Piece of the Puzzle

Evaluating the Soil Biotechnology wastewater treatment plant at ACCEPT Society, Bengaluru

A report by Arghyam

Arghyam
Safe, sustainable water for all

Piece of the Puzzle: Evaluating the Soil Biotechnology wastewater treatment plant at ACCEPT Society, Bengaluru

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Civil Design and Construction was carried out by Hinren who played a proactive role. M.S. Sunil Kumar and Kiran Rao were involved from their side.

Water sample tests were carried out at Bangalore Test House.

At Arghyam, the project was executed by Mrinalini Goswami under the guidance of Vijay Krishna. B.K. Harish Kumara came on as a consultant at a later stage to take the work forward and created the first draft of this report. The final version of this report was written by Aarti Daryanani with direction from Ayan Biswas. Report design was by the firm Barapani and co-ordinated and supervised by Madhavi Purohit at Arghyam. The project was championed and guided by the senior management of Arghyam including former CEO Sunita Nadhamuni, current CEO Mala Subramaniam, Chairperson Rohini Nilekani, advisors S. Vishwanath and Ravi Narayanan. We thank all of them.

Preface

Through this action-research project we have attempted to better understand Soil Biotechnology (SBT) as an option for decentralised wastewater treatment. The current sanitation scenario of urban India is one of severe lack of collection, treatment and disposal systems for domestic sewage. In order to tackle this problem and protect water resources from contamination, while also augmenting usable water resources, there is an urgent requirement to identify appropriate technologies for wastewater treatment. Decentralised technologies are increasingly attractive because of several advantages, especially in the Indian context.

SBT is a decentralised wastewater process which makes use of respiration, photosynthesis and mineral weathering in order to purify domestic, municipal and some types of industrial wastewater. In this project, we sought to understand the SBT technology from all angles, through an installation at ACCEPT Society on the outskirts of Bangalore. We have been monitoring the process of installation and maintenance closely and monitored the input and treated water quality over a period of time. In this report, the technology is explained along with information on the construction of the plant. In order to assess the efficiency of the plant, numerous water quality tests were carried out over the last two years. The chemical parameters measured reflect satisfactory results thereby proving the technical feasibility of this plant, enabling the recycled wastewater to be used for local irrigation. A cost-benefit analysis undertaken shows the economic feasibility of SBT, with a RoI of 22 years.

Although our analysis of SBT has shown positive results, it is recognised that the time period of observation is limited and significantly less than the full life cycle.

We expect this report to be a useful addition to the knowledge base on wastewater treatment in India and enable better decision-making in this regard.

Summary

Soil Biotechnology (SBT) first came to Arghyam's attention as a promising decentralised wastewater treatment technology in 2007. Arghyam continued to learn more about the technology and this culminated in financial support for the installation of a SBT plant of 15 KLD (Kilolitres per day) capacity at the campus of ACCEPT Society, an AIDS-care hospice on the outskirts of Bangalore.

The plant is currently performing well and providing water that is being used to support the agricultural and horticultural activities on campus. With some exceptions, the plant is meeting the standards specified at the time of project design. These standards are high, and match or exceed international standards for many parameters including nitrogen and phosphorus. These parameters are important in the context of pollution and eutrophication of natural water bodies and contamination of drinking water supplies (typically groundwater).

We find SBT has the potential to meet high water quality standards for use in agriculture, toilet flushing as well as discharge to rivers and waterbodies. The technology has a relatively high startup cost and a land footprint that may be larger than other technologies on offer. However its great benefit is that it requires no power for the wastewater treatment per se. Overall the ongoing operation and maintenance (O&M) expense is very low. Therefore, while comparing the Total Cost of Ownership (TCO), SBT is found to be substantially less expensive than many conventional technologies at the lower end of the capacity scale (10-200 KLD). The other major advantage is that there is no necessity for skilled manpower for operation.

For these reasons, SBT is a strong candidate for wastewater treatment for specific situations. Finally it is a green technology, which uses less power and discharges no methane as part of the treatment process.

Our conclusion is that SBT is worth considering in any wastewater treatment technology decision up to the capacities of a few million litres per day (MLD).

1. Introduction

1.1 Decentralised water management in the urban context

Water underpins all aspects of human society, from ecology to agriculture to industry. With no known substitute, this resource is a unique treasure.

The push from rural India because of agrarian distress, and the pull to big cities in search of new livelihoods, has seen cities growing both horizontally and vertically with a decadal growth rate of 32%, from 2001-2011 (Census of India, 2011). This expansion however has not been accompanied by a growth of supporting infrastructure including water supply and wastewater treatment facilities.

In addition to urbanisation, organic population growth and increased economic activity are increasing the demands on freshwater. Consequently, the quantity of wastewater is on the rise. Inadequately treated/untreated wastewater is being disposed of onsite or into open drains and lakes leading to public health problems and the pollution of water resources.

Wastewater management includes wastewater collection, transport, treatment and reuse or disposal. Wastewater management in India has mainly focused on centralised approaches. Although this approach allows for the treatment of greater quantities of wastewater and consequent economies of scale, it has numerous drawbacks. A centralised approach incurs high capital and operation and maintenance costs. It also requires skilled manpower in order to ensure sustainability. Additionally, centralised wastewater treatment infrastructure disrupts other important infrastructure (eg. roads) in an urban setting.

Thus decentralised technologies for wastewater treatment such as Decentralised Wastewater Treatment Systems (DEWATS) and Soil Biotechnology (SBT), which bridge the gap between onsite sanitation and conventional centralised systems, are a promising middle road for urban wastewater management in India. Regulations such as the one by the Karnataka State Pollution Control Board (KSPCB) mandating the construction of Sewage Treatment Plants (STPs) for residential complexes with 50 apartments or more in Bangalore, or those generating more than 50m^3/day or more of sewage, are also increasing the demand for appropriate wastewater treatment systems.

As a technology, SBT stands as an attractive option to address the challenges of wastewater treatment in India. This report seeks to assess SBT's effectiveness in treating wastewater, through the analysis of the construction and operation of one such treatment facility.

1.2 Soil Biotechnology Treatment (SBT) — The process

The SBT system was developed after two decades of research by Prof. H.S. Shankar and associates at the Chemical Engineering Department of Indian Institute of Technology (IIT), Bombay. Following this development, Prof. Shankar founded Vision Earthcare, a company which seeks to provide wastewater treatment solutions using this technology. Other service providers have also licensed this technology.

"*SBT is a wastewater treatment process, which is based on a bio-conversion process where fundamental reactions of nature, namely respiration, photosynthesis and mineral weathering take place in a media housing micro & macro organisms which bring about the desired purification. SBT is an oxygen supplying biological engine and so the process can treat all types of water – domestic, municipal and industrial.*" (Vision Earthcare, 2013)

Since then, SBT has been installed in more than 20 locations, treating wastewater volumes between 5-10 MLD in industries, housing societies, resorts, schools, universities, ashrams, hotels and municipal corporations. As explained by a patent document and other research papers produced by the research group at IIT (IIT Bombay, 2003; Kadam et al., 2008; Kadam et al., 2009), SBT incorporates the use of specific micro-organisms.

These are part of the process that cleans organic waste through oxidation and releases carbon dioxide. Nitrification followed by de-nitrification convert the nitrogen load in the wastewater to elemental nitrogen gas. Primary minerals, which form the base media in the bioreactors within which the purification processes take place, create a pH buffering effect. Whilst earthworms serve to aerate and regulate bacterial populations, trees and shrubs planted on the surface of the bioreactor act as bio-indicators to signal a properly functioning plant.

The physical (civil) structures consist of a raw water tank, a bioreactor containment structure, a treated water tank and associated piping, pumps and electrical installations. The process is meant to handle domestic sewage and industrial sewage containing primarily organic effluent. Treated water quality of various levels can be obtained, from river discharge quality up to near drinking-water quality, from an SBT depending on the requirement and investment potential.

i) Chemistry

Process Chemistry

Respiration

$(CH_2ON_xP_yS_zK_y)_n + nO_2 + nH_2O = nCO_2 + 2nH_2O + \text{Mineral (N, P, S, K)} + \text{Energy}$ (1)

Photosynthesis

$nCO_2 + 2nH_2O + \text{Minerals (N, P, S, K)} + \text{Sunlight} = [CH_2ON_xP_yS_zK_y]_n + nO_2 + nH_2O$ (Photosynthