



# Performance evaluation of a decentralized wastewater treatment system in India

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Received: 31 May 2018 / Accepted: 10 May 2019 / Published online: 22 May 2019  
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## Abstract

A Decentralized Wastewater Treatment System (DEWATS) provides an economically feasible and efficient wastewater treatment solution especially in developing countries. It has an enormous potential for developing a sustainable environmental sanitation system. In this study, the treatment efficiency of eight DEWATS plants was evaluated in the state of Maharashtra, India, for their performance in terms of selected physico-chemical parameters of the wastewater. Although the efficiency of some of the plants was lower than that reported in literature, the effluent quality of all the plants was within the permissible discharge limits of the Central Pollution Control Board for all the parameters. Comprehensive assessment of Plant I was carried in terms of its technical and socio-economic aspects. Moreover, LCA tool has been utilized to evaluate the environmental impacts of the operation stage of DEWATS. The midpoint, CML 2001 (April 2015) methodology was adopted, in which 11 impact categories were considered. From the life cycle impact assessment and interpretation, the main impacts are identified as releases of COD, P-PO<sub>4</sub><sup>3-</sup>, and N-NH<sub>4</sub><sup>+</sup> to water bodies and disposal of sludge. Due to negligible energy consumption, the operation stage was found to be less damaging to the environment. It was concluded that DEWATS can be a good alternative for treating wastewater with negligible energy and chemical consumption.

**Keywords** Decentralized wastewater treatment system · Physico-chemical parameters · Coliform removal · Life cycle impact assessment · Environmental impacts · Socio-economic aspects

## Introduction

In many developing countries, including India, providing extensive sewerage network and reliable and affordable wastewater treatment is a challenge (Singh et al. 2011). In India, out of the

total quantity of the sewage generated, only 34.3% was getting treated in the year 1978; whereas, at present, 37.6% of it is getting treated (CSE 2011; Indiatat 2006). Centralized sewerage and wastewater treatment systems cover only a portion of larger urban areas, and on-site sanitation is often inappropriate in

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Responsible editor: Philippe Loubet

**Electronic supplementary material** The online version of this article (<https://doi.org/10.1007/s11356-019-05444-z>) contains supplementary material, which is available to authorized users.

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densely populated settlements. It has been observed that the collection of the wastewater and its treatment at a centralized treatment facility cannot be considered as an economically feasible and sustainable alternative as it relies on the sophisticated treatment technology and highly skilled technical expertise for its operation and maintenance (Massoud et al. 2009; Singh et al. 2009). In order to overcome this, Decentralized Wastewater Treatment System (DEWATS) can be implemented as beneficial intermediate and complementary solution, especially in developing countries as it comprises of treatment and discharge or reuse of wastewater close to its source of generation (WIN-SA 2014). It is an important component of the Community-Based Sanitation (CBS) framework that offers the possibility of relatively swift sanitation improvements in rural, near urban, and dense urban settlements (Water and Sanitation Program 2013). In developing countries, natural or advanced treatment systems like DEWATS are commonly used; whereas in the developed countries, common treatment systems installed include filtration using different membranes and batch reactors like sequencing batch reactor (Singh et al. 2009). In order to determine the location specific treatment system, an evaluation of site conditions needs to be performed before installing a particular treatment technology (EPA 2015). The Bremen Overseas Research and Development Association (BORDA) is a non-government organization (NGO) working for over four decades in the field of sanitation and urban development. Its main objective is to provide better living conditions to the underprivileged communities as well as to protect the environment by providing sanitation facilities in a decentralized manner. As a part of this work, they have developed decentralized wastewater treatment systems which are being installed at many locations in Asian sub-continent as well as in African region (Win-SA 2014; BORDA 2017a, b). DEWATS provides an economically feasible state of the technology as all the locally available construction material can be used Gutterer et al. 2009. Smaller plants especially designed for the wastewater of one residential area or industrial enterprise can thus be applied for more efficient wastewater treatment (Sönmez et al. 2012). According to Battilani et al. 2010, DEWATS technologies are raising interest among water stakeholders who are keenly interested in new single family, onsite and cluster technology, and advanced wastewater treatment to reduce the cost of centralized wastewater treatment which are governed by an expensive piping infrastructure. In the case of the decentralized wastewater sector, very little research has been done to establish the long-term performance of onsite or cluster systems, or the effect that various management approaches may have on by performance.

The main advantages of the DEWATS with extensive systems are as follows (Sasse 1998; Gutterer et al. 2009):

1. Reliable, robust, and buffer shock loads.
2. No (or very little) energy is required.
3. Operation and maintenance (O &M) cost is very low and does not require highly skilled personnel.
4. Limited sludge production.
5. Reduces the risks associated with system failure.
6. Provides a viable resource recovery option in terms of reuse of treated wastewater and biogas utilization.
7. Facilitates multiple stakeholder network establishment to address water pollution problems.

Despite these distinct advantages and wide-scale implementation across the world, there are very few studies documenting the performance evaluation of DEWATS in terms of achieving compliance of the prescribed standards (WIN-SA 2014).

DEWATS provide treatment for both domestic and industrial sources with treatment level ranging for organic wastewater flows from 1 to 1000 m<sup>3</sup>/day. Without considering facilities for necessary chemical pretreatment of wastewater from industries, DEWATS applications are based on four basic technical treatment modules Gutterer et al. 2009:

1. Primary treatment involves sedimentation and floatation. Settler functions as a sedimentation tank which retains the particles via settling mechanism over a period of time.
2. Secondary anaerobic treatment in fixed-bed reactors consists of baffled upstream reactors or anaerobic filters. It works on the principle of anaerobic decomposition of solids (suspended and dissolved). This is achieved by mixing the fresh wastewater with already acclimatized active biomass in the sludge.
3. Tertiary aerobic treatment in sub-surface flow filters results in the degradation of dissolved organic matter via aerobic and facultative microbial population.
4. Tertiary aerobic treatment in polishing ponds.

In India, 77 BORDA DEWATS plants have been installed until the year 2017 (BORDA 2017a, b). The details of all the plant locations along with the starting year of operation, funding agency, etc. are presented in Electronic Supplementary Material Table 1 (ESM 1). ESM Figure 1a depicts distribution of these plants according to the year of starting the operation. Out of the total plants, 11 and 56 plants have been funded by Government and Private organizations respectively. The categorization according to the project type is shown in ESM Figure 1b. According to the available data, only at 2 locations, prefabricated DEWATS units have been installed; whereas at remaining 73 locations, conventional DEWATS have been installed. In India, at none of the locations, a pretreatment in the form grease trap or screen has been installed. Only at FSTP in Leh, a screen has been installed. The settler followed by anaerobic baffled reactor (ABR) and anaerobic filter (AF) is the most common treatment module

combination as can be seen from ESM Figure 1c. In terms of post treatment modules, horizontal gravel filter (HGF) seems to be the most preferred technology. The different types of post treatment technologies installed in DEWATS plants in India are represented in ESM Figure 1d. The categorization of these plants based on design treatment load is depicted in ESM Figure 1e with the maximum number of plants handling up to 50 m<sup>3</sup>/day hydraulic load. ESM Table 2 represents a concise literature review on DEWATS performance evaluation studies for the wastewater treatment.

The generation of wastewater is increasing because of the population growth and improved living standards. As a result, the required treatment capacity and the number of wastewater treatment plants (WWTPs) are also increasing in relation to this growth (Subramani and Jacangelo 2015). Thus, there is a need for comprehensive environmental assessments of a range of wastewater treatment (WWT) options to meet different treatment standards from a life cycle perspective that primarily focus on broader environmental consequences. In this context, LCA can determine what choices provide the best environmental performance (Castillo et al., 2016; Fang et al. 2016). LCA is a standardized and sophisticated tool to “compile and evaluate the inputs, outputs and the potential environmental impacts of a product/process/service system throughout its life cycle” (ISO 2006a).

A considerable amount of resources can be saved if LCA-based methodology is adopted in upgradation of existing WWT and management. LCA is an attractive way to be answering the question, “How can we make our processes more sustainable?” Further, LCA allows the expansion of system boundaries to include all impacts upon the environment, which helps to avoid the possibility of “problem transfer” (Guinée et al. 2001, 2011). The environmental impact of a given WWTP depends on the technological configuration because each specific technology has a characteristic consumption of resources, energy, and chemicals. It is a useful tool to quantify the environmental sustainability of the alternative options (Kalbar et al. 2016; Castillo et al. 2016).

Many researchers have considered LCA analysis as a best practice for the assessment of the environmental impacts of a complex group of processes such as those of WWTPs or urban water cycles (Pintilie et al. 2016). LCA as an optimization tool was first applied in the 1990s in the field of WWT. Since then, the number of internationally published LCA studies on WWT has increased sharply. During the last two decades, a considerable number of studies have been carried out worldwide on LCA of WWT technologies, sludge treatment technologies, and water recycling technologies. As applied in the field of WWT, LCA has been proven as a useful tool for evaluation and computation of the environmental

footprint of a given WWT technology or WWTPs in both design and operation phases.

Emmerson et al. (1995) was the first to apply LCA in the field of wastewater treatment. The study focused on the inventory phase to evaluate different small-scale WWT technologies. With the advancements in LCA methodology and development of various impact categories, several studies applied LCA to identify the hotspots quantitatively evaluating the environmental impacts associated with WWTPs. Corominas et al. (2013) performed a critical review to describe the challenges for LCA applied to WWT and analyzed the reviewed studies following the LCA phases: goal and scope, inventory, impact assessment, and interpretation, in order to identify common elements and distinguishing aspects. Moreover, studies on LCA of sewage sludge were reviewed for their methodological and technological assumptions by Yoshida et al. (2013). LCA has often been used to compare conventional and natural WWT systems (Pan et al. 2011). In comparison with conventional technologies, eco-friendly technologies such as biological filters, constructed wetlands, soil biotechnology, and sand filtration system have been proposed as better alternatives with lower environmental impacts and reduced pollutant loads (Yildirim and Topkaya 2012; Garfi et al. 2017; Lutterbeck et al. 2017) as these technologies are highly efficient for heavy metal removal and have low energy demand. Till date, there are very few studies in Indian context dealing with LCA and wastewater treatment (Kalbar et al. 2012a; Kalbar et al. 2014; Kamble et al. 2017; Raghuvanshi et al. 2017; Singh et al., 2017a, b). The objective of this LCA study was to assess the environmental impacts of operation phase of the DEWATS. ESM Table 3 presents a brief review of studies on LCA applied to natural wastewater treatment systems.

The aim of the present study is to evaluate the wastewater treatment efficiency of BORDA DEWATS. Eight plants throughout India were analyzed for the environmental, socio, and economic parameters. These plants were located at Thane (1), Nagpur (4), and Pune (3). Table 1 represents details of eight BORDA DEWATS plants evaluated during the study period. These plants were categorized into two types, namely institutional and municipal. The periodic monitoring of these plants was carried out in order to assess the treatment efficiency of the BORDA DEWATS. Plant I was monitored with monthly frequency for the relevant physico-chemical and microbiological parameters along with the study of socio-economic aspects. For the first time, a detailed evaluation was performed for DEWATS plants receiving the effluents from different sources. The evaluation has been carried out not only in terms of treatment efficiency, but also in terms of socio-economic analysis of selected plants (two) and environmental impacts for the Plant I which was evaluated for the entire study period through LCA.

**Table 1** Detailed plant description

Plant location	Source of wastewater	No. of users	Capacity (MLD)	Influent quality	Effluent quality	Type of plant	Efficiency	Sludge treatment
I Pune	Toilets, bath room, wash, and laundries	450	0.035	COD 600 mg/l BOD 300 mg/l	COD 30 mg/l BOD 11 mg/l	Institutional	95%	Off-site sludge treatment
II Pune	Combined wastewater	–	0.0075	–	–	Institutional	–	Off-site sludge treatment
III Thane	Toilets and bathroom	–	0.007	–	–	Municipal	–	Off-site sludge treatment
IV Nagpur	Toilets, kitchen wash area	1st phase—5000 2nd phase—800	0.04	COD 820 mg/l BOD 180 mg/l	COD 208 mg/l BOD 18 mg/l	Municipal	75%	Off-site sludge treatment
V Nagpur	Toilets, kitchen wash area	180–200	0.02	COD 520 mg/l BOD 120 mg/l	COD 140 mg/l BOD 32 mg/l	Institutional	73%	Off-site sludge treatment
VI Nagpur	Public toilets, urinal, and bathroom	–	0.012	COD 520 mg/l BOD 120 mg/l TSS < 200 mg/l <i>E. coli</i> present	COD < 20 mg/l BOD < 60 mg/l TSS > 20 mg/l <i>E. coli</i> remedied	Municipal	–	Off-site sludge treatment
VII Pune	Combined wastewater	–	0.024	–	–	Institutional	–	Off-site sludge treatment
VIII Nagpur	Public toilet, slaughter house, and Fish market	–	0.022	–	–	Municipal	–	Off-site sludge treatment

– data not available

## Materials and methods

### Plant description

#### Plant I

Plant I is an institutional type of DEWATS plant situated in Pune with the treatment capacity of 0.035 Million Liter per Day (MLD). The wastewater from different sources is collected in decentralized septic tanks and the effluent from all the septic tanks is then collected in a common collection tank near the treatment system, which consists of the settler, baffled reactor, anaerobic filter, planted gravel filter, and collection tank. Table 2 gives treatment units, actual site photographs, and available dimensions of each unit.

#### Plant II

It is an institutional type of DEWATS plant situated in Pune with the treatment capacity of 0.0075 MLD. The wastewater from hostel toilets, kitchen area, and bathroom is collected in decentralized septic tanks. Wastewater treatment consists of

two levels, primary and secondary. The treated water is used for gardening and farming.

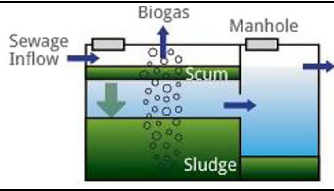
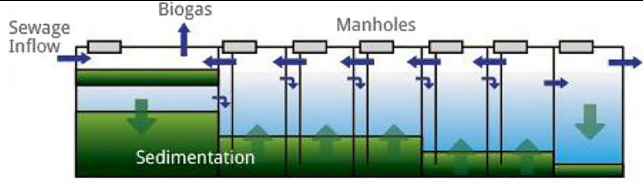

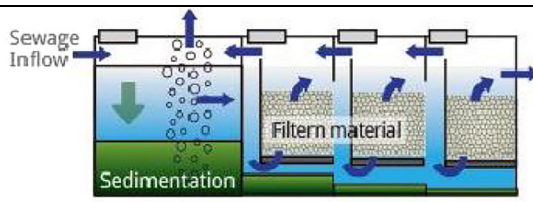
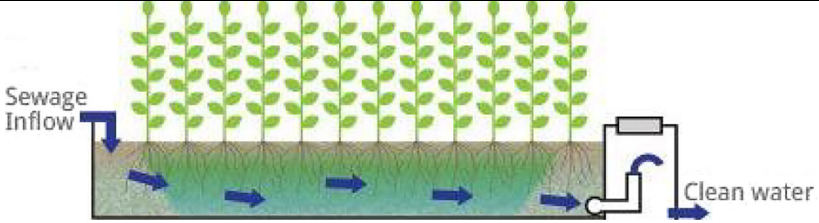

#### Plant III

It is situated in Thane district and has the treatment capacity of 0.007 MLD. It mainly consists of an anaerobic baffled reactor (ABR) with biogas settler. Plant mainly recycles the blackwater from toilets and washbasins. Blackwater and greywater are first sent to a “biogas settler.” The effluent from the biogas settler flows by gravity to an anaerobic treatment system consisting of ABR and up-flow filter (UF). The treated water and urine, which are separately collected in a tank situated outside the toilets, are intended to be used for the proposed garden. The sludge generated from different treatment units like the biogas settler, baffled reactor, and UF is dewatered on sludge drying beds.

#### Plant IV

Plant IV is a municipal type of BORDA DEWATS plant located at Nagpur with a treatment capacity of 0.04 MLD.

**Table 2** Treatment units and dimensions of Plant I

Unit	Design	Actual Image and dimensions
		[Length x Width x Height] (in meters)
Settler		4.7 x 2.2 x 8.4
Anaerobic Baffled Reactor (ABR) + Anaerobic Filter (AF)		 10.5 x 4.7 x 2
Anaerobic Filter		--
Planted Gravel Filter (PGF)		 13.3 x 8.1 x 1.9

-- data not available

The plant treats blackwater and greywater from all the possible sources from the community in 2 phases. In Phase I, the wastewater streams from all the sources are collected in a common tank. The outflow is connected to the treatment system consisting of a settler and a rock bund. In Phase II, a regulated quantity of wastewater ( $40 \text{ m}^3$ ) from the settler is diverted for further treatment modules—a baffle reactor, planted gravel filter, and collection tank.

#### Plant V

This BORDA DEWATS plant is situated in Nagpur and has the treatment capacity of 0.02 MLD. The wastewater from different buildings is collected in 8 septic tanks then collected in a common tank and conveyed to the DEWATS

unit, which consists of a settler, baffled reactor, planted gravel filter, and collection tank.

#### Plant VI

Plant VI is a municipal type of BORDA DEWATS plant located at Nagpur with a treatment capacity of 0.012 MLD. The plant treats blackwater from pay and use public toilets. Initially, the wastewater streams are channeled from all the sources and are collected in a common register near the treatment system. It is then passed through a settler then subjected to anaerobic treatment in an anaerobic baffled reactor (ABR). The third unit process in this wastewater treatment plant consists of an anaerobic filter (AF).

### Plant VII

Plant VII is an institutional type of BORDA DEWATS plant located at Pune with a treatment capacity of 0.024 MLD. The plant has been operating since 2005 and treats combined wastewater generated from school and pharmacy. In the primary treatment, the wastewater is allowed to pass through a settler. The settler is made as a sub-soil constructed tank with one partition wall. The sludge storage volume provided is for 18 to 24 months. Here, the minimal biological oxygen demand (BOD) reduction is between 20 and 25%. The wastewater is then treated in ABR. In the baffled reactor, up to 90%, BOD is reduced and the pathogen reduction ranges between 40 and 75%. The operation and maintenance of the system are simple. The spatial requirements for construction are compensated through pleasing landscapes. Finally, the treated effluent from PGF goes into a pond for effluent quality control. In the pond, further sedimentation or stabilization could take place (normally not needed). The treated wastewater is mainly stored in the pond to be reused for the irrigation of open areas.

### Plant VIII

Plant VIII is a municipal type of BORDA DEWATS plant located at Nagpur with a treatment capacity of 0.022 MLD. The plant has been functional since 2012 and treats combined wastewater generated from public toilet, slaughter house, and fish market. The wastewater generated from all sources gets collected in a common tank near the treatment system, which consists of following modules: the wastewater firstly goes to a biogas settler which is a sedimentation tank. Remaining wastewater goes to ABR. The wastewater is pumped into the next treatment module via a pump sump provided at the end of the baffle reactor. The tertiary treatment is provided by means of PGF. The treated effluent is finally stored in a collection tank and it can be reused for irrigation or for safe disposal.

The flow diagrams of the DEWATS under study are presented in ESM Figure 2 through ESM Figure 4. The common and abundantly available wetland plants at respective sites have been used in PGF. The available details of the dimensions of the treatment modules for selected plants are shown in ESM Table 4.

### Physico-chemical analysis

To determine the efficiency of BORDA DEWATS system, Plant I was monitored for the period of 12 months. Composite samples were collected from influent and effluent locations in pre-sterilized containers. These samples were then analyzed for various physico-chemical parameters like pH, conductivity, color, total solids (TS), total suspended solids (TSS), volatile solids (VS), volatile suspended solids (VSS),

alkalinity, oil and grease, chlorides, free ammonia, and dissolved oxygen (DO). The analysis of wastewater was carried out for parameters like chemical oxygen demand (COD) and biochemical oxygen demand (BOD) to estimate the organic load of influent. In terms of nutrients, the samples were analyzed for total ammoniacal nitrogen (TAN), total Kjeldahl nitrogen (TKN), phosphates, and nitrates. The wastewater samples were also analyzed for the presence of heavy metals like zinc, lead, copper, chromium, iron, and arsenic. All the parameters were analyzed as per Standard Methods for the Examination of Water and Wastewater (Clesceri et al. 2005).

### Microbial analysis

The most probable number (MPN) method was used for enumerating the microbial load (fecal coliforms) in the collected wastewater samples. The discharge standards for coliforms can be developed only by carrying out the performance evaluation of the currently operating wastewater treatment plants. The Central Pollution Control Board (CPCB) has carried out such a study in the past (CPCB 2013).

### Life cycle assessment

The LCA has been carried out with GaBi software (version 6.0) provided by Thinkstep. The LCA methodology used in this study is in accordance with the international standards ISO 14040-44 series (ISO 2006a, b). There are four necessary phases for an LCA study: goal and scope definition, life cycle inventory (LCI), life cycle impact assessment (LCIA), and interpretation of the results based on the system boundaries and assumptions that were considered. The four phases are described in detail below:

**Goal and scope definition** It constitutes the first phase of an LCA and aims at defining the objective and boundaries of the study and the quality of data used. The goal of this LCA study was to evaluate and quantify the environmental impacts of DEWATS (Plant I). The objectives of this LCA were to perform a contribution analysis to identify the most significant impact category and to perform a contribution analysis to identify the processes that contribute most to the impact categories determined earlier.

