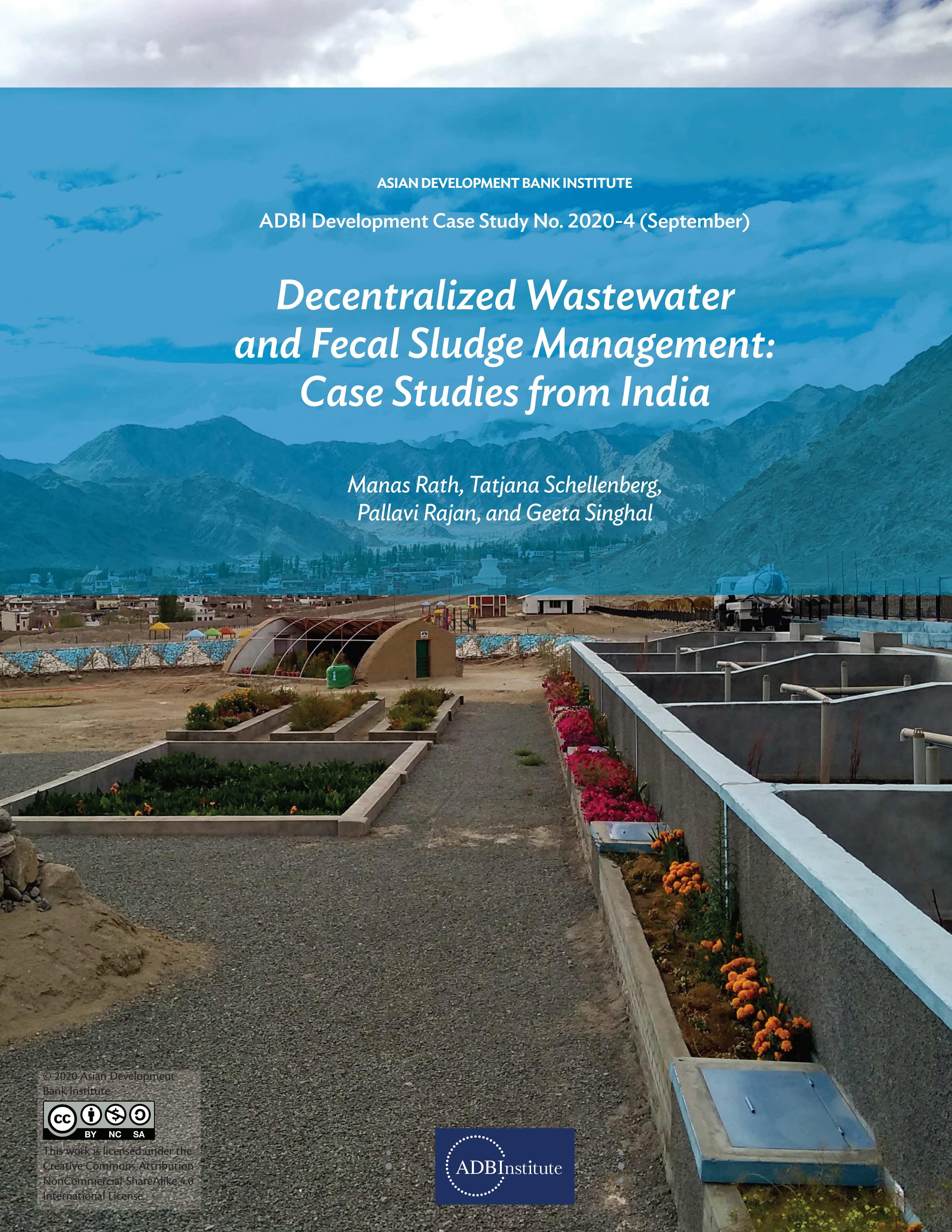

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Decentralized Wastewater and Fecal Sludge Management: Case Studies from India

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Introduction

India has 4% of the world's water resources, but with 1.38 billion people, it is home to 17.7% of the world's population. The Water Stress Index 2019 by London-based Verisk Maplecroft ranks India as the 46th highest risk country (Verisk Maplecroft 2019). India is also 13th on the Aqueduct's Water Risk Atlas and listed as one of the world's "extremely highly water-stressed countries" (World Resources Institute 2019). The India Water Tool[1] and FAO (2003) have detailed maps of water stress across India.

The disparity between local resources and demand by people, agriculture, and industry has increased water stress in most regions—in 26 of India's 32 largest cities, 10%–60% of total water demand remains unmet, and it is the poor who get the least amount of water. Groundwater level is dropping rapidly and quality is deteriorating, causing a shortage in the supply for agricultural and drinking purposes. Many industries are constrained by the insufficient water supply, and frequent conflicts among farmers have occurred over sharing of limited water resources. The Government of India expects water demand to increase by 20%–40% over the next 5 years, and changing weather and monsoon patterns make it increasingly uncertain how this demand will be met. In 2018, the Government of India's think tank, Niti Aayog, estimated that by 2020, 20 major cities including Bengaluru, New Delhi, and Hyderabad, with over 100 million residents will reach Day Zero when groundwater resources get fully depleted (NITI Ayog 2019).

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[1] India Water Tool. Water Stress Map. http://www.indiawatertool.in/.

Compounding the water shortage are two facts: (i) most of India's water sources are highly polluted; and (ii) very little wastewater is actually treated and reused, making water the other single-use resource wreaking havoc on the climate with its pollution.

Industrial pollutants and fecal matter are major pollutants particularly in urban areas and rivers flowing through large cities, as only 10%–12% of urban India's 40 billion liters of wastewater per day is adequately treated before being discharged into the environment. Extensive open defecation (which has lessened), poor quality of septic tanks and pits (which has worsened), and open drains, for example, facilitate the flow of fecal matter into water bodies, causing health and environmental problems.

The treatment of wastewater and fecal sludge is critical to (i) provide clean water and improve health as a result; (ii) increase water supply through the reuse of treated water; and (iii) improve the urban environment.

However, the Government of India has inadequate funds to build a large-scale, centralized sewerage system in most cities. These systems are also time-consuming to build, some taking 5–9 years to complete; disruptive as they entail breaking up existing roads; do not cover all parts of the town due to topography, small streets, and other challenges; cost-intensive to maintain; and often result in failure owing to poor design and weak operation and maintenance (O&M). Further, systems are not yet designed for treating and reusing the wastewater. A decentralized solution for sewage and fecal sludge management is therefore the only option for India to quickly increase the amount of treated water and raise the share of treated wastewater that is reused locally and productively (thereby reducing the amount of water extracted from the environment).

This case study presents stories of decentralized sewage treatment plants (STPs) and fecal sludge management (FSM) in India. The stories provide lessons which government and private players can apply to address India's massive water and sanitation problem.

Case 1: Decentralized Wastewater Treatment at Aravind Eye Hospital, Puducherry

AT A GLANCE	
Year built	2006
Wastewater type	Domestic wastewater from toilets, bathrooms, and kitchen
Design capacity	307 cubic meters (m^3) per day
Construction time	8 months
Treatment efficiency	About 90%–95%
Land area required	1,774 square meters (sq m) (including 1,300 sq m for planted gravel filter module)
Reuse of treated water	Gardening and toilet flushing
Chemical input	None
Plants in filter bed	*Canasindica*
Water saved	100,000 m^3 per year
Energy requirement	80 kilowatt-hours per day
Construction cost	$170,000 (₹11,163,000)
Total cost	$0.10 per m^3 of treated water (₹6.31)

Aravind Eye Hospital (AEH) in Puducherry is one of India's leading specialty eye hospitals. Visitors enter the hospital by crossing a small bridge over a pond with a fountain and a colorful garden of assorted flowers. More than 600 people pass through this entryway daily but nearly no one recognizes that the green landscape is actually an ecological wastewater treatment plant. A flourishing planted gravel filter connected underground to a polishing pond treats wastewater from the large hospital and supplies water for irrigating the entire landscape.

AEH was founded in 1976 by G. Venkataswamy in Madurai out of a deep desire to serve the poor. Doctor V, as he is called, combined his vision for curing blindness along with best business and operations practices to drastically reduce the cost of eye surgery while improving quality, to make world-class eye care affordable and accessible to those who cannot afford regular medical care. More than a third of hospital patients are treated free of charge, and each patient decides whether to pay for the services. And yet, this entirely self-funded nonprofit organization earns a surplus consistently without foreign investment or government support. The hospital opened with only 11 beds initially. It is now one of the largest eye institutes globally, with over 4,000 beds across 12 eye care centers, serving as a role model not only in India but also worldwide. In 2008 alone, AEH conducted 4.2 million outpatient consultations and 478,028 surgeries (Aravind Eye Care System 2018). Of the 12 AEH facilities across India, the hospital in Puducherry was established in 2003 on a total area of 20.2 acres and can accommodate 602 patients.

Total savings: ₹44 million–₹50 million over 25 years

About Puducherry

Formerly known as Pondicherry, Puducherry is located on the east coast of South India, about 2 hours south of Chennai, and covers 19.54 square kilometers (km^2). Although rich in water resources as a result of heavy rainfall, the government has declared the region water scarce. Rainfall patterns of southwest and northeast monsoons accumulated over 50 days amount to 1,250 millimeters (mm) of rain or a total of about 200 million cubic meters of water available annually. Per capita availability amounts to about 200 cubic meters (m^3) per person, putting the spatially water-rich region under the water-scarce category in relation to demand. Even with rainwater harvesting structures in place, the growing population and the rise in tourism contribute to the sharp surge in demand, while urbanization results in lower groundwater recharge as a result of concrete and many more sealed surfaces (Table 1).

