel to operate the system. Innovative high cell density systems such as MBBR and MBR entail significant power consumption and elaborate maintenance, requiring large number of skilled professionals. The major reasons for failure of STPs were related to mechanical, electrical and labour problems. Regular monitoring and maintenance is required with due diligence in all the treatment technologies for proper functioning.

Key words: DEWATS, municipal wastewater, qualitative evaluation, South India

INTRODUCTION

Commonly noticed water woes in India include water scarcity and environmental pollution due to untreated/partially treated wastewater. Sewage treatment plant (STP) capacity is inadequate as nearly 21% of wastewater is only being treated. It amounts to 6,000 million L/d (Central Pollution Control Board (CPCB) 2005). Inadequate and un-safe discharge of untreated domestic/ municipal wastewater has resulted in contamination of 75% of all surface water i.e at the rivers, ponds and lakes across India (Seshadri 2011). Only 6% of Urban Local Bodies (ULBs) ULBs have some form of wastewater treatment system. The ULBs have established only 50% of household connection to centralized STP (Environmental Protection agency (EPA) 2002; Central Pollution Control Board (CPCB) 2005). The chief concerns in these circumstances would be environmental pollution due to partially/ untreated wastewater, consequences of urban development and the veracity of water shortage.

Decentralized wastewater treatment system (DEWATS) has been promoted and practiced with verve and vigour since the late 90's in India. DEWATS employs a combination of onsite and/or cluster systems

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and is used to treat and dispose of wastewater from dwellings and businesses close to the source (Obropta & Berry 2005). DEWATS consist of a variety of approaches for collection, treatment, and dispersal/reuse of wastewater for residential, industrial or institutional facilities, clusters of homes or businesses, and entire communities (municipal) (National small flows clearinghouse (NSFC) 2000). These systems can serve on a variety of scales including individual dwellings, businesses, or small communities; Treat wastewater to levels protective of public health and water quality; Comply with prescribed discharge regulatory codes; and work well in rural, suburban and urban settings (Klatte 2004; Inspiration 2013). The advantages of decentralized wastewater treatment includes but not limited to: being cost-effective and economical, avoiding large capital costs, reducing operation and maintenance costs, promoting business and job opportunities, green and sustainable, benefiting water quality and availability, using energy and land wisely, responding to growth while preserving green space, safe in protecting the environment, public health, and water quality, protecting the community's health, reducing conventional pollutants, nutrients, and mitigating contamination and health risks associated with wastewater (National small flows clearinghouse (NSFC) 2000; Environmental Protection agency (EPA) 2002; Klatte 2004). The application and sizing of treatment units based on DEWATS and onsite technologies are defined by performance requirements, wastewater characteristics, and site conditions.

Of the >100 nos of decentralized wastewater treatment plants (WWTPs) of different technology types that have been installed all over India, not all are well functioning (Central Pollution Control Board (CPCB) 2005). There have been several failures including lack of knowledge on operation and maintenance. Further prevalent causes such as intermittent energy supply, lack of skilled manpower and irregular maintenance, process instability, plant aging, hydraulic shock loading and overloading, design and installation problems has been reported (Environmental Protection agency (EPA) 2002). Out of the 115 centralized Sewage treatment plants (STPs) in Class I cities and Class II towns, nearly 45 STPs failed to achieve the prescribed discharge standards (Central Pollution Control Board (CPCB) 2005). The extent of cost recovery is minimal since the marketability of treated water is poor (Environmental Protection agency (EPA) 2002; Central Pollution Control Board (CPCB) 2005).

There is a constant need for innovative Wastewater treatment plants (WWTPs) with pointers on treatment, reuse of water, energy reuse or nutrient reuse. These options have to be sustainable, affordable and yield benefits such as higher wastewater treatment ratios and water scarcity mitigation. Till date there has been no consolidated evaluation and review of all the existing decentralized plants. There is only limited knowledge on the performance of those available existing technologies. To drive forward the future wastewater management strategies in India, a complete review and evaluation of WWTPs is well-timed, so as to develop sound conclusions and recommendations. Consequently careful selection of new technologies for future introduction will be based on existing experiences in India. There is a pressing yet realistic need for upgradation of existing WWTPs and development of advanced treatment options for upcoming WWTPs.

The main goal of this investigation is to assess and evaluate the performance of DEWATS plants meant for residential, industrial and municipal facilities in South India. This paper will address this objective of conducting an independent evaluation of already existing decentralized WWTPs in South India.

The specific objectives of this investigation include:

(i) To conduct an independent and integrated assessment of the existing technologies in India
(ii) To assess the potential of various technologies and evaluate the performance of municipal and household wastewater treatment, reclamation and reuse strategies
(iii) To characterize the wastewater from each units from different WWTPs adopting different technologies
(iv) To investigate the efficiency of organics, nutrients, solids and coliform removal from the existing WWTPs adopting different technologies

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MATERIALS AND METHODS

The strategy of the work plan was divided into 2 phases.

(i) PHASE 1 – Documentation

The general scope of this investigation spanned nearly 1900 STPs, out of which 13 plants with 6 technologies were taken up for evaluation from the Southern states. It included updating documentation, careful selection of case studies, and collection of background information on case studies. For the Southern states, through the data collection, over 50 listings of companies and Institutes were contacted. The sites for evaluation were chosen in Tamilnadu and Karnataka.

(ii) PHASE 2 – Evaluation

It comprised of technical and environmental performance evaluation of the WWTPs, and carrying out hygienic assessment. The PHASE 2 involved both Qualitative evaluation (QE) and In depth evaluation (IDE) by grab sampling and composite sampling, respectively. For the purpose of this publication, the discussion will be restricted to qualitative evaluation. The parameters monitored for QE includes pH, total and soluble COD, total and soluble BOD, TSS/MLSS, ammoniacal nitrogen, nitrate nitrogen, total and inorganic phosphate and total/faecal coliforms. These parameters were analysed according to American Public Health Association (APHA) (2005).

Qualitative evaluation (QE)

The Table 1 depicts the Qualitative evaluation (QE) that was carried out for the chosen 13 plants with a sampling frequency of every 6 months from 2013 to 2014. This was followed by individual case studies of each plant during IDE. The schematic of the treatment technologies in each STPs from the chosen sites are depicted in Figure 1. The details of treatment train, the results of the wastewater

Table 1 | List of technology and STP details for QE

SL NO	TECHNOLOGY	PLANT ID	LOCATION	CAPACITY (MLD)	STARTUP YEAR	TYPE OF WASTEWATER	FLOWSHEET
1.	Aerated Lagoon (AL)	AL-1	Tamilnadu	1.4	2004	Institutional	Aerated Lagoon + Clariflocculator + Sand Filter + Chlorination
2.	Extended aeration (EA)	EA-1	Tamilnadu	1.70	2012	Institutional	Extended aeration + Clariflocculator + Chlorination + Sand Filter + Polishing pond
		EA-2	Tamilnadu	1.00	2004		
		EA-3	Karnataka	1.00	2008	Institutional	
		EA-4	Karnataka	0.20	2011	Institutional	
3.	Anaerobic filter/ Vortex (CSR VORTEX)	CSR-1	Pondicherry	0.008	2009	Residential	Anaerobic Baffled Reactor + Anaerobic Filter + Vortex /Planted Filter
		CSR-2	Pondicherry	0.0054	2010	Residential	
		CSR-3	Pondicherry	0.0055	2011	Institutional	
		CSR-4	Pondicherry	0.0075	2009	Residential	
		CSR-5	Pondicherry	0.0090	2010	Residential	
		CSR-6	Pondicherry	0.035	2004	Residential	
4.	Constructed Wetland (DEWATS others)	DEWATS-1	Tamilnadu	0.0025	2013	Institutional	Settling Tank + Wetland
5.	Membrane bioreactor (MBR)	MBR-1	Karnataka	1.5	2004	Municipal	Membrane Bioreactor + Chlorination
6.	Moving bed Biofilm reactor (MBBR)	MBBR-1	Tamilnadu	0.4	2010	Institutional	Moving bed biofilm reactor + Settling (alum) + Sand Filter + Activated Carbon Filter + Chlorination

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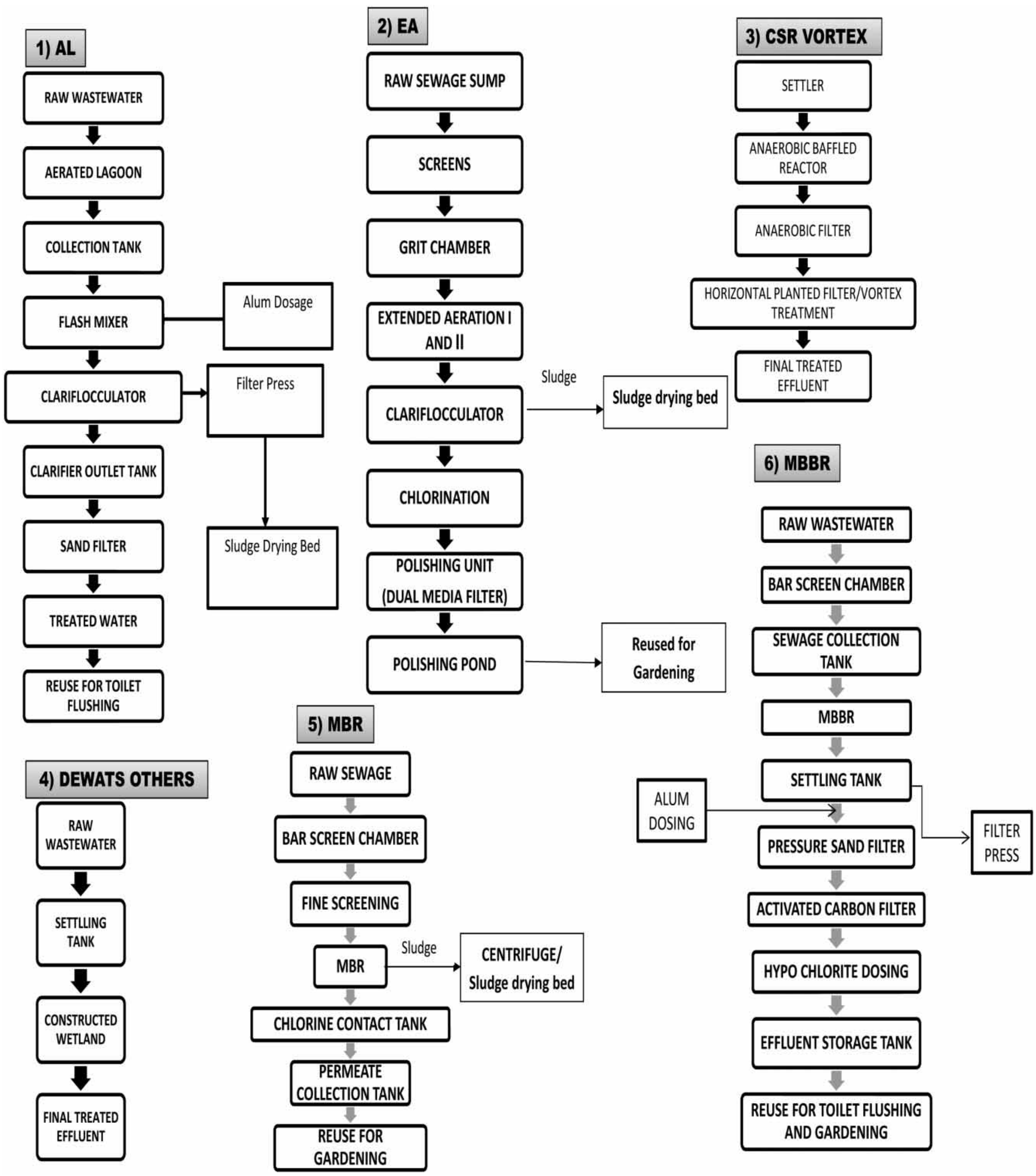

Figure 1 | Schematic Flowchart of the 6 Treatment Technologies Assessed In South India.

analysis and operation and maintenance are explained in this manuscript. The QE of the 6 treatment technologies is based on the organic, nutrient, solids and coliform removal, and plant details on operation and maintenance.