**Functional unit** A functional unit which represents the function of the system under study must be established in this phase. It is the base for the comparison in the life cycle inventory. In this study, the functional unit was defined as 1 m<sup>3</sup> of treated wastewater. It is used in most of the studies and it adequately represents the system function when considering the final effluent quality (Fang et al. 2016; Ioannou-Ttofa et al. 2016; Hernandez-Padilla et al. 2017).

**System boundaries** When identifying the parts of the system to be considered in the system boundaries of wastewater units, very different choices can be made and these choices will affect the results. System boundaries considered for LCA affect largely on the final results and hence shall be judiciously selected (Tillman et al. 1998). In this study, only operation phase (primary processes—treatment of wastewater, sludge treatment and disposal, emissions to air, water and soil from treatment plant) was considered. This approach is in agreement with similar LCA studies (Pasqualino et al. 2009; Foley et al. 2010; Kamble et al. 2017). The emphasis was put on the operation stage since it was considered the most relevant stage (Rodríguez-García et al. 2011). The system boundary of this study is represented in Fig. 1.

The assumptions made in this study are listed below:

1. The analysis was limited to the operation stage and no considerations were given to the construction and demolition phase, as these phases account for intensive data requirement (Lassaux et al. 2007; Hospido et al. 2012; García-Montoya et al. 2016).
2. The influent BOD was assumed to be 200 mg/L, which is the average BOD5 value in India (Kalbar et al. 2012b; CPCB, 2016).
3. The data for electricity consumption (primary data) for this LCA study was collected from plant operators, and the background data was used from the software to assess the environmental impacts.

4. Electricity was assumed to be generated from hard coal, lignite, hydropower, nuclear, waste to energy, coal gases, natural gases, oil, wind, biomass, and solar. The energy process used for modeling in GaBi software was an Indian electricity grid mix, medium voltage.
5. Indirect emissions due to electricity consumption were only considered. Direct process emissions which are biogenic in nature were excluded from the analyses due to lack of data.
6. For transportation of sewage sludge to the landfill site, the distance of 50 km was assumed.
7. The truck used for transportation was assumed to be a truck-trailer; diesel driven, Bharat stage IV, cargo; consumption mix; up to 28-ton gross weight/12.4 ton payload capacity. Diesel consumption was assumed to be based on type of truck used and distance in kilometers.
8. For reuse scenario, the effluent reuse rate was considered to be 100%.
9. The tap water production process is used from Gabi 6.0 software.

**Life cycle inventory** In the second stage following the goal and scope definition, LCI is performed, which involves data collection and interpretation of inputs and outputs. The allocation procedure is also conducted during the LCI phase, which consists of distributing input and output flows among the process. For this study, the LCI consists of the following: inputs (electricity, influent, and diesel) and outputs (effluent, emissions to

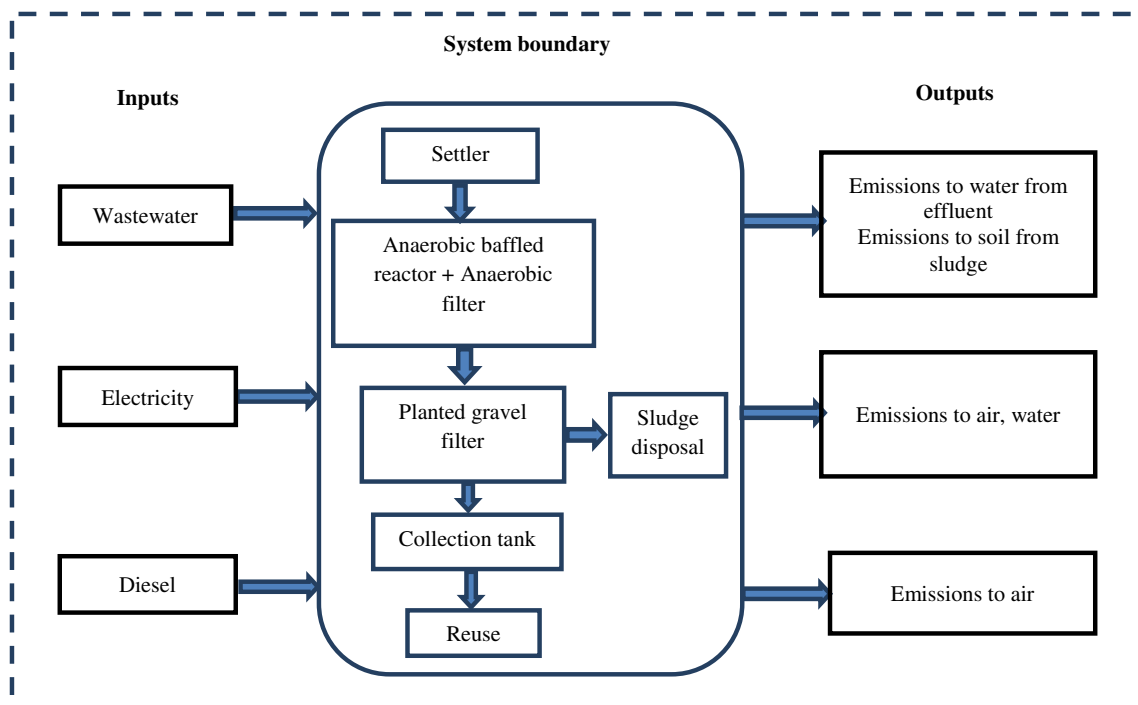


Fig. 1 System boundary for Plant I

air, water, and soil, recycled water, and disposed sludge). Life cycle inventory data (input and output) of Plant I is reported in Table 3.

**Life cycle impact assessment** Impact assessment is an important step in quantifying the environmental impacts. Its purpose is to convert LCI data into potential impacts associated with products and processes. In this study, a midpoint-based CML 2001 (April 2015) method was used for life cycle impact

assessment (LCIA) as it gives a separate score for each type of environmental impact. CML 2001 (Guinée et al. 2011) was the most favored and frequently used method for the quantification of impacts because of its extensive impact categories and accuracy proved by earlier studies (Lorenzo-Toja et al. 2016). Some studies generated similar LCA results showing no effect of LCA methods, whereas the results of other studies that demonstrated choice of methodologies did influence LCA results significantly. Selection of this method is in agreement

**Table 3** Summary of the operation phase life cycle inventory for inputs and outputs of DEWATS (Functional unit–1 m<sup>3</sup> of treated wastewater)

Sr. no.	Parameter	Unit	Data source
<b>Inputs</b>			
1	Electricity consumption (pumping of sewage)	MJ	0.131 Plant operators
2	Sludge generated (dry matter)	kg	0.0003 Plant operators
3	Transportation of sludge to landfill	km	50 Plant operators
3.1	Type of truck used for transportation		Truck-trailer; diesel driven, Bharat stage IV, cargo; consumption mix; up to 28-t gross weight/12.4-t payload capacity
<b>Outputs</b>			
4	Emissions to air	kg	0.133 Indirect emissions due to total electricity consumption and transportation of sludge to landfill. Taken from Gabi database
4.1	CO <sub>2</sub> (fossil)	kg	0.0151
4.2	CH <sub>4</sub> (fossil)	kg	2.07E–005
4.3	SO <sub>2</sub>	kg	8.84E–005
4.4	CO	kg	7.35E–006
4.5	Nitrogen oxides	kg	6.27E–005
4.6	Heavy metals	kg	1.03E–007
4.6.1	Zinc	kg	3.41E–008
4.6.2	Lead	kg	1.33E–008
4.6.3	Copper	kg	1.63E–009
4.6.4	Chromium	kg	1.91E–013
4.6.5	Arsenic	kg	6.1E–009
5	Emissions to water	kg	0.000441
5.1	COD	kg	5.28E–006 Analyzed in lab, APHA method
5.2	N-total	kg	1.38E–011 Analyzed in lab, APHA method
5.3	Phosphorus	kg	5.26E–011 Analyzed in lab, APHA method
5.4	Heavy metals	kg	3.07E–009 Analyzed by ARCOS, simultaneous inductively coupled plasma (ICP) spectrometer
5.4.1	Zinc	kg	5.85E–010
5.4.2	Lead	kg	1.66E–010
5.4.3	Copper	kg	2.21E–010
5.4.4	Chromium	kg	2.61E–010
5.4.5	Iron	kg	1.01E–005
5.4.6	Arsenic	kg	2.07E–013
6	Emissions to soil	kg	6.38E–008 Taken from Gabi database. (no literature or secondary data was available)
6.1	Heavy metals	kg	6.38E–008
6.1.1	Zinc	kg	2.33E–008
6.1.2	Lead	kg	1.28E–009
6.1.3	Copper	kg	8.55E–009
6.1.4	Chromium	kg	3.01E–008



with the published studies (Pennington et al. 2004; Hospido et al. 2012; Chen and Chen 2013; Rodriguez-Garcia et al. 2014).

Eleven potential impact categories, viz., abiotic depletion potential (ADP fossil, elements), acidification potential (AP), eutrophication potential (EP), freshwater aquatic ecotoxicity potential (FAETP), global warming potential (GWP), human toxicity potential (HTP), marine aquatic ecotoxicity potential (MAETP), ozone layer depletion potential (ODP), photochemical ozone creation potential (POCP), and terrestrial ecotoxicity potential (TETP), were considered in this study.

### Socio-economic aspects

In addition to environmental and technological assessment, social and economic aspects of the wastewater treatment process should be studied. In terms of social aspects, data regarding details of sewer blockages, grievances with respect to the plant, employment generation due to this plant etc., was collected from concerned authorities by visiting the actual site. The capital cost and operation and maintenance (O & M) cost incurred, land area requirements were considered for studying the economic aspects of DEWATS plants (Plants I and II).

## Results and discussions

### Plant I

pH is one of the most critical parameters for the proper functioning of anaerobic treatment system. According to Nguyen et al. 2010, the optimum pH range for the methanogenic bacteria is in the range of 6 to 8. At higher pH values, the presence of free ammonia inhibits anaerobic metabolism and also can result in the accumulation of excess quantities of volatile acids which is not desirable for proper functioning of an anaerobic system. During the study period, the influent pH varied from 6.0 to 7.3, whereas that for effluent was in the range of 6.5 to 7.6, which is within the range of discharge standards. This pH provides suitable conditions for establishing active anaerobic microbial population, and in general indicates effective anaerobic treatment conditions (Batstone et al. 2002). During the study period, the conductivity of influent and effluent was varying from 215–1065 to 64–944  $\mu\text{S}/\text{cm}$  respectively. There was a significant decrease in the turbidity of the treated effluent throughout the monitoring period except for the month of November. There was hardly any reduction in the concentration of TDS in the effluent. Similar results have been reported by Sutar and Kulkarni (2016) while evaluating TDS removal efficiency from kitchen wastewater by DEWATS. They reported TDS removal efficiency of 33% and 30% by ABR and HGF respectively. It has been reported that the microorganisms in biofilm of AF act as a substrate for

attachment of suspended and dissolved solids and thereby reduces effluent TDS concentration Jamshidi et al. 2014. Dissolved oxygen in the effluent was found to increase than that in the influent during the sampling period.

The influent's COD shows two peaks in August (251 mg/L) and September (239 mg/L) compared to the overall range of 76–227 mg/L of the rest of the studied period. Further, there is a highest peak in November of 472 mg/L which doubles the rest of the values. This outlier may suggest an experimental error during the laboratory analysis or could be related to specific characteristics of the wastewater. The effluent shows two COD peaks in August–September (95–99 mg/L) and April (97 mg/L), whereas the rest of the values vary between 15 and 57 mg/L. The efficiency varied from 51.7 to 94.9% with an average efficiency of 72.1%. These values indicate somewhat inconsistent performance of the plant in terms of COD removal. The lower COD removal efficiency could be attributed to low influent COD concentration. As reported in literature, in a study by Foxon et al. 2004, COD removal efficiency of about 65–90% can be achieved using ABR alone. AF could achieve approximate efficiency of 79.6–95.3% for COD removal (Sasse 1998). Singh et al. 2009 had reported the efficiency of DEWATS system consisting of ABR and hybrid constructed wetland to be capable of 90% COD removal.

The BOD of the influent varies between 25 and 63 mg/L except in December, with the peak concentration of 110 mg/L. The effluent BOD concentration varied from 4 to 15 mg/L except for the peak concentration in the post monsoon months of September and October and later in the month of April with a concentration of 26 mg/L. The average BOD removal performance of the plant was estimated to be 71.6%. Foxon et al. 2004 had reported BOD removal performance of ABR to be around 70–95%; whereas Sasse 1998 estimated that AF can remove BOD with 84.7–91% efficiency. ABRs enable biological degradation of organic matter by allowing the wastewater to flow through active sludge bed accumulated under the baffles. In the case of AF, biodegradation of organic material is accomplished by providing increased contact time between active microbial biomass settled on filter surface and the wastewater (Gutterer et al. 2009). Despite achieving lower performance than that reported in literature, the effluent concentration was within CPCB's prescribed limit of 30 mg/L throughout the study period (CPCB 1986).

The TSS content of the inlet wastewater was varying between 58 and 143 mg/L. The effluent TSS concentration was in the range of 7 to 73 mg/L with an average removal efficiency of 68.9%. In a typical DEWATS system, AF plays an important role in removal of suspended solids by providing biofilm as a source of attachment Jamshidi et al. 2014. These are suitable for wastewaters with a low percentage of suspended solids (Gutterer et al. 2009). TSS concentration was found to be within the prescribed limit of 100 mg/L irrespective of the

influent concentration and season. The VSS comprises 62–79% of the TSS, except in December, where the VSS content only accounts for 20% of the TSS. This may be due to the specific nature of the wastewater.

The TKN and ammonium content show a similar pattern, with the lower and higher peaks in October (TKN 15.7 mg N/L, ammoniacal nitrogen 12.3 mg N/L) and February (TKN 39.5 mg N/L, ammoniacal nitrogen 36.7 mg N/L) respectively. The rest of the values are contained within 21.8–30.8 mg N/L for the TKN, and 16.2–25.2 mg N/L for the ammoniacal nitrogen. The average removal efficiency was observed to be 28.1% and 35.2% for TKN and ammoniacal nitrogen respectively. The effluent concentrations of both these parameters were within their respective prescribed limits. Ellingsen 2010 could achieve overall ammoniacal nitrogen removal efficiency of 57% when ABR pretreatment was followed by constructed wetland. Jamshidi et al. 2014 treated the wastewater generated from small population using the combination of ABR and Bio-rack wetland planted with *Phragmites* sp. and *Typha* sp. The removal efficiency obtained for TN removal was 79% with an overall HRT of 21 h and 77% with 27 h HRT respectively.

The phosphate of the influent shows two peaks in July and October (3.5 mg P/L) and remains almost constant (0.7–1.5 mg P/L) during the rest of the period of operation of the plant. The effluent concentration ranges from 0.2 to 3.2 mg/L. The removal efficiency shows seasonal variation ranging from 9.7 to 71.6% with an average removal efficiency of 42.4%. This treatment system seems to perform better than other systems reported in literature. Hendrianti and Karnaningroem 2016 reported only 2–13% PO<sub>4</sub> removal efficiency with ABR treatment used in conjunction with stone media biofilter. Nguyen et al. 2010 have concluded that even though ABR is efficient to treat the low strength wastewater containing organic matter and suspended solids, the process is not effective in nutrient removal. ABR and Bio-rack wetland with *Phragmites* sp. and *Typha* sp. could achieve 21% and 14% PO<sub>4</sub>-P removal by 21% with HRT of 21 and 27 h respectively.

The average concentrations of significant physico-chemical and microbiological parameters for Plant I are shown in Table 4.

### Heavy metal analysis

CPCB has stipulated standards for heavy metals in general discharge standards in effluents to be discharged in inland surface water. The concentration of heavy metals like copper (Cu), zinc (Zn), manganese (Mn), iron (Fe), and lead (Pb) in the influent and effluent of Plant I, during the study period, is shown in Table 4.

### Microbial analysis

The microbial quality of the wastewater can be easily accessed by identifying the indicator organisms such as total and fecal coliforms in it (Kermani et al. 2008). This is due to the fact of the abundant presence of bacterial of fecal origins and enteric viruses in the untreated wastewater. According to Rodgers et al. 2003, the typical count of total and fecal coliforms in raw wastewater typically ranges from 10<sup>7</sup>–10<sup>9</sup> to 10<sup>6</sup>–10<sup>8</sup> per 100 ml respectively. The safe reuse for non potable purposes and disposal of wastewater in the water bodies or on land can be assured by the means of bacteriological examination of wastewater. The coliform count serves as an indicator for the possible presence of pathogens in treated effluent and is a very important consideration in deciding the best possible reuse. Coliform count in the influent was lower than 100 MPN/100 ml until September 2014, probably because of the monsoon season which dilutes the microbial load. In subsequent sampling, the coliform count was found to be 1600 MPN/100 ml. *Salmonella* and *Shigella* were not detected during the study period in influent as well as in effluent. The presence of *Escherichia coli* was detected in the months of November and December.

The NRCDC's prescribed limit for fecal coliform count is 1000 MPN/100 ml for discharge on land as well in receiving water bodies. The coliform count in the effluent is within these limits, except during the months of March and April in the year 2015. But, the average percent removal of coliform by the studied DEWATS systems was estimated to be only 36.1%. In contrast, in a study conducted by Jamshidi et al. 2014, very high (99%) reduction in total coliform was obtained. The log removal potential of Plant I was varying from 0.050 to 0.368 with an average of 0.217. However, high SD values reveal that the coliform inactivation in the treatment plant is very unstable. Ellingsen 2010 has reported that sorption is not a predominant bacterial removal mechanism. The more favored mechanism for it could be filtration and straining in regions where biofilm is properly developed in addition to other processes like die-out and predation.

### Other plants

The performance evaluation result for all the eight DEWATS plants under study is presented in Table 5.

The highest BOD removal efficiency of 98% was observed for Plant V followed by Plant VII (96.8%). Similar results were reported by Sakthivel et al. 2012 when they evaluated 5 DEWATS plants at different locations. The BOD removal efficiency for all the plants was reported to be in the range of 90–93%. Among the plants evaluated in this study, the least efficient performance was reported for Plant VI (22.2%) and Plant III (41.4%). In terms of COD removal also, these plants perform poorly with 21.7% and 36.4% efficiency respectively.

**Table 4** Performance evaluation of Plant I in terms of average concentration of wastewater quality parameters

Parameter	Stage in DEWATS					
	Inlet		ABR + AF		Outlet	
	Average	Std. dev.	Average	Std. dev.	Average	Std. dev.
pH	6.7	0.4	6.8	0.4	7.2	0.3
Conductivity	524.6	259.0	453.7	323.9	372.1	292.9
Turbidity	17.0	9.5	3.7	2.2	3.3	–
TDS	249.1	59.3	184.5	37.5	189.5	91.1
VS	265.7	65.7	165.5	68.5	168.4	110.4
DO	3.5	0.4	4.0	0.9	4.4	0.3
Copper	0.015	–	–	–	0.015	–
Zinc	0.050	0.032	0.027	0.010	0.021	–
Manganese	0.675	–	0.037	0.020	0.206	–
Iron	0.126	0.077	0.099	0.057	0.043	0.039
Lead	0.011	–	0.010	–	0.012	–
Coliform	837	804	–	–	612	–
Salmonella	Absent	–	–	–	Absent	–
<i>E. coli</i>	Present	–	–	–	Present	–
Shigella	Absent	–	–	–	Absent	–

Std. dev Standard deviation, – not analyzed; Units (mg/l, unless otherwise mentioned): conductivity– $\mu\text{S}/\text{cm}$ , turbidity–NTU, coliforms–MPN/100 ml, *E. coli* and *Shigella*–CFU/100 ml, *Salmonella*–MPN/4 g

This low efficiency for organic matter removal could be attributed to lower influent load, intrusion of storm water, and loss/flushing out of microbial biomass (Pietruschka et al. 2015). The best COD removal performance was reported for Plant VII (98.3%) followed Plant V (97.8%). It has been also reported that ABR can treat the different types of wastewaters and its efficiency shows marked improvement with high organic load in the influent (Pietruschka et al. 2015).

In terms of TSS removal, the efficiency varied from as low as 7.9% for Plant III to as high as 94.9% for Plant V. ABR is

one of the types of high-rate reactors with different hydraulic retention time (HRT) and Solid retention time (SRT) and thus facilitates the growth of the slow-growing anaerobic bacteria to be contained within the reactor irrespective of the flow of the wastewater (Nguyen et al. 2010). Sutar and Kulkarni 2016 have also highlighted the role of ABR in reducing suspended solids prior to further treatment by constructed wetland.

In this study, the highest ammoniacal nitrogen removal of 46.7% was reported for Plant VIII. The lowest removal efficiency of 2.8% was obtained for Plant VI. In the case of TKN

**Table 5** Efficiency Evaluation of eight DEWATS Plants

Plant	BOD			COD			TSS			NH <sub>4</sub> -N			TKN			P-PO <sub>4</sub> <sup>3-</sup>		
	In	Out	%E	In	Out	%E	In	Out	%E	In	Out	%E	In	Out	%E	In	Out	%E
I	36	11	69.4	186	51	72.6	39	21	46.2	18	11	38.9	22	15	31.8	1.79	1.13	36.9
II	NA	NA	–	704	165	76.6	143	37	74.1	22	21	4.5	28	24	14.3	4.81	1.09	77.3
III	14.5	8.5	41.4	44	28	36.4	31.5	29	7.9	NA	0.29	NA	4.98	3.7	25.7	NA	1.1	73.8
IV	628	31	95.1	2042	90	95.6	447	35.5	92.1	12	9.8	18.3	21	6.7	68.1	6.3	2.1	66.7
V	655	13	98.0	1994	43	97.8	487	25	94.9	8.4	4.7	44.0	11	6.8	38.2	8	0.9	88.8
VI	18	14	22.2	69	54	21.7	64	38	40.6	7.2	7	2.8	9.8	9.6	2.0	3.7	0.1	97.3
VII	349	11	96.8	892	15	98.3	187	18	90.4	NA	0.04	NA	4.94	4	19.0	NA	5	NA
VIII	716	29	95.9	2494	93	96.3	368	96.5	73.8	7.5	4	46.7	13	6.7	48.5	5.4	0.8	85.2
SD	322.9	9.2		987.5	47.9		186.8	25.0		6.2	6.8		8.4	6.8		2.1	1.5	

In–influent; Out–effluent; %E–% efficiency; Units: All the values (in and out) are in mg/L; SD standard deviation

removal, the highest removal of 68.1% was reported for Plant IV, whereas the worst performance was reported for Plant VI, with only 2% TKN removal.

The performance of different DEWATS plants was also studied for PO<sub>4</sub> removal. The highest removal efficiency of 97.3% was reported for Plant VI. Plant I with only 36.9% was the worst performing plant in terms of phosphate removal.

The efficiency of nitrogen and phosphorus removal occurs due to the combination of the processes such as nitrification/denitrification along with their uptake by plants as nutrients respectively in planted gravel filter (Jamshidi et al. 2014). On the other hand, it has already been reported that post ABR treatment is very essential for reducing the nutrient concentration (Pillay et al. 2008; Nasr and Doma, 2009).

**Life Cycle Assessment**

It should be noted that WWTP-related LCA results are case specific. The results vary based on plant design, process selection, scale, wastewater quality, and other factors (Stokes and Horvath 2010). However, some general conclusions can still be obtained about the contributors of WWTPs to each impact category. Environmental impacts from the treatment facility are mainly caused by the use of electricity required to pump effluent for reuse purpose, sludge transportation, and its disposal to landfill site. Results with respect to all impact categories are discussed below.

**Energy consumption** The total energy consumption over the life cycle of the plants has been found to be 0.131 (MJ/m<sup>3</sup>). It is in the range of the similar studies carried out in India (Singh and Kazmi 2017) and other countries (0.36 MJ/m<sup>3</sup> to 5.4 MJ/m<sup>3</sup>). Research studies carried out such as Pasqualino et al. (2011) reported 0.34–2.16 MJ/m<sup>3</sup>, Rodriguez-Garcia et al. (2011) reported 0.36–3.24 MJ/m<sup>3</sup>, and Amores et al. (2013) and Niero et al. (2014) have reported the same values, i.e., 0.72–2.34 MJ. In terms of energy consumption, this plant

has an advantage over conventional or other natural technologies.

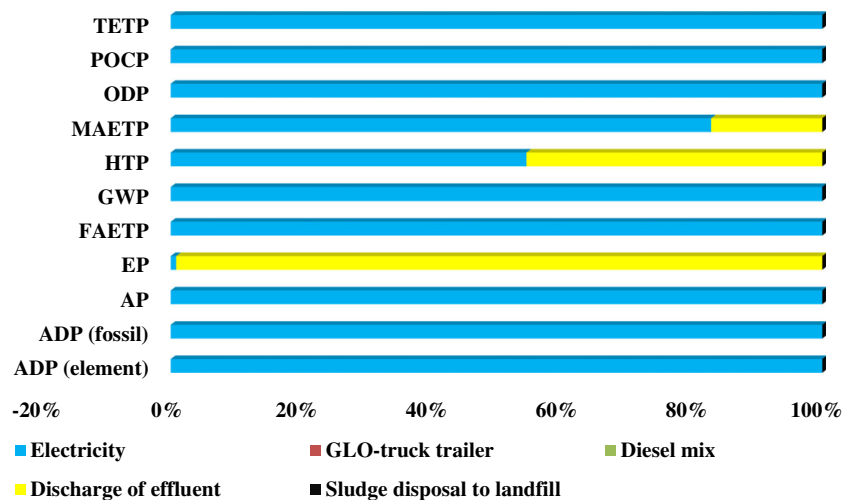
**Global warming potential** The energy consumption for the operation of the plant is found to be the largest contributing factor for CO<sub>2</sub> emissions and GWP (0.0157 kg CO<sub>2</sub> equiv). The global warming potential (GWP), due to transportation of sludge to landfill site, is found to be negligible, i.e., less than 1% of total impact, and can be neglected from the analysis. This finding is similar to previous studies carried out in India (Kamble et al. 2017).

**Eutrophication potential** Due to the remaining nutrients, the effluent has been considered the most relevant environmental issue when performing environmental evaluation of WWTPs (Garrido-Baserba et al. 2014). In addition to the eutrophication potential (EP) that results from a plant’s direct emissions to the environment, there are also indirect emissions from upstream and downstream processes such as energy generation or chemical production that have the potential to cause eutrophication. The main factors are the total nitrogen (TN) and total phosphorus (TP) and to a lower extent COD contained in the effluent. DEWATS has an EP value (0.00098 kg phosphate equiv) which is lower as compared to other natural treatment systems (Kamble et al. 2017).

**Acidification potential** Acidification potential (AP) is due to the contribution from substances that produce sulfuric acid when they are in contact with water. Emissions triggering acidification are mainly caused by electricity consumption. In this study, AP is found to be 0.000140616 kg SO<sub>2</sub> equiv.

**Abiotic depletion potential (ADP)** Abiotic depletion potential (ADP) is due to the contribution of the various emissions to the extraction of resources, including their availability, energy content, concentration, and rate of use. ADP (element) in WWT is a measure of a system’s non-renewable global

**Fig. 2** LCIA results of Plant I for various impact categories using CML 2001–April 2015



**Table 6** Socio-economic assessment of Plants I and II

Criteria	Essentials	Plant I	Plant II
General aspects	Location	Pune	Pune
	Approximate number of population served	Approx. 300	–
	Starting date of operation	2005	2005
	Energy demand of plant	No energy required, only one pump for reusing treated water	Nil
	Purpose of installing the plant	Sanitation and conservation of water	Protect the village environment
Environmental impact, health, and hygiene	Operation and maintenance	Sludge removal once a year	Sludge removal once a year
	Source of wastewater	Hospital	Hostel toilets, bathrooms, kitchen
	Sludge reuse	Converted to manure	Converted to manure
	Level of treatment	Primary to tertiary	Primary and secondary
	Reuse of treated wastewater	Gardening	Gardening, farming
	Presence of pathogens (coliforms) in treated water	Yes but within limit prescribed standard	Not analyzed
	Anticipated health risk	No	No
	Safety measures adopted	No safety measures, except in built	No safety measures, except in built
	Amount of sewage received per day	35 m <sup>3</sup> /day	7.5 m <sup>3</sup> /day
	Amount of waste water per day (inflow and outflow)	35 m <sup>3</sup> /day	7.5 m <sup>3</sup> /day
Economic aspects	Capital cost (in Rs.)	19.29 Lacs	7.5 Lacs
	Operation and maintenance cost per annum (in Rs.)	Approx. 12,000	Approx. 10,000–15,000
	Details of sewer blockages	No occurrence till date	No occurrence till date
Social aspects	User complaints w. r. t. cost of the plant	Nil	Nil
	Any other grievances w. r. t. plant	No	No
	No of employees	Labor employed for other work also helps with the plant. No labor employed especially for the STP.	Hostel staff and 1 staff employed
	Users (if any)	Hospital staff	Hostel residents
	Social Security for employees and workers (insurance, pension, etc.)	No one employed for STP	Nil

– data not available

resource consumption. Coal consumption also has a major contribution in ADP (fossil) category. In this study, ADP (element) is found to be 5.72E–10 kg sbequiv and ADP fossil is found to be 0.171 MJ.