Table 1: Population of Puducherry

Year	1971	1981	1991	2001	2011
Urban population	198,288	316,047	516,985	648,233	852,753
Total population	471,707	604,471	807,785	973,829	1,247,953
% urban population	42%	52%	64%	67%	68%
Urban population growth		59%	64%	25%	32%

Source: Office of the Registrar General & Census Commissioner, India. 2011 Census. https://censusindia.gov.in/2011-common/censusdata2011.html.

Excessive extraction of groundwater has caused the water table to drop 7–30 meters over the past years. In some areas, this has caused ingression of seawater by 5–7 kilometers (km) from the coast. Industries have polluted the groundwater with contaminants such as heavy metals, salts, and fluorides. In recent years, the sewerage network in Puducherry has been expanded under the Atal Mission for Rejuvenation and Urban Transformation (AMRUT) program of the Government of India and a report by the Municipality of Puducherry (2018) claims that 81.83% of households are connected to the underground sewer system. This figure is likely to drop sharply in areas right outside the municipal area, which are nonetheless part of the Puducherry metro area. A more holistic study of the region will be useful.

Water saved each year: >100,000 m^3

Planning the Sewage Treatment System

According to BORDA engineers involved in the project, the eco-sensitive architects who designed the hospital had suggested building a decentralized and sustainable, nature-based wastewater treatment system. A team of three organizations—the Malanadu Society from Delhi, Auroville

Centre for Scientific Research from Auroville, and BORDA designed and built in 2002–2003 a sewage treatment plant based on the decentralized wastewater treatment system (DEWATS). The plant was easy and affordable to maintain, ecologically sensitive, and robust.

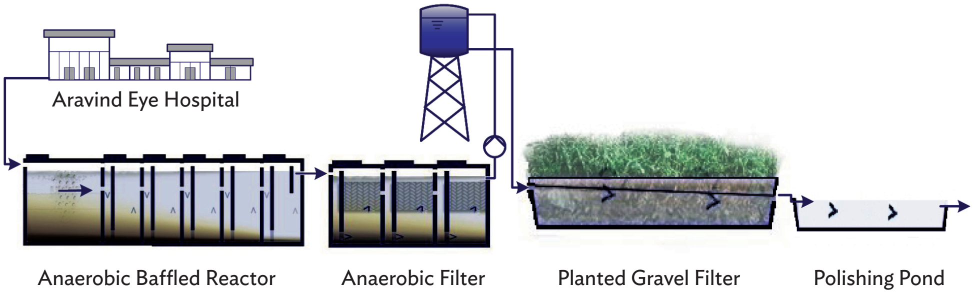
Given the relatively large size of the system, the team had to evaluate various technology options because most of the larger nature-based systems were either pilots or built in moderate climate zones and may not function well in Puducherry's hot and wet tropical climate. The design team identified as the most suitable solution a combination of an anaerobic baffled reactor (ABR) and a planted gravel filter (PGF).

In the early 2000s, sewage treatment was not a priority for either the local authorities or the pollution control boards, who had to be convinced that such a biological approach would work before they would grant approval. Since 2003, the government has recognized and accepted biological- and nature-based technologies, such as like DEWATS and soil biotechnology (SBT), as viable, reliable approaches for treating sewage.

Despite the heavy construction cost, the AEH management and board based on the calculation of the life cycle cost against the minimal operating cost, recognized that the system was the ideal solution. The plant was commissioned in February 2003 and started operating after construction period of 8 months (Figure 1).

Designing the Sewage Treatment Plant

Figure 1: Schematic Overview of DEWATS Setup at Aravind Eye Hospital



DEWATS = decentralized wastewater treatment system.
Source: Consortium for DEWATS Dissemination (CDD) Society. https://cddindia.org/.

DEWATS is based on the principles of simple and low-cost maintenance, low-energy requirement, and on-site treatment without chemical inputs. AEH generates around 307 m^3 per day of domestic wastewater, which is treated effectively, meeting all requirements stipulated by India's environmental laws and regulations. According to the hospital, the treated wastewater is reused for irrigating the vegetable and fruit garden and the rich surrounding landscape. A substantial quantity of the treated water is reused for toilet flushing. As a result, the hospital saves more than 100,000 m^3 of freshwater every year—equivalent to the amount required for more than 2,000 people, assuming each person uses 135 liters of water per day.

The system has six major modules:

1. **Grease trap.** It captures oil and grease floating on the water, while the wastewater underneath is discharged further into the settler.
2. **Settler.** A sedimentation tank allows organic and inorganic solids to settle so that they can be stabilized through anaerobic digestion, while suspended and dissolved materials are passed on to the next stage after a retention time of about 2 hours.
3. **Anaerobic baffled reactor.** Water flows through a series of chambers slowly, allowing the solids to settle down into a layer of activated sludge for further decomposition of contained pollutants. As these chambers are airtight, an oxygen-less environment is created at the bottom of the tank and anaerobic bacteria starts digesting the fecal matter, producing a significant quantity of biogas but leaving very little organic matter behind. Thus, the chambers do not have to be cleaned often—perhaps every 4–5 years. The biological oxygen demand (BOD) reduction rate at this stage is 75%–85%, while the pathogen reduction is 40%–75%. The baffled reactor is designed to be resistant to shock loads and variability in flow volumes, within reason. And as it is built as an underground chamber, the land above can be used for parking, walking areas, and keeping machinery, among others.
4. **Anaerobic filter.** A fixed-bed reactor maximizes the area for anaerobic organisms for digesting wastewater pollutants further. The design is based on a continuous upstream flow, and BOD reduction of this unit is 70%.
5. **Horizontal planted gravel filter.** Multiple mechanisms are used at this stage, such as biological conversion, physical filtration, and chemical adsorption, with mainly aerobic and anoxic processes. Specific plants are grown, and water from the anaerobic filter is allowed to flow in a controlled manner through the roots of the plants, allowing them to absorb nutrients and chemicals from the water.
6. **Polishing pond.** In the last stage, an open pond enriches the water with oxygen and eliminates pathogen germs through UV disinfection by the sun's rays. Floating aquatic plants chosen initially to control algal growth and improve the aesthetics of the pond were later found to be unnecessary—in fact, they overgrew quickly and reduced oxygen in the water, causing algae to bloom. The system worked perfectly without these plants. The water is retained in the pond and then pumped out for irrigation and flushing.

Table 2 gives an overview of the modules and treatment process.

Table 2: Overview of DEWATS Modules and Treatment Process

Module	Treatment Process	Type of Treatment
Grease trap	Separating oil and grease	Primary
Settler	Sedimentation and sludge stabilization	Primary
Upflow anaerobic baffle reactor	Anaerobic degradation of suspended and dissolved solids	Secondary
Upflow fixed-bed anaerobic filter	Anaerobic degradation of suspended and dissolved solids	Secondary
Planted gravel filter	Filtration, degradation of suspended and dissolved solids, and pathogen removal	Tertiary
Polishing pond	Polishing of water and pathogen control	Post

Source: Consortium for DEWATS Dissemination (CDD) Society.

Given the flat land contour, the effluent of the anaerobic filter is pumped into a container at the rooftop and then released into the PGF to maintain a specific flow rate. A pump installed in the polishing pond circulates and oxygenizes the water through a fountain.

The only visible parts above ground are the PGF and polishing pond, which are aesthetically integrated with the gardens and landscape as seen in the photo. As the wastewater flows through the filter subsurface of the PGF and is oxygenated in the process, there is no odor, flies, or any other nuisance. The anaerobic treatment modules such as the settlers, ABR, and anaerobic filter are all below ground.

Planted gravel filter and polishing pond at Aravind Eye Hospital after construction (photo by Consortium for DEWATS Dissemination [CDD] Society).

Operation and Maintenance and System Monitoring

Wastewater reused: Equal to water consumed by 2,274 people

AEH's landscaping team and a trained gardener operates and maintains the DEWATS, following a regular maintenance schedule for periodic checks of the sewer line systems and regular harvesting of plants in the PGF to clean the filter of organic matter and prevent clogging. The filter media of the PGF and anaerobic filter is washed once in 8 and 6 years, respectively. Sludge in the settler, ABR, and anaerobic filter is removed every 4–5 years.

Water samples from the polishing pond are tested periodically according to guidelines set by the Pollution Control Board.

Treatment efficiency is maintained at an average of 90%–95% BOD removal, with a final BOD of <10 milligrams per liter (mg/L) and a chemical oxygen demand (COD) removal of <30 mg/L, meeting statutory norms. Nitrates are not removed as these are good for the plants when the treated water is used for gardening.

The system has been operating for 13 years with no major difficulties.

Sewage Treatment Plant Costs

Hospital staff perform routine O&M activities so no additional staff are needed for DEWATS-related tasks. Table 3 lists certain cost-incurring activities, either for purchasing materials or hiring specialized operators.

Table 3: Sewage Treatment Plant Costs

Expenditure	Cost	Cost per Day
Construction cost	₹11,163,000 (25-year life)	₹1,223
Electricity	₹400 per day for pump	₹400
Remove floating scum	₹9,000 every 3 months	₹100
Sludge removal	₹48,000 every 6 years	₹22
Daily pump operator	₹38 per day	₹38
Cleaning of filter bed	₹120,000 every 8 years	₹41
Total	**₹1,824 per day** **₹54,720 per month** **₹6.31 per cubic meter**	

Source: Authors.

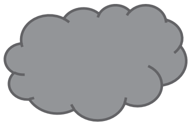
Beneath the green landscape surrounding the entrance to Aravind Eye Hospital is actually an ecological wastewater treatment plant (photo by CDD Society).

Benefits and Impact

DEWATS brings the following benefits to the Aravind Eye Hospital (Figure 2):

1. **Low life cycle cost.** An STP that uses other technologies like the moving bed biofilm reactor (MBBR) would cost about ₹5 million to install and about ₹186,000 per month to operate, or ₹55.8 million over 25 years. Thus, life cycle cost over 25 years would be about ₹61 million. In comparison, life cycle cost for DEWATS amounts to $16.6 million over 25 years—a savings of 73%.
2. **Water savings:** About 100,000 m^3 of wastewater is treated and reused each year, which is the equivalent of freshwater required by 2,274 people per day (at 135 liters per person per day).
3. **Low-cost water:** Water tankers can cost ₹60–₹150 per m^3 while municipal water costs ₹5–₹15 per m^3 for commercial customers. Water from borewells can cost as little as ₹4 per m^3. At ₹6.31 per m^3, treated water through DEWATS is at par with or costs lesser than other options.
4. **Electricity saved:** DEWATS saves 20–160 gigawatt-hours (GWh) of electricity each year compared with other technologies like MBBR, sequencing batch reactor (SBR), or membrane bioreactor (MBR), which is the equivalent of 18–142 tons of carbon dioxide (CO_2) each year.

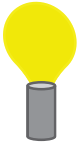
CO_2 emissions saved per year: Equivalent to 18–142 tons



Aside from the tangible benefits, DEWATS also establishes Aravind Eye Hospital as a responsible entity that protects the local environment and conserves scarce resources. It also reduces the load on the municipal system because it is independent of the sewerage network, thereby saving local authorities money both for water supply (water is subsidized in India) and wastewater treatment.

Replicability

Electricity saved each year: 20–160 GWh



Since 2008, several states in India have passed regulations requiring on-site STPs for large wastewater generators. The recurring water shortage and the rising cost of municipal water (especially for commercial users) are also leading many factories, real estate projects, malls, hospitals, hotels, and office buildings to build STPs that enable treated water to be reused for flushing, landscaping, air conditioning, and others.

DEWATS is distinctive in that it deploys a simple treatment technology in a pathogen- and pollution-sensitive location. The system is well-designed without the cost cutting that can affect performance or robustness, and it has been well-maintained for several years. In most cases, STPs are typically not very well designed to keep costs low, and not properly maintained to cut costs—and as a result, they often fail or do not perform optimally.

Decentralized STPs can be a win for the system owner (who can reuse the low-cost treated water), the local community (freshwater is conserved and made available to those who need), and the local authorities (who spend less on water supply and sewage treatment systems). There are an estimated 20,000 small-scale STPs in India, but many of them are defunct and not operational or operate suboptimally. To keep fecal matter out of water bodies and the environment, there is a need and opportunity to replicate DEWATS widely particularly in areas with no sewerage networks.

Biological and nature-based systems have the advantage of being eco-friendly and simple and cost lesser to operate, although they can take up more space than electromechanical technologies. One option is to use hybrids to reduce their footprint. For example, a sand and carbon filter can be used instead of the PGF for tertiary treatment, which reduces the footprint by about 1,300 square meters (m^2), or nearly 73%. According to research by the project, Small-Scale Sanitation Scaling-Up in South Asia, conducted by EAWAG Aquatic Research, the O&M cost (especially for electricity) would increase the treatment cost to about ₹9.50–₹10.00 per m^3, which would still be much cheaper than the ₹40–₹60 per kiloliter (kl) for treated water from the MBBR, SBR, and MBR technologies.[2]

According to BORDA's data, there are about 400 DEWATS-based STPs in India out of an estimated 20,000 small-scale, decentralized STPs, indicating an effective and highly scalable technology and solution.

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[2] Eawag Aquatic Research. Small-Scale Sanitation Scaling-Up (4S) in South Asia. https://www.eawag.ch/en/department/sandec/projects/sesp/4s-small-scale-sanitation-scaling-up/.

Case 2: Fecal Sludge Management in Devanahalli, Bangalore, and Karnataka

India's first dedicated fecal sludge treatment plant is located in Devanahalli (photo by CDD Society/BORDA).

AT A GLANCE	
Year commissioned	2015
Wastewater type	Fecal sludge from septic tanks and soak pits
Design capacity	6,000–8,000 liter per day
Influent quality	Biochemical oxygen demand (BOD) 15,000–40,000 mg/L
Quality of treated fecal sludge	Nitrogen (N), phosphorus (P), and potassium (K) ratio = 20:4:1; organic carbon = 16.5%
Treated effluent quality	<30 mg/L BOD
Plants in filter bed	*Canasindica, Cyprus Papyrus*
Reuse of treated water	Landscaping of fecal sludge treatment plant
Sludge generated	2,500 liters generates 60 kilograms of dried sludge
Energy requirement	0.25-horsepower motor only
Construction cost	₹6.7 million
O&M cost	₹48,000 per month, including management and technical supervision

Sanitation in Devanahalli

Devanahalli is 36 kilometers (km) away from the center of Bangalore and home to Bangalore's Kempegowda International Airport. While ideally located for growth, Devanahalli has suffered setbacks when a few prominent information technology companies withdrew plans to open offices there because of persistent water problems. Since the new airport opened in 2008, the town population of roughly 28,000 according to India's 2011 Census has grown by 21%. Originally a village (in fact, it is still surrounded by farmland), commerce and services are now the dominant occupations for the people of Devanahalli (Table 4).

Table 4: Sanitation Features in Devanahalli as of November 2018

Item	Details
Total population	28,000
No. of households	6,500
No. of pits and septic tanks	>4,000
Pit size	3–5 rings
Average frequency of cleaning pits	2–5 years
No. of community toilets	3

Sources: Town Municipal Committee of Devanahalli; and CDD Society.

Devanahalli does not have an underground drainage system. Most households in the town use pit latrines or septic tanks for containing fecal waste. An estimated 4,000–5,000 liters of fecal sludge are cleaned from these septic tanks and soak pits daily and transported either to a farm to be mixed with the soil, or dumped at remote locations.

In 2015, the Consortium for DEWATS Dissemination (CDD) Society approached the Town Municipal Committee (TMC) of Devanahalli and offered to build a fecal sludge treatment plant that will provide services to the town and at the same time serve as a sanitation research and development site. The sanitation situation then was as follows:

1. Toilets and Containment

According to the baseline survey conducted by CDD Society in 2015, 90% of households had toilets and 6% of the population practiced open defecation (nearly 100% of households have toilets now and the town has eradicated open defecation). About 78% of toilets had a single pit, 10% had septic tanks of which only 3% were twin pit and the remaining 6% discharged directly into the open stormwater drains along the streets of Devanahalli. At least 65% of septic tanks and soak pits had no lining and therefore leached fecal matter directly into the soil.

2. Transport

Pit latrines need to be desludged every 2 to 5 years depending on their size but the 2015 survey showed that 44% of households never had their pits cleaned, while 40% had their pits cleaned within the past 5 years. Pits were cleaned manually then, but in the past few years, mechanized cleaning has become the norm wherein vacuum suction desludging trucks, also called "honeysuckers," suck out the septage and carry it away. According to TMC records, desludging vehicles service an average of 3–4 septic tanks per pit weekly and charge ₹1,200–₹1,500 depending on the size of the septic tank and/or pit latrine and complexity of the procedure. Private service providers also charge a similar amount per service. According to Devanahalli TMC estimates and interactions with local private desludging operators, roughly 40% of Devanahalli's total desludging operations was performed by TMC and 60% by private operators.

3. Treatment and Reuse

The town was using a certain amount of fecal sludge for agriculture, supplying it to nearby farms where it is allowed to dry in a large trench and then mixed with soil and used as manure for growing food crops like grapes and ragi. There is no specific "treatment" applied to the sludge, but the current process eliminates to some extent the hazards associated with fecal sludge. However, there may still be the risk of bacterial contamination of the food if eaten raw. Not all farmers routinely adopt this approach, some may pour the sludge directly on the farm, raising the risk of health and skin problems for farmhands, and contaminating food supplies. Also, desludging service providers have to dispose of the sludge in other locations when there is no demand from farms during off season.

The Need for Fecal Sludge Management

The Swachh Bharat Mission launched in 2014 pledged to construct 120 million toilets to end open defecation. Most of these toilets have an on-site sanitation system (or septic tanks and soak pits) rather than a sewerage connection, because only about 250 out of nearly 7,000 towns and cities in India have partial sewerage networks. However, BORDA studies indicate that by 2020, over 70% of urban toilets will have on-site containment systems.

With its low population density and low water supply, Devanahalli is too small to build a sewerage system. However, in keeping with its elevated status as the location of the new airport, the town wanted to improve its waste management system and had begun designing a new scientific landfill for solid waste. When the nonprofit organizations, BORDA and the CDD Society, offered to build India's first dedicated fecal sludge treatment plant (FSTP) in the town, the municipal council welcomed the opportunity and provided land for it.

TMC offered a prominent location for the plant on the highway, which cuts through the town and thus giving easy access to suction trucks—a key consideration to keep operators from discharging the waste in unauthorized but convenient locations. Because the plant was located within the town, it was essential that the plant was kept clean, odorless, and not a nuisance to nearby businesses or residents, who would otherwise resent the facility and push for its closure.

Rajesh Pai, senior technical advisor to BORDA-South Asia and CDD Society, designed the FSTP with the following objectives:

1. **Low cost and easy to maintain.** Municipal infrastructure is often abandoned because of high operating costs or complex repairs. The FSTP had to be affordable for a small-town municipality to operate.
2. **Clean, odorless, and with aesthetic appeal.** These attributes were necessary to gain the support of residents. BORDA and the CDD Society focused on nature-based technologies and used the same approach to design the FSTP.
3. **Flexible and robust technology.** The plant should be able to manage varying quantities and qualities of sludge inflow as a consistent daily quantity could not be assured, and it should operate throughout the year despite changes in temperature and weather.
4. **Minimal use of land at an accessible location.** Land is always difficult to allocate in towns; hence, a smaller parcel is more viable and can be located at convenient and accessible locations where desludging trucks can reach easily and quickly.