RESULTS AND DISCUSSION

Organic and nutrient removal during QE

The performance of all the 13 STPs during the course of QE is depicted in Figure 2. The MBR-1 showed a total COD removal of 97%, as observed in Figure 2(a). Off the 6 CSR STPs, the CSR-6

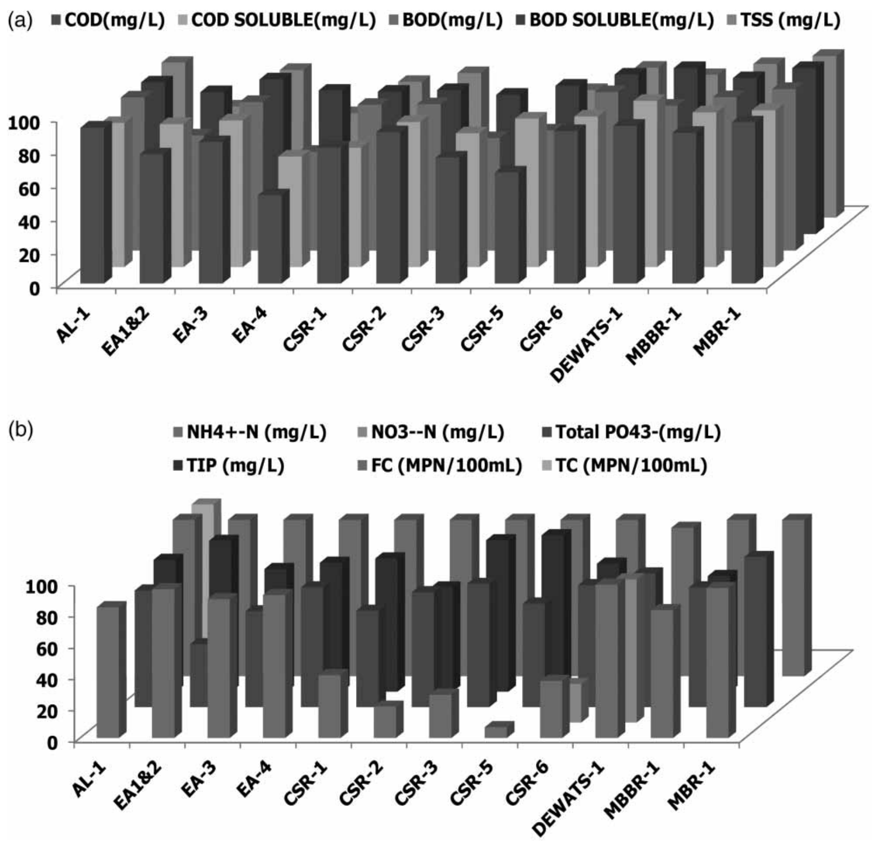

Figure 2 | Performance Evaluation of STPs.

STP has shown the maximum organic removal in terms of total COD of 92% with the lowest from CSR-5 at 67%. Overall, the disparaging results from different STPs with similar technology, with common geography and design could be due to difference in operation strategies and maintenance. In general, the performance of organic removal in CSR Vortex systems were due to the longer HRT 0.167 d (anaerobic baffled reactor), 0.75–0.917 d (anaerobic filter) (Baetens 2009) and the development of highly concentrated bacterial population in the anaerobic filter (Gerardi 2003). The extremely stable digestion process was achieved even during significant variations in operation strategies and maintenance. The high SRT of 365 d is advantageous for anaerobic digesters, since it can maximize removal capacity, reduce required digester volume, and provide buffering capacity for protection against the effects of shock loadings and toxic compounds in wastewaters and sludges (Gerardi 2003).

With regards to soluble COD removal, the extended aeration system at EA-4 fared lowest at 66% removal compared to the other technologies. The trite performance of EA-4 for soluble COD was similar to total COD removal (53%). The magnitude of higher removal of soluble COD when compared to total COD could be because of the fact that in a typical extended aeration system, the soluble COD, which is the readily degradable portion of the COD in wastewater, is the fraction removed during aerobic treatment processes (Metcalf & Eddy 2002). This theory holds good for all the 3 extended aeration systems in this QE.

The nutrient removal in terms of ammoniacal nitrogen was better in biofilm based systems such as MBR-1 (95%) and in extended aeration systems including EA-1&2 and EA-4 with 94% and 91% respectively, as shown in Figure 2(b). But the highest ammonia removal efficacy of 98% was pronounced in DEWATS-1 plant then followed by MBR-1. MBR-1 is proven to be an advanced high cell density systems having complete biomass retention, high reactor loading and low sludge production (Mahimairaja & Bolan 2004; Berge *et al.* 2005; Bertino 2010) and utilized for treating

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ammonia rich wastewaters such as landfill leachate, distillery and tannery effluents etc., The constructed wetland in DEWATS-1offers ammonia removal by the principle of bioremediation where the bacterial action on the surface of roots and leaf litter removed most of the nutrients in biotransformation (Kivaisi 2001; Metcalf & Eddy 2002). The nitrogen and phosphorus from municipal wastewater is removed through plant uptake, ammonia is removed through volatilization and nitrification and denitrification (Environmental Protection agency (EPA) 1993; Kivaisi 2001; Kaur *et al.* 2012).

Main findings from removal of organic, inorganic and biological pollutants removal during QE

The chief findings from the monitoring during QE are presented in Table 2. Upon comparing different technologies, the MBR-1 followed by DEWATS-1 had exhibited maximum total COD removal efficiency. With respect to total BOD removal efficacy MBR-1 then followed closely by CSR VORTEX (CSR-6) had topped the list. Soluble COD and BOD was maximum removed in DEWATS-1. Solids removal is best in MBR-1 compared to other treatment options. Pathogen count was lowest in MBR-1, MBBR-1 and AL-1. Ammoniacal nitrogen and nitrate nitrogen removal was highest in DEWATS-1. Nutrient removal by constructed wetland has been well documented in several literatures (Kivaisi 2001; Kaur *et al.* 2012). From these inferences, 4 STPs were eventually chosen for in depth evaluation including, CSR VORTEX (CSR-6), MBBR-1, AL-1 and EA-4. These 4 STPs were in turn evaluated in comprehensive detail, to identify if their performance was good only during the grab sampling days, or otherwise, with additional parameters included in the monitoring scheme.

Comparison of performance for the 13 plants in QE – technology wise

The performance of AL and EA technologies during QE is presented in Figure 3. As per the CPCB general standards for discharge of environmental pollutants of effluents into inland surface waters (Central Pollution Control Board (CPCB) 1986), the AL-1 STP had conformed to the limits. In all the EA systems, COD and TSS concentration in the treated effluent met the permissible limits. EA-4 did not meet the standard limits in terms of coliforms and BOD.

Table 2 | Chief findings from QE

		Technology – Location ID	
Sl No	**Parameters**	**Highest removal (%)**	**Lowest removal (%)**
1.	COD(mg/L)	MBR-1 (97)	EA-4 (53)
2.	COD SOLUBLE(mg/L)	DEWATS-1(>99)	EA-4 (66)
3.	BOD(mg/L)	MBR-1(97)	EA-4 (59)
4.	BOD SOLUBLE (mg/L)	DEWATS-1 (>99) MBR-1 (>99)	CSR-3 (84)
5.	TSS (mg/L)	MBR-1 (97)	CSR-3 (47)
6.	$NH_4^+ - N$ (mg/L)	DEWATS-1 (98)	CSR-5 (7)
7.	$NO_3^- - N$ (mg/L)	DEWATS-1 (91)	CSR-6 (25)
8.	Total PO_4^{3-}-(mg/L)	MBR-1 (96)	EA-1&2 (40)
9.	TIP (mg/L)	CSR-5 (>99)	CSR-2(66)
10.	TC (MPN/100 mL)	AL-1 (>99)	–
11.	FC (MPN/100 mL)	MBR-1 (>99) MBBR-1 (>99)	DEWATS-1 (95)

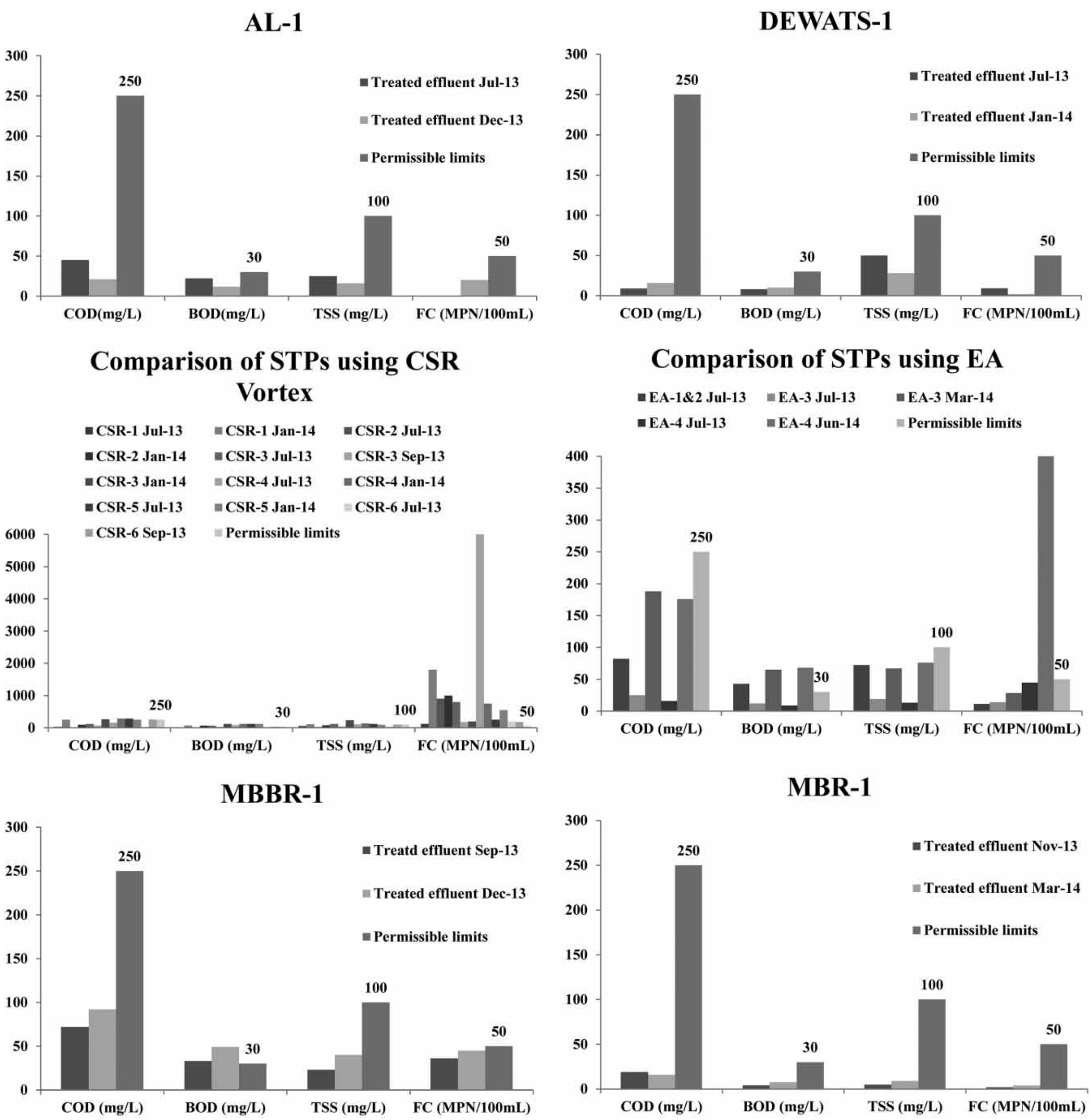

Figure 3 | Comparison of performance of 6 technologies during QE.

In CSR Vortex systems, CSR-3, 4, 5 & 6 did not conform to the limits for COD. In terms of BOD, except CSR-6 all other 5 STPs did not meet the discharge standards prescribed by Central Pollution Control Board (CPCB) 1986. Except for CSR-2 and 6, other CSR plants did not achieve the limits for solids concentration. For coliforms removal, all STPs of CSR Vortex were not meeting the standards. DEWATS-1 and MBR-1 conformed to the limits of CPCB. In MBBR-1, too all other parameters met the standards.

Main findings from overall QE

Wastewater reclamation and reuse

Off the 13 STPs in QE, the EA-1 and 2 utilized the treated effluent for agricultural purposes. The rest of the STPs reclaimed the treated water by reusing it for gardening and toilet flushing.

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Sludge management and resource recovery

The sludge produced in AL-1 (145 kg/d) and EA-1, 2, 3 and 4 is directed to the sludge drying bed and eventually used as manure for gardening. In the MBBR-1 system, about 574 g of dry solids was generated per day. The sludge that is generated was dried using filter press and used as manure. In DEWATS-1, no sludge was produced from the constructed wetland. Yet the sludge/silt management of the effluent produced from the settling tank is ambiguous. In CSR Vortex systems, since the SRT is 365 d, the sludge from the anaerobic baffled reactor and the filter (CSR-1 about 7 kg/year; CSR-2 about 8 kg/year; CSR-3 about 9 kg/year; CSR-4 about 13 kg/year; CSR-5 about 14 kg/year and CSR-6 15 m^3/year) was withdrawn using external pump in trucks and outsourced for further applications at a dedicated site near the STPs.

Impact of STPs

All these different technologies have varying degrees of local impact due to foul odors, release of corrosive and harmful gases such as H_2S, CH_4, and NH_3 and flies nuisance. In CSR Vortex systems, since most of the units are underground it mainly prompted unpleasant odors and mosquito menace. In MBBR-1 EA-1 to 4 and DEWATS-1, the nearby community faced similar problems. In AL-1 and MBR-1, very rarely complaints of noise and bad smell have come to notice.

Plant operation and maintenance

From the QE, it could be understood that for effective plant performance, it needs to be properly operated and maintained. The effective hours of continuous operation enabled improved plant performance. The Operation and maintenance (O&M) of STPs is dependent upon a number of factors including: Uninterrupted energy supply, Skilled manpower and Preventive & regular maintenance (Central Pollution Control Board (CPCB) 2013). In case of natural treatment technology such as DEWATS-1, energy requirement is quite low, whereas conventional treatment technologies such as EA need considerably high demand of energy. Advanced high cell density systems such as MBBR-1 and MBR-1 too, require significant power consumption and elaborate maintenance. Besides, O & M problems, the typical plant performance related issues were due to intermittent energy supply, lack of skilled manpower, irregular maintenance, process instability, plant aging, hydraulic shock loading and overloading, improper construction, design and installation problems, power outages and recurrent mismanagement (Environmental Protection agency (EPA) 2002; Sherri & Wong 2010). Natural treatment technology STPs requires few personnel to operate the system whereas advanced & conventional treatment technology based STPs requires large number of skilled professionals. The major issues for failure of STPs observed during qualitative evaluation were related to mechanical, electrical and labour problems. Specifically the frequently associated problems were that of aerator and clariflocculator, motor and pump related. The common reasons for success of STPs were good civil engineering and design, sound construction and supportive management. On-going and periodic monitoring and maintenance is required with due diligence in all the treatment technologies for proper functioning (Environmental Protection agency (EPA) 2002).

CONCLUSIONS

The QE of the 13 WWTPs with 6 technologies have yielded interesting outcomes which are primarily dependent upon access to plants, operating personnel and uninterrupted power supply. The performance of the plants during QE in terms of organic, nutrient, solids and coliform removal is based on the

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strength and merit of each technology and the choices adopted in sustainable practices of the same. Some of the challenges that were faced during the QE includes but not limiting to, operation of WWTPs only during evaluation days and its implications in the effluent quality, lack of maintenance of laboratory records, difficulty in access to sites, operating personnel not forthcoming and transparent about O & M difficulties faced in the STPs and most commonly lack of information in the choice of technology and reluctance to share openly the data on WWTPs performances.

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