**Ozone depletion potential** Ozone depletion potential (ODP) mainly refers to the emission of gases that reduce the ozone layer (principally CFC-11, CFC-12, and Halon 1301) and these emissions are found to be minimal. The value for ODP is 3.66E–13 kg R11 equiv.

**Photochemical ozone creation potential (POCP)** Photochemical ozone creation potential (POCP) is due to the contribution of the various emissions to the formation of photo-oxidant substances (particularly ozone and peroxyacetyl nitrate) through the photochemical oxidation of volatile organic substances and carbon monoxide. Energy production is the primary contributor to the POCP impact

category. The value obtained for POCP in the current study is found to be 6.98E–06 kg ethene equiv.

**Toxicity potentials (FAETP, MAETP, TETP, and HTP)** The main contributor to toxicity potential is the indirect emissions of metals associated with the production of electricity. This finding is in the same line with the previous research (Piao et al. 2016; Ioannou-Ttofa et al. 2016). On the other hand, direct emissions contributing to ecotoxicity are heavy metals discharged into the water and soil environments (Kalbar et al. 2013; Risch et al., 2014). Further, the disposal of sludge containing heavy metals contributed substantially to the ecotoxicity. TETP (0.000246848 kg DCB equiv) is dominated by the presence of heavy metals in the sludge being Zn (2.33E–008 kg), Pb (1.28E–009 kg), and Cu (8.55E–009 kg) as the main contributors. This impact category is directly proportional to the amount and quality of sludge produced by the treatment system. Concerning FAETP (0.0000429 kg DCB equiv),

the emissions of metals that take place during electricity production dominate the impact. The discharge of treated water is the second element, mainly contributing to the release of Zn, Ni, and Cu to the aquatic environment (Hospido et al. 2012). MAETP (31.44 kg DCB equiv) was considered the most important category, since the characterization factors in this category (for energy consumption, sludge production, etc.) are generally higher than those of other impact categories. The results are in agreement with the results of earlier studies (Dikinya and Areola 2010; Kalbar et al. 2014; Zhao et al. 2015). HTP (0.0101 kg DCB equiv) is mainly because of the release of heavy metals in water, air, and the soil environment.

The wastewater treatment system arose as a toxicity removal process instead of being a toxicity generator. In addition, it is also necessary to assess the toxic impacts of heavy metals and metalloids, organic micro-pollutants, pharmaceuticals and personal care products (PPCPs), and pathogen-related issues, as these studies have not been undertaken with the required vigor and frequency. Future studies should assess toxicity and the potential of pathogen risks in an LCA.

LCIA results for chosen impact categories are shown in ESM Table 5. LCIA results for various impact categories for Plant I derived using CML 2001 for April 2015 are depicted Fig. 2.

**Evaluation of benefit from reuse of the treated effluent** In order to cope with water scarcity, wastewater reuse and resource recovery are one of the promising areas where technology is responding to the need for pollution prevention and resource efficiency. In the current study, tertiary effluent was used to replace tap (fresh) water, and the benefits are gained from water saving. Such kind of benefits are considered to be equivalent to a saving of energy that otherwise would be consumed for the production of the same quantity of tap water or use of freshwater (Singh et al. 2018). ESM Table 6 represents LCIA results of Plant I for two different scenarios (No reuse and Reuse).

### Socio-economic aspects

It focuses on information related to the social acceptance of DEWATS technology in addition to its economic aspects. The criteria for selecting a technology should not be only based on its implementation cost but also should take into consideration the cost of operation and maintenance along with its benefits like reuse of treated wastewater. Table 6 represents socio-economic aspects of Plant I and Plant II under study. Some of the conventional sewage treatment technologies like Up-flow Anaerobic Sludge Blanket (UASB) has significant land requirement but has the least energy requirement. The capital cost for UASB is Rs. 68 lacs per MLD. Activated sludge plant (ASP) requires land area of 450 m<sup>2</sup>/MLD with similar capital cost as UASB. The power consumption by ASP is significant (180 kwh/day/MLD) as compared to UASB. Membrane

bioreactor (MBR) and sequential batch reactor (SBR) have the least land requirement, but on the other hand require highest amount of energy among these technologies. Additional investment is required in terms of chemicals to be used and hiring skilled manpower for operating these conventional treatment technologies (CPCB 2013).

DEWATS has higher land requirement than treatment technologies like MBR and natural treatment technologies like Reed bed system. It has the same land requirement as SBR and lower land requirement than stabilization pond (SP). In terms of capital expenditure, DEWATS is economically feasible than MBR and SP. One of the biggest advantages of DEWATS technology is the very affordable requirement of operation and maintenance cost (CDD 2017).

### Conclusion

Most of the Indian cities depend on the centralized systems for domestic wastewater treatment which not only require high capital cost but also have high O and M costs. With the rapid rate of urbanization, introducing a decentralized wastewater management system could prove as an effective solution to minimize the pollution load. During the study, DEWATS's sustainability aspect was assessed from the point of view of its technical as well as its economic feasibility and its environmental impacts. Although no health issues have been reported till date, further treatment like conditioning pond would be required to promote safe reuse of treated wastewater. It is one of the most promising technologies to treat wastewater. As compared to other conventional or natural wastewater treatment systems, this technology has environmental benefits, due to its low cost, less energy demand, and simple operation. The results obtained from LCA can be utilized to identify environmental hot spots and optimize the process. However, the application of LCA is limited to the evaluation of the environmental sustainability of processes. Hence, additional indicators introducing economic and social dimensions considering regional and local priorities are needed to measure the sustainability of WWT technologies. There is a clear need for a paradigm shift in the selection of the wastewater treatment processes. In addition to the technical and economic issues, the environmental and social aspects should also be considered in the decision making process.

**Acknowledgments** With funding from The Government of India [Department of Science and Technology, File DST/IMRCD/SARASWATI/2012/(G)/II] is gratefully acknowledged. The cooperation of the plant management teams extended during the study period is highly appreciated.

**Funding** The research was conducted under the collaborative project "Supporting consolidation, replication and up-scaling of sustainable wastewater treatment and reuse technologies for India (SARASWATI)"

and co-funding from the European Commission within the Seventh Framework Programme (grant agreement number 308672).

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