The project aimed to introduce an integrated decentralized fecal sludge management system in Devanahalli and assess the system's effectiveness in addressing the town's sanitation needs. The system also provided resource recovery options (soil conditioner and nutrient-rich water) and presented an opportunity to explore whether such a system could be replicated in other towns and cities across India.

According to Mamtha AS, TMC environmental engineer, Devanahalli gets less than 70 liters of water per capita per day (LCPD), which makes it unsuitable for installing an underground drainage system that requires a minimum of 100 LPCD to operate smoothly. Biome Environmental Trust, a research organization, had already prepared a sanitation safety plan in conformity with World Health Organization guidelines. The plan showed the urban local body's intent to improve sanitation conditions and its awareness of the downside of improper disposal of raw fecal sludge. In fact, they were already experimenting with makeshift solutions to treat raw sludge.

Finally, the key factor was the strong interest and will of local administrators in supporting the idea of FSM services and their willingness to risk implementing an untested concept in India. The main proponents at TMC were all women—the chief officer, the environmental engineer, the senior health inspector, and the junior health inspector.

CDD Society first organized training sessions for town and state government officials to give them an understanding of what FSM entails.

In addition to planning the FSTP, CDD Society carried out several actions to ensure the delivery of a holistic and robust FSM service in the town:

1. It conducted a detailed household survey to understand the state of sanitation, toilets, among others.
2. It developed a draft FSM policy for Karnataka state to help smaller towns in the state adopt FSM in parallel with building toilets under the Clean India Mission.
3. It started helping TMC to prepare four resolutions and by-laws to implement FSM, keeping in mind data collected during the survey and the town's practical realities:

   (i) All private honeysuckers operating in Devanahalli must register with TMC. All fecal sludge collected in Devanahalli by any operator must be taken to the FSTP.
   (ii) TMC will contract a private company with relevant experience and technical capability to operate the FSTP, rather than operate the plant on its own.
   (iii) TMC will charge a sanitation fee which will be added to the local property tax; this revenue will be used to offer town residents scheduled and quality FSM services in an equitable manner using a cross-subsidy model.

4. CDD Society conducted workshops for municipal officials and elected leaders, state government officials from the Directorate of Municipal Administration and Urban Development Department of the Government of Karnataka, as well as community members, on the need to improve sanitation and implement FSM for health and environmental benefits.
5. CDD designed and built financial models to help TMC make FSM services as sustainable as possible by
   (i) identifying various revenue streams such as service fees from users who request for septic tank cleaning services, advertising billboards on the FSTP site, and selling treated sludge and water, among others;
   (ii) studying costs for providing “on-call” and “scheduled” cleaning services; and
   (iii) developing a property tax structure based on property size and affordability especially for economically weaker families, to cover the cost of providing FSM services based on (ii) above.

Thus, CDD performed a range of activities far exceeding the engineering work of designing and building the FSTP.

Designing and Building the Fecal Sludge Treatment Plant

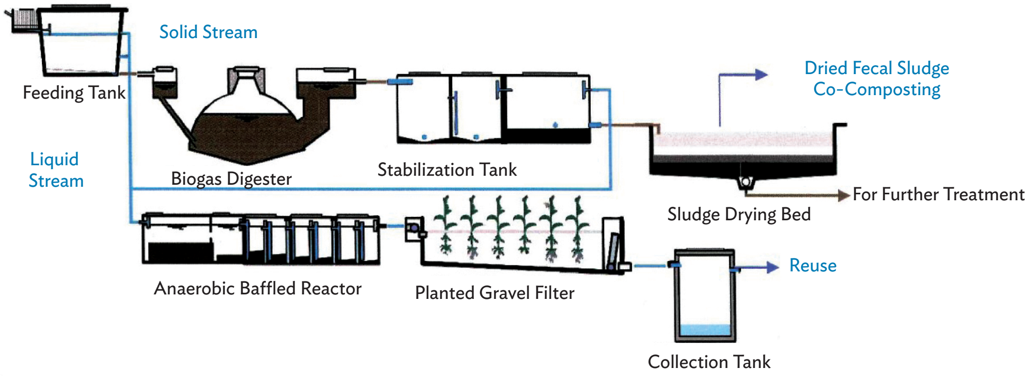
The FSTP is still the central element of FSM because without a properly designed facility to discharge and treat fecal sludge, other activities will have no impact (Table 5). In addition to meeting the objectives for which it was built, the design of the Devanahalli FSTP also needed to be further generalized to ensure replicability in most parts of India.

Table 5: Associated Costs of Building the Devanahalli Fecal Sludge Treatment Plant

Area of the FSTP	650 m^2
Capacity	6,000–8,000 liters of fecal sludge per day
Capital cost	About ₹6.5 million ($93,000 at 2018 exchange rate)
Operating cost	Approximately ₹600,000 per annum ($8,500 at 2018 exchange rate)
Technology	Anaerobic digestion and unplanted sludge drying beds, with DEWATS for water treatment

DEWATS = decentralized wastewater treatment system, FSTP = fecal sludge treatment plant, m^2 = square meter.
Source: Authors.

Figure 2: Schematic Diagram of the Treatment Process at the Devanahalli Fecal Sludge Treatment Plant



Source: CDD Society.

The desludging vehicle deposits the fecal sludge through an inlet into the feeding tank where it is allowed to settle. Excess water is removed and treated separately, and the solid faction, which is a thick sludge, is also treated separately. The water that is later extracted from the solid faction is returned to the water treatment section where it is fully treated and compliant with statutory norms. Figure 2 shows a diagram of the treatment process.

Table 6 describes the modules and the treatment process.

Table 6: Modules and Treatment Process of the Devanahalli Fecal Sludge Treatment Plant

Module	Treatment Process
1. Screen chamber	Any solids in the sludge are removed
2. Feeding tank	Solids are separated from the liquid
3. Treatment of solid faction (which is still a thick sludge after excess water is separated in Step 2)	
(a) Biogas digester	Anaerobic digestion
(b) Stabilization tank	Anaerobic digestion and stabilization
(c) Sludge drying beds	Dewatering (sludge is dried through percolation and evaporation)
(d) Co-composting	Dried sludge and organic waste are composted for pathogen removal
4. Treatment of liquid faction	
(a) Settler	Sedimentation
(b) Anaerobic baffle reactor	Anaerobic digestion and treatment of upflow sludge blanket
(c) Anaerobic filter	Attached growth–filtration process
(d) Planted gravel filter	Filtration and nutrient removal using plants

Source: Authors.

Co-composting phase. This phase refers to composting of two or more raw materials together. Organic materials such as animal manure, saw dust, wood chips, bark, slaughterhouse waste, sludge or solid residues from food and beverage industries are typically used for co-composting. In Devanahalli, municipal solid waste is used with dried fecal sludge for co-composting.

This step produces two results: the elevated temperature of the compost mounds due to the exothermic metabolic activity of bacteria kills and inactivates pathogen, particularly helminth eggs and e. Coli. The resultant output is a much better and balanced soil conditioner, as the carbon, potassium, nitrogen, and phosphorus balance is better than with fecal sludge or organic waste alone. Fecal matter has a high moisture and nitrogen content, while organic solid waste is high in organic carbon and has good bulking properties (i.e., it allows air to flow and circulate).

Construction phase: It took about 10 months to build the plant as the design had to be changed to meet Highway Authority regulations. The municipal office obtained environmental permits from the State Pollution Control Board.

The plant was commissioned on World Toilet Day on 19 November 2015.

India's first fecal sludge treatment plant in Devanahalli, Karnataka (photo by CDD Society/BORDA).

Delivery of Services and Operation and Maintenance Contracts

For the first 2 years after commissioning, TMC operated the FSTP under the supervision of CDD Society. CDD Society also helped TMC implement other FSM-related actions.

The site was also used for research and development (R&D) on the characteristics of fecal sludge, and new techniques were tested. According to the guest register, over 2,700 people have visited, including local schoolchildren to principal secretaries for urban development and senior officers from large foundations and development banks.

The municipal suction truck and a few private operators continue to transport fecal sludge to the FSTP. One employee operates the system for 8 hours per day and lives on the plant site. The plant uses very little electricity (for a pump that takes percolated water from the drying beds into the DEWATS system) and has no electromechanical machinery—thus it does not rely on steady electricity supply and needs only a semiskilled operator.

CDD Society has trained and supervised TMC personnel to operate the plant since the beginning, emphasizing also the importance of wearing protective gear and following protocol for the operators' health and safety.

Monitoring

During each stage of the treatment process, CDD Society collects extensive data, which help to improve future designs. CDD Society has developed an 89-page handbook on the monitoring mechanism.

Under CDD Society's supervision, TMC maintenance staff check and monitor the delivery of each truck load of fecal sludge and collects data such as the characteristics of incoming sludge (pH, conductivity, total dissolved solids [TDS], and turbidity) to ensure there are no hazardous chemicals that will disrupt the bacterial processes. They also test weekly or monthly certain parameters, such as sludge accumulation in each chamber of the system.

During the initial months, the effluent water was tested every week, but this has now become monthly tests in line with statutory requirements.

First Government Contract for Integrated Fecal Sludge Management Services

In 2017, TMC issued a tender for a private party to operate both the FSTP and TMC's desludging truck. This became India's first integrated FSM contract, the first of its kind involving the operation of assets that are already in place.

TMC awarded a 1-year contract in the amount of ₹2.4 million to a consortium of Kam-Avida Enviro Engineers Pvt Ltd, Hoolock Technologies Pvt Ltd, and Cube Bio-Energy Pvt Ltd, all experienced in the different maintenance aspects of treatment systems and FSM services. As the primary operating partner, Hoolock Technologies is responsible for customer management, scheduling services, operating the truck and the FSTP, and compliance and reporting actions to TMC and the Karnataka Pollution Control Board, says Hoolock manager Amresh Sinha.

Due to changes in its leadership, TMC needed time to determine whether the scheduled cleaning of septic tanks was the right way forward, or whether on-call services were adequate for the town. TMC extended the contract for about 6 months and decided it would take over the operation of the treatment plant. The advantage of simple technology is that the municipality can easily manage the entire system with a little training and support. The challenge, however, is whether the FSM will continue to operate in a robust manner as part of the municipality's regular activities. A survey of operations in recent months suggests that capacity utilization has dropped, possibly because private players are no longer being actively pursued and requested to bring sludge to the plant.

Operation and Maintenance Costs

The total cost for fecal sludge treatment including all positions of O&M amounts to ₹300 per day, excluding the operator's salary. Construction costs reached about ₹6,700,000 (Table 7).

Table 7: Operation and Maintenance Cost for Fecal Sludge Treatment

O&M Expenditure	Total Cost	Details
For the Fecal Sludge Treatment Plant		
Plant operator	₹13,500/month	Full-time, semiskilled
Electricity	₹1,500/month	1-horsepower pump running 2 hours per day; lighting
Regular maintenance	₹30,000/year	Periodic cleaning of tanks and filter media
Tests and monitoring	₹2,000/month	Lab testing of treated water samples
Other repairs	₹120,000/year	Breakage due to wind, painting, changing valves, and minor improvements
Subtotal	**₹354,000/year or ₹29,500/month**	
For the De-Sludging Truck		
Truck driver	₹13,500/month	Also receives customer calls and schedules visits
Truck operator	₹13,500/month	Operates the pump, manages desludging jobs
Fuel (diesel)	₹18,000/month	For the truck and suction pump
Regular maintenance	₹6,000/month	Tires, cleaning pumps, oil and coolant change, etc.
Tracking devices and tech	₹6,000/month	GPS system, software for billing, etc.
Major maintenance	₹100,000/year	Overhaul of engine or motors, etc.
Subtotal	**₹784,000/year or ₹65,300/month**	
For the Co-Composting Unit		
Plant operator (2)	2 x ₹13,500/month	Two operators for all operations
Regular maintenance	₹2,000/month	Cleaning, etc.
Electricity	₹1,250/month	For lighting and crushing equipment
Consumables	₹2,000/month	Safety gear, bags, sawdust, shovels, etc.
Effective micro supplies	₹2,500/month	Effective microorganisms for better composting
Subtotal	**₹417,000/year or ₹34,750/month**	
Management, Technical Supervision, and Customer Service		
Project manager	₹20,000/month	Overall operations management (33% of time)
Technical supervisor	₹12,000/month	Tests, training, monitoring (25% of time)
General costs	₹10,000/month	Travel, phone, printing, etc. (excluding taxes)
Subtotal	**₹504,000/year or ₹42,000/month**	
Total	**₹20,59,000/year or ₹172,000/month**	

Source: Authors.

Replicability

According to TMC, the FSTP has worked reliably for over 3 years, through changing seasons and personnel turnover, indicating a robust and resilient technology and design.

While TMC has adopted resolutions to register and monitor private service providers to ensure that fecal sludge is not discharged on farms or other locations, this has not been implemented stringently. In some cases, private players have discharged sludge on farms (particularly during seasons when farmers need water and fertilizer and pay the truck operator ₹200–₹300 for the fecal sludge). Perhaps because the health and environmental risk is not very high, disciplinary action has not been imposed in such cases. Hoolock claims that much of the sludge does arrive at the FSTP, although there are no reliable data to support this.

Since the FSTP was built, there has been heightened awareness in the town on sanitation and waste management. TMC was very active in building toilets under the Swachh Bharat Mission, and the town also had its own fecal sludge management services. As a result, Devanahalli was declared open-defecation free (ODF+) in October 2018.

More importantly, because the treatment system cost so low to operate, TMC was able to allocate budgets for O&M of FSM services and engage private operators, thereby bringing in accountability and their technical skills. Customer response time seems to have improved although no data are yet available.

Earlier, customers had to visit the TMC office, fill out a form, pay the fees, and wait 1–4 days for the desludging truck to arrive. Now they simply call a phone number and pay the truck driver after the service is completed. This may have increased the share of business for the TMC truck.

Farmers now understand the health risks of using raw fecal sludge and now purchase the dried sludge. Hoolock Technologies says it has sold over 20,000 kilograms (kg) as soil conditioner and fertilizer at ₹4–₹7 per kg.

At least 40 FSTPs have been built or are being developed across India using similar technologies and approaches to the Devanahalli plant, according to CDD Society. Over 1,400 government officers and engineers have visited the plant and have been inspired by its cleanliness, efficiency, simplicity—and low cost. CDD Society has conducted over 30 training programs at the plant, from design and engineering, to operating the FSM systems.

Awards, Recognition, and Resources

India’s first fecal sludge treatment plant in Devanahalli, Karnataka has received several awards and recognition:

- Dasra India featured the Devanahalli plant in a YouTube video, available here: https://www.youtube.com/watch?v=WZgT2Vwfvwc.

- The Urban Management Centre on behalf of the Government of India designed an e-learning module on FSTP technology and FSM based on lessons from the Devanahalli model (UMC Ahmedabad 2018).
- The FSTP technology was short-listed to be featured at the National Fair of India Innovation Initiative, 2016 and was declared among the top 50 innovative technologies by the Confederation of Indian Industry.
- Devanahalli TMC participated and achieved 3rd place out of more than 100 participating teams in Novatia, 2016, an international business plan competition conducted by BITS Goa.
- Devanahalli achieved ODF+ status in 2018.
- Devanahalli was recognized and awarded “Best Town for Sanitation Practices” among 119 towns, by the City Managers Association, Karnataka and the Directorate of Municipal Administration, Government of Karnataka, in 2018.

Case 3: Fecal Sludge Management in Leh, Ladakh

India's first public–private partnership for fecal sludge management services, the fecal sludge treatment plant in Leh (photo by BORDA).

AT A GLANCE	
Year commissioned	2017
Wastewater type	Fecal sludge from septic tanks and soak pits
Design capacity	12,000 liters/day, serving a town of 45,000 residents
FSTP technology	Planted drying beds and planted gravel filter with polishing pond
Influent quality	15,000–40,000 mg/L of BOD
Treated effluent quality	<30 mg/L of BOD
Treated water reuse	Landscaping of FSTP
Energy requirement	None
Suction truck specifications	7-ton gross vehicle weight truck; rotary vacuum pump (318 m^3/hour flow); 3,000-liter capacity
Capital cost	₹7.8 million (FSTP) + ₹2.3 million (truck); ₹224 per capita
O&M cost	₹310,000 per month (₹82 per capita per year)

The Case for Fecal Sludge Management in Leh

The town of Leh is located 3,500 meters above sea level in the Union Territory of Ladakh in north India. It has a population of about 45,000 people and it is visited by over 300,000 tourists annually (and growing sharply) for its landscape and culture. Leh faces very harsh temperatures in the winter with lows up to −30°C, very low air pressure, and very little precipitation (<100 millimeters [mm] per year). The roads to Leh are closed for 5 months of the year due to snow. While the traditional lifestyle in Leh is very sustainable, the influx of tourists along with erratic weather patterns due to climate change are negatively affecting the local ecosystem.

An ongoing study by Ladakh Ecological Development and Environmental Group (LEDeG 2019) and BORDA finds that about 60% of the water used in Leh is drawn through borewells.[3] As flush toilets (which use soak pits) have become increasingly popular, toilet waste is discharged into the groundwater without being treated. Water tests conducted by scientists from the Technical University of Munich in 2017 found high levels of e. Coli, nitrogen, and other pollutants, which become a health hazard as residents drink the groundwater directly. This can also create a problem for the tourism industry, which accounts for over 80% of the local economy.

The municipality says that while the town is building a sewerage network (costing ₹1.1 billion or $16 million), which will become operational in 2019–2020, it will cover only about 40% of the town. Therefore, in early 2017, the Ladakh Autonomous Hill Development Council (LAHDC) and the Municipal Committee of Leh (MCL) recognized the urgency to implement FSM as quickly as possible, to protect the water supply and prevent health disease outbreaks.

Background

While MCL and LAHDC wanted to implement FSM in Leh, they faced two main problems:

1. Who will design and manage the system and the plant? They had no technical understanding of what needed to be done, especially as Leh's harsh climate conditions would preclude other solutions that worked in other places from being copied there.
2. How will the system be funded? No budget had been allocated for FSM. Leh has a short construction window, from May to September. Additionally, the lengthy process of government planning and procurement would mean the system could not be built in 2017.

In April 2017, MCL invited a technical NGO, BORDA and its partner CDD Society to perform a technological and commercial evaluation of how FSM could be implemented in Leh—including technology choices, septic tank cleaning processes, costs and fee structure, and others. BORDA presented the following recommendations:

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[3] BORDA. FSM for Leh. Pamphlet. https://www.borda-sa.org/wp-content/uploads/2018/08/BORDA_FSM_for_Leh_HF.pdf

(i) Scheduled FSM services is required, to minimize the pollutants that flow into the ground—every septic tank should be cleaned annually.
(ii) The planted drying bed technology, yet untested in India, would be ideal as it is easy to operate and works in all climates (except in extremely high rainfall areas).
(iii) A public–private partnership (PPP) can address the two challenges mentioned above.

MCL consulted owners of local businesses, industry associations, and citizen groups to determine whether they accept the need for FSM and are willing to pay the requisite fee. The Leh Hotel Owners Association was particularly influential. Recognizing that FSM is critical to protect their business interests, they agreed to the tariffs and annual scheduled desludging plans. MCL announced that hotels, guesthouses, and restaurants refusing to pay would have their trade licenses revoked—putting on itself the huge responsibility of carrying out such action if needed.

Structuring the Public–Private Partnership

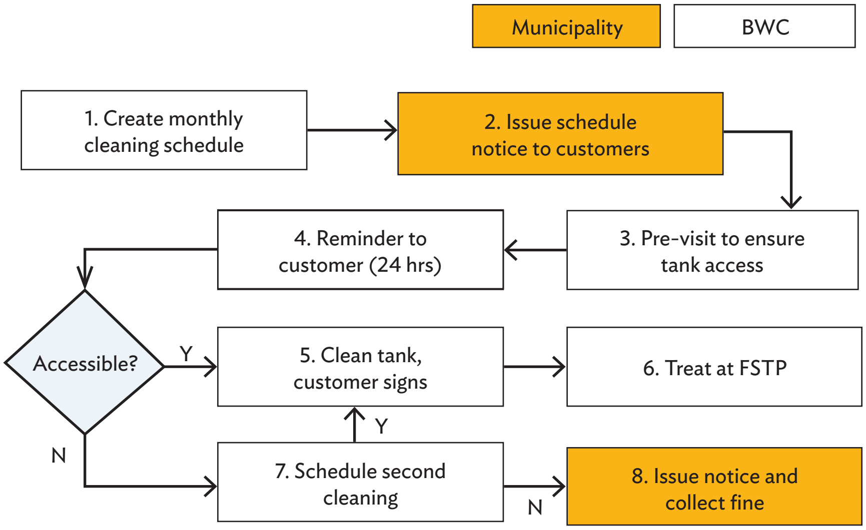
MLC identified the Blue Water Company (BWC) as the partner who had the capacity to manage both a treatment plant and desludging operations and was willing to invest the capital required in the project. The key terms of the agreement negotiated in May 2017 were as follows:

- A turnkey integrated contract to design, build, finance, and operate a fecal sludge treatment plant (FSTP) as well as scheduled cleaning services in Leh.
- MCL's suction truck will be given to BWC to operate.
- The contract period will be 5 years, extendable by 2 years.
- MCL will provide suitable land; the FSTP must be **built within 3 months**.
- The municipality will **enforce a scheduled annual cleaning** and collect a fee of ₹3,500 per cleaning.
- BWC will be paid 90% of the fee collected **after** delivering the service and upon submitting complete records.
- Other private service providers will be allowed to operate in Leh, but MCL will ensure that they bring fecal sludge to the FSTP and pay BWC a tipping fee for treatment services.

Thus, while BWC invested about ₹11 million to design and build the FSTP (₹7.8 million for construction costs due to high cost of materials and labor in Leh and ₹3.2 million in engineering, manpower, and travel costs), the local government paid nothing upfront and did not even have to commit to guaranteed future payouts—in fact, MCL turns a profit from FSM services as it retains 10% of the fees collected.

According to Snehit Prakash who manages BWC work in Leh, BWC schedules the cleaning of septic tanks and informs the customer in advance so that the tank is made accessible at the right time. BWC cleans the septic tank and treats the fecal sludge to meet the requisite standards. At the end of the month, BWC provides MCL with a list of tanks cleaned, and MCL pays BWC 90% of the fees collected. Figure 3 shows the full process chart.

Figure 3: Process Flow and Roles for Fecal Sludge Management in Leh

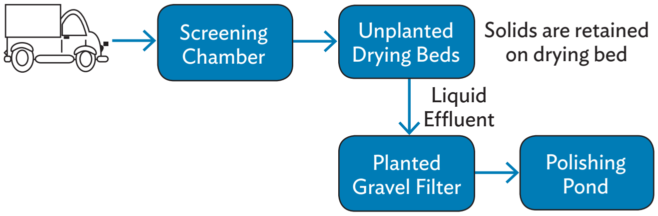


BWC = Blue Water Company, FSTP = fecal sludge treatment plant.
Source: The Blue Water Company.

Technology

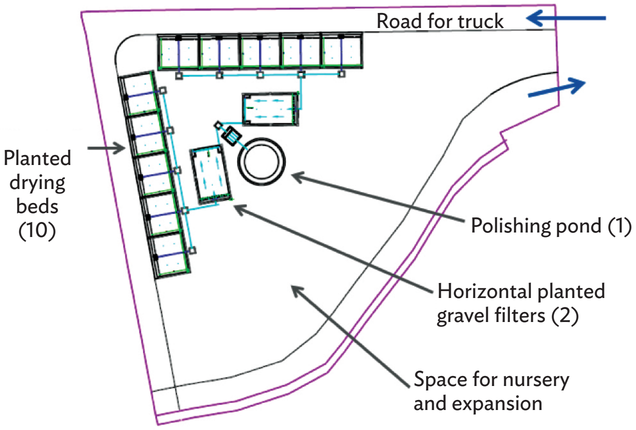
The FSTP uses **planted drying beds** using gravity-based aero-stabilization, into which the fecal sludge is discharged through a screen that captures any large inorganic solids (Figure 4). The solids are retained on top while the liquid percolates through the filter media into a DEWATS sewage treatment plant (STP), and then finally into a polishing pond for solar radiation and disinfection (Figure 5). The entire system has no moving or electric parts. The FSTP has a capacity of 12 kiloliters per day (KLD) and occupies an operating area of about 6,000 square feet (ft^2). Extra land is available for expansion.

Figure 4: Process Flow of the Fecal Sludge Treatment Plant in Leh



Source: CDD Society.

Figure 5: Master Layout of the Fecal Sludge Treatment Plant in Leh



Source: CDD Society.

Blue Water Company staff discharges fecal sludge onto the drying bed (photo by BORDA).

Fecal solids are left to dry on the drying bed for 3–5 years and removed once it reaches a certain thickness. This technology requires minimal operation, although the beds have to be constantly monitored for blockages that prevent water percolation and algae growth on the fecal matter, among others. It works best in hot and dry places with strong sunlight as the sludge dries quickly and the bed is ready for its next load. In the rainy season, the drying beds should be covered with transparent covers to keep water from filling the bed and overflowing. Covering the bed will affect the rate of drying so this method may not be suitable for high-rainfall areas. There is some smell for only about half an hour after the truck discharges its load.

Water from the polishing pond is currently used for landscaping on the FSTP premises. In the future, it will be used to develop green spaces at a children's park being built on the next plot.

Operations and Customer Service

Every week a schedule of cleaning operations is created, with certain time slots left open for emergency calls. Aside from the hotels and households of Leh, BWC is also contracted to clean the septic tanks of army establishments, whose large septic tanks also leach into the same underground water tables. By serving the army, BWC is also in effect protecting the town's water resources.

Blue Water Company (BWC) staff cleans a septic tank at army facility (photo by BWC).

An operator or site engineer usually visits each customer 2–3 days before the scheduled cleaning to ensure that the septic tank is accessible. At the appointed time, the truck operator and truck driver will clean the septic tank and return to the FSTP. When work is completed, the customer signs four copies of the service delivery note, which includes a customer feedback section—the customer keeps a copy of the note and one copy each goes to the FSTP, BWC for its records, and MCL for payments.

The team is composed of the following:

1. The **project manager** who oversees overall project and team management and operations planning, interfacing with local authorities and key customers.
2. The **process engineer** monitors the efficiency of processes and new product and system development and innovation.
3. The **operations supervisor** plans and oversees daily operations, inspects the FSTP and truck maintenance, handles customer scheduling and interface, and keeps documentation and records.
4. The **FSTP operator** operates the FSTP, tests incoming sludge, and sometimes assists in desludging operations.
5. The **truck driver** drives the truck and carries out the desludging operations.
6. The **office manager** and accountant manages all operational and financial records and ensures compliance, etc.

During peak season a second operator is recruited to provide full-time support to the truck driver and assist with desludging operations (Figure 6).

The plant remains closed from around 15 November until 15 March as the septic tanks freeze due to extremely cold weather.

It costs BWC about ₹3.3 million to execute all operations for a year. Thus, it needs to complete about 1,000 desludging services each year to break even, which is difficult given the winter season and the capacity of the treatment plant. To cater to demand, BWC built a small unit to treat gray water from kitchens and restaurants. There are plans to increase the capacity of the plant, but the town will be building a sewage treatment plant in the next 2–3 years, after which demand for FSM services will reduce and therefore, such an investment may not be financially viable. The plant capacity may be increased in 2019 to serve more customers.

Innovation

Suction trucks have to deal with one major challenge in Leh. Most of the small towns have narrow lanes, preventing the truck from parking close enough to the property and the suction motor from pulling out sludge easily. Some countries have developed small pushcart-based mobile suction units (called the “gulper” in some African countries) to address this challenge. Each unit can carry only about 200–500 liters, which makes cleaning an Indian tank containing 3,000–10,000 liters of sludge extremely tedious.

The team in Leh experimented with different motors and developed a technique of using a separate off-board motor to supplement the desludging truck’s own suction motor. The motor is placed near the septic tank and helps to pull the sludge up vertically and out of the tank and pushes it into the truck. The truck’s motor can now pull the sludge horizontally for much longer distances. Desludging distance has increased from only 30–50 feet to over 400 feet. The motor also helps to pull sludge on inclined slopes when the truck is parked higher than the septic tank.

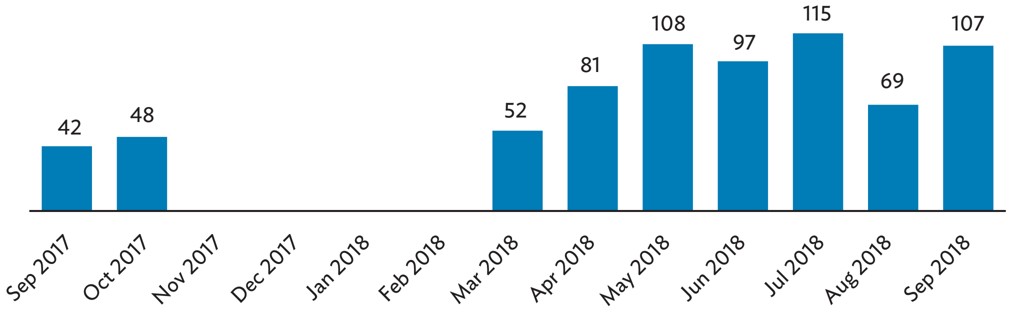
This technique won the AMRUT Technology Challenge Award from the Department of Science and Technology of the Government of India, and it is being adopted by other towns.

Another innovation is the “agitator,” which is a fan attached to the hose pipe when it is lowered into the septic tank to churn the sludge and make it more uniform, and hence easier to pull out. Due to the cold, the sludge often hardens at the bottom of the tank and can be very difficult to suck out, so this device helps ease the process.

Replicability

1. **True partnership can expedite implementation.** The project took under 4 months to negotiate and implement, between April and August 2017, while FSM projects in other towns take 12–21 months. First and most importantly, strong leadership by the MCL administrator smoothened the path. Second, a fair contract that reduced some of the risks faced by BWC while also sharing the financial upside with MCL aligned the interests and concerns of all parties. And last, the participation and buy-in of local stakeholders, particularly the Ladakh Hotel Owners Association, created confidence around the business and operations model. These three factors were critical in establishing a good PPP to serve the people’s needs and encourage those involved to put in their best effort.
2. **No financial risk to the government.** The government has neither invested any capital nor committed to future payments. BWC is paid a share of revenues earned and only after it has delivered the required services. Such a structure however requires a high level of trust that the government will continue to enforce underlying rules and regulations and share revenues as agreed.
3. **Increased accountability.** Since only one party is responsible for construction and O&M, it has to take full responsibility for system failures and cost escalations. In contrast, when multiple players are involved in designing, building, and operating a system, there is invariably a tendency to lay the blame on others and the project suffers.

Figure 6: Number of Desludgings per Month



Note: Operations cease in November–February due to winter.
Source: Blue Water Company.

4. **Improved performance.** As operations stabilized, BWC increased the cleaning schedules to an average of nearly 100 per month, compared with the earlier 4–6 scheduled per month when MCL provided services on an on-call basis—a 16–25x increase. This increase in cleaning frequency will greatly reduce the amount of contaminated wastewater flowing into the ground. Already, over 2.5 million liters of fecal sludge have been collected and treated.
5. **Ring-fenced financial flows.** All customer fees and payments to BWC are deposited into a separate bank account, making it easy to track performance and ensure available funds to pay BWC when needed.

The fecal sludge treatment plant occupies an area of about 6,000 square feet (photo by CDD Society).

6. **Improved quality of life of sanitation workers.** Sanitation workers face some of the most hazardous working conditions for minimal pay. The FSTP has a comfortable office, kitchen, lounge, and bedroom, which empower operators and make them feel dignified, considering they work often late at night or in the harsh sun and extreme cold.
7. **Efforts to improve septic tanks.** The first step of the fecal sludge value chain—poor quality of septic tanks and dominance of soak pits—remains a huge concern especially in areas with high water tables. MCL has asked BWC to prepare guidelines for septic tanks and conduct stringent inspections of new ones being built in town. However, existing soak pits need to be repaired and upgraded into septic tanks, which can require substantial breaking and reconstruction at the customer's site and associated costs.

The fecal sludge treatment plant uses planted drying beds, into which the fecal sludge is discharged through a screen that captures any large inorganic solids (photo by CDD Society).

Other towns can learn from Leh's approach to this partnership to expedite deployment and improve FSM and other key services. The ideal contract should have been valid for 10–12 years or even longer, but this was not feasible because of local regulations.

Case 4: Public–Private Partnership for Decentralized, Small-Scale Sewage Treatment Plants, New Delhi

Background

Delhi is facing an acute water shortage of over 50 million gallons per day and the problem is only becoming worse each year. Only 40% of the wastewater it generates is treated, and the Yamuna river, which receives this effluent, is becoming one of the most polluted rivers in the world. Being a large and green city, a large amount of water is used for horticulture. In 2016, the New Delhi Municipal Corporation (NDMC) decided to install small-scale, decentralized STPs around the city to treat sewage locally and reuse the treated water for horticulture.

First, NDMC needed to pilot the concept of three STPs—two plants with a capacity of 1 million liters per day (MLD) and the other plant for 1.1 MLD, a cumulative capacity of 3.1 MLD. NDMC issued separate tenders for each plant. It issued two contracts—one to Vision Earthcare Pvt Ltd, which uses soil biotechnology (SBT), and the other to SS Engineering Corporation, which uses membrane bioreactor (MBR) technology.

The Innovation – A Game Changer

According to Chandrashekar Shankar, founder of Vision Earthcare, NDMC did not issue a standard contract wherein the service provider is paid to build and operate the STP. Rather, it issued a public–private partnership (PPP) agreement stipulating that NDMC would supply raw sewage and space to build the STP, and then buy the treated sewage at a price of ₹31–₹37 per kiloliter, provided that the treated sewage met certain criteria such as biochemical oxygen demand (BOD), chemical oxygen demand (COD), and total suspended solids (TSS), among others.

The standard type of contract often fails because typically the government makes large investments upfront and if the system fails for a variety of reasons (poor design, neglected O&M, technical failure, or others), the investment is written off. Private providers often inflate the capital cost to earn a profit but neglect their O&M commitments.

With the new PPP structure, Vision Earthcare as the private provider is free to choose any type of technology and design that can optimally perform the task, instead of aiming to meet specifications of a consultant who prepared the project report. Vision Earthcare now has complete responsibility and control for designing, building, investing in, and operating and maintaining the plant, and can optimize costs, features, and specifications to minimize cost and earn a return on investment. NDMC issued the contract for a period of 12 years, and the interests of NDMC and Vision Earthcare are aligned.

Location of Sewage Treatment Plants

The STPs provided for in the PPP agreement are located in areas with underground drainage networks so that water can be diverted from the sewerage system to the new STP. Vision Earthcare studied the sewage flow in the area and the opportunities for reuse in nearby water parks and road dividers before deciding on the capacity of each STP. Delhi generates 2,225 million liters of sewage daily, hence diverting 3 MLD of that amount is not a problem.

Overview of the Continuous Aerobic Multistage System Using Soil Biotechnology (CAMUS-SBT)

SBT is a natural and green technology based on biomimicry. It uses less than one-third of the electricity used in conventional systems such as the common and well-known MBR technology. SBT requires minimal and simple maintenance and therefore incurs low O&M costs.

Vision Earthcare has developed a proprietary approach for SBT called the continuous aerobic multistage system using soil biotechnology (CAMUS-SBT), to address the weakness of earlier approaches used by SBT engineers.

Vision Earthcare has built over 100 of these systems, hence proving the technology reliable. Installing a sewage facility in the historic and popular Lodhi Gardens was met with resistance initially; however, SBT is a biological system and can be designed to integrate well with the landscape, says C. Shankar. Naturally, the system cannot under any circumstances emit odor, breed mosquitoes, flood, or create any health or visual problem.

Tasked to operate the system for 12 years, Vision Earthcare is confident about undertaking such a responsibility, whereas another O&M provider may not understand the system well enough or take accountability for the strict requirements, underscoring the benefit of integrated contracts that increase accountability.

Benefits of the Public–Private Partnership Contract and Scalability

For the government or the New Delhi Municipal Corporation

1. A single party is responsible for designing, building, and operating the plant—greater accountability.
2. No need to pay a large amount upfront for infrastructure that may not solve the problem. NDMC pays only after the sewage is treated.
3. While the price of the treated water is higher than normal freshwater, it is lower than the cost of running large STPs and a sewerage network and cheaper than using water tankers (which cost ₹100 per kiloliter). Thus, NDMC saves money and freshwater.

4. A long-term contract is an incentive for parties to build good quality systems that will work well for 12 years or more with minimal repairs. In shorter contracts such as those for 3–5 years, the provider has reason to cut costs and deliver a poor-quality product.
5. Only good, qualified, and reliable providers will make such an investment and take on responsibility for long-term O&M.

For the private provider

1. Flexibility in designing, building, and operating the system, provided that certain parameters (such as the area provided by and performance of the other partner) are fulfilled.
2. If NDMC defaults on payments for any reason, they can sell the water to other private or public customers—not an optimal situation but a hedge against nonpayment. The risk of nonpayment by the government is a significant concern for private providers.

These “pay for performance” contracts in which a service provider is paid after satisfactory completion of a task, are becoming increasingly common because they provide a tremendous opportunity to improve public investments and engage responsible, credible private players. One criticism is that the cost to government increases due to the private player’s profits and risk assessment. But overall, as the government does not make large upfront investments or fixed payment commitments, these contracts are likely to save money and improve public service outcomes.

This decentralized approach to sewage treatment has long been recommended but state agencies who normally manage STPs and the associated infrastructure, have found it too cumbersome. By engaging private players and ensuring 100% treatment and reuse of wastewater, NDMC has taken a huge step toward making Delhi more water secure and preventing environmental pollution. More recently, the idea of building 600 such STPs around Delhi has been suggested by the Delhi Jal Board which manages water supply in the city. Other cities need to quickly follow and adopt the approach, although the challenge of allocating land for such STPs will need to be addressed.

Case 5: Sewage Treatment Plant Using the Membrane Bioreactor Technology at the Ritz Carlton Hotel in Bangalore

AT A GLANCE	
Technology used	Membrane bioreactor
FSTP design capacity	300,000 liters/day (300 kiloliters per day)
Reuse of treated water	Flushing, landscaping, artificial water bodies, air conditioning
Capital cost	₹32 million
O&M cost	₹100,000/month + electricity (total about ₹250,000/month)

Background

Indian cities are growing, water demand is rising, and 22 of the largest 32 cities have water shortages of 10%–60%. The cost of generating water is increasing as large cities have to bring water from farther away, in the process also sparking urban–rural conflicts and competition between agricultural, industrial, and urban users.

India properly treats less than 25% of its urban sewage, which means that 40 billion liters of untreated sewage is being released into the environment every day. The infrastructure gap in the wastewater treatment sector is a threat and municipalities simply do not have the funds or expertise to build and maintain the types of system needed by these growing cities—sewerage networks and STPs that treat wastewater properly and make the treated water available for reuse in a variety of ways.

There is now more focus on the “polluter pays” principle and hence, the government has required buildings that generate large amounts of wastewater to build and operate their own STPs. Bangalore has been one of the early adopters of this principle. Since about 2010, buildings can install STPs and then reuse the treated water for various applications such as flushing, landscaping, road washing, and recharging water bodies. High-quality STPs, such as the MBR type, can treat sewage to potable levels so that treated water can be used safely for air-conditioning, industrial applications, car washing, and even drinking and bathing. One such system is installed at the Ritz Carlton Hotel in Bangalore.

The Sewage Treatment Plant

The Ritz Carlton has a zero liquid discharge system, meaning that the hotel reuses all wastewater within the property. Its 300-kiloliter MBR system uses a combination of membranes and biological treatment methods, both highly advanced and very expensive. The system is installed in the second basement of the hotel building and does not occupy land space.

According to the facility manager in charge of the STP, on average, the system receives 240 KLD of wastewater, 200 KLD of which is recovered and reused for flushing, watering gardens, and filling decorative waterbodies (but not the swimming pool). The sludge from the MBR system is combined with the treated organic waste and used as an organic fertilizer in the gardens.

The hotel group's internal policies and quality parameters compelled them to invest in the best possible technology regardless of cost. Even the slightest color or odor in the flushing water or on the lawns would be unacceptable to the luxury standard of the brand. Therefore, the hotel established as a priority consistent, high quality treatment in its criteria for selecting the vendor and type of technology.

The second most important criterion was the life cycle cost of the system. While MBR is the most expensive STP technology to buy and operate, its capacity to produce safe reusable water meant huge savings especially in the face of Bangalore's water shortage and expensive water sold from tankers. According to research by BORDA, the STP construction cost of ₹3.2 million was barely 0.6% of the total project cost (estimated at $100 million or ₹6 billion). The cost of building an STP is therefore not a major financial burden for large infrastructure projects and buildings to absorb.

The hotel outsources O&M to an external service provider through an annual maintenance contract, which provides semi-comprehensive coverage for labor, maintenance, and replacement of electromechanical components like pumps and blowers. The contract does not cover replacement of the filter media and membranes, and the hotel pays for electricity bills. The filters in the tertiary system are replaced every 2 years; and the membranes have not been replaced in the life cycle of the system so far. Three operators are required to operate the STP in 8-hour shifts. The hotel also employs one supervisor to oversee operations as part of the maintenance contract. In addition to regular O&M, the operator conducts daily checks on the water quality, testing the following parameters: hardness, mixed liquor suspended solids (MLSS), chlorine, pH, and turbidity.

Replicability

Large apartments, hotels, hospitals, colleges, commercial buildings, malls, and factories use a large amount of water and generate a substantial volume of wastewater. Thus, they can easily afford the additional financial and operational costs of the STP, considering also that governments must invest heavily in building and operating a networked water supply and sewerage infrastructure.

The STP owner has the advantage of greater water security and flexibility in the use of the property's water resources. However, when most buildings invest in inferior systems and/or operate them improperly, the STP becomes a nuisance and eventually goes into disuse. To prevent this from happening, the State Pollution Control Board and municipalities must put in place stronger frameworks and monitoring protocols, also in accordance with recommendations from the Small-Scale Sanitation Systems Scaling Up Project (4S) conducted by EAWAG, IIT-Madras, and BORDA.[4]

Over the past decade, an increasing number of states and cities in India have passed regulations requiring large buildings to install on-site sewage and organic waste management systems. Although many loopholes and problems have yet to be addressed and implementation remains weak, this direction seems to be a clear trend going forward.

Conclusions

Until 2015, FSM services in urban India have been poor and unregulated. Out of nearly 7,000 towns and cities, only 250 cities have managed to build and maintain centralized sewerage networks, resulting in nearly zero wastewater treatment and reuse and consequently high extraction of freshwater from the environment and widespread pollution of water bodies.

As the case studies illustrate, decentralized, small-scale sewage treatment plants are effective in treating and reusing sewage in buildings, campuses, and residential neighborhoods. Treatment technologies are evolving continuously and, with remote internet-of-things–based monitoring and control systems, operating costs are also decreasing rapidly, making these systems affordable—they typically cost less than 0.5% of a real estate project's budget—and less problematic to operate such as in the case of Aravind Eye Hospital.

Retrofitting existing buildings and campuses is complicated and expensive, but prefabricated STPs and government incentives can increase the number of buildings with such STPs. As seen in Delhi, dense neighborhoods in small and large towns can relatively easily build local sewerage networks without waiting for citywide solutions and use the treated water for parks and recharging groundwater. Better municipal regulations and enforcement can also increase the adoption of such systems.

Providing good quality, organized, and regulated FSM services may be a big step forward from current services. But building a fecal sludge treatment facility is critical to prevent pollution. To improve services at reasonable cost for users, municipalities need to engage with and regulate and support private players who clean septic tanks. Across India, several examples offer a variety of municipal and privately operated models which towns can adopt. But planning for the long term as shown in the approach adopted by the town of Leh is key to major improvement in the local environment's sanitary conditions. A piece-meal approach of simply building a new FSTP but changing nothing else will be inadequate.

The financial investment required for installing a decentralized sanitation solution is minimal. However, innovation is required in choosing a suitable technological option from among those

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[4] Eawag Aquatic Research. Small-Scale Sanitation Scaling-Up (4S) in South Asia. https://www.eawag.ch/en/department/sandec/projects/sesp/4s-small-scale-sanitation-scaling-up/.

promoted in awareness campaigns and featured in these projects. The town of Leh had to adopt a variety of fecal sludge management techniques to address climate and logistical constraints.

Because holistic planning and systemic solutions have become a requirement, multiple government agencies and municipal departments need to plan and collaborate their efforts to produce significant results. The town of Devanahalli, for example, coordinated with nonprofit organizations and private sector providers to build and operate India's first dedicated fecal sludge treatment plant.

Building a broad consensus and overcoming the inertia of existing systems will remain the primary barrier to widespread adoption of decentralized sanitation solutions. These case studies show that the efforts in addressing seemingly insurmountable conditions have not only been worthwhile, but have also yielded beneficial results.

Lessons Learned and Success Factors

The establishment of a policy to promote small sewage treatment plants (SSTPs) in India in 2006 has led to a remarkable growth in the number of installations in the country's rapidly expanding urban areas, especially in big cities. However, many of these systems have either underperformed or failed.

Small-scale sanitation (SSS) sector developments in India have not been informed by a holistic, in-depth assessment of lessons learned. There has been very little research on the enabling conditions for the successful long-term operation and management of SSS systems at scale.

Sludge management is a major issue in SSS projects. Due to the lack of alternatives, untreated sludge is commonly disposed of in uncontrolled ways, posing potential high public health and environmental risks.

In a comprehensive performance evaluation of SSS in India, Klinger et al. (2020) identified 14 critical success factors for sustainable operation of SSS projects, illustrated with the cause–effect chain (see Figure 6 in Klinger et al. [2020]).

This case study has been developed solely as a basis for class discussion. It is not intended to serve as a historical record, a source of primary data, or an illustration of effective or ineffective management.

For better understanding, the case study could be read together with the performance evaluation of small-scale sanitation (SSS) in India, including a detailed assessment of 35 SSS projects with analyses of the relevant biochemical and microbial parameters.

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Study Questions

1. What local factors may prevent a property owner, real estate developer, or municipality from adopting decentralized wastewater management solutions? How can these be overcome given specific local conditions, keeping in mind financial requirements, responsibility for proper O&M, and monitoring performance to ensure compliance with all standards and regulations?
2. What factors affect the choice of technologies for a decentralized STP or FSM system? How should life cycle costs and requirements be evaluated so as to identify the best long-term solution?
3. What statutory and regulatory frameworks can speed up the adoption of decentralized sanitation solutions?
4. How can small-scale STPs and FSM be integrated into the plan for a particular city, and what other systems can complement these to improve overall sanitation in a town?
5. How can markets be developed for the treated waste and fecal sludge generated by these systems? How will this help improve the economics of decentralized sanitation?

Recommended reading:

Reymond, P., R. Chandragiri, and L. Ulrich. 2020. Governance Arrangements for the Scaling Up of Small-Scale Wastewater Treatment And Reuse Systems – Lessons from India. https://www.frontiersin.org/articles/10.3389/fenvs.2020.00072/full.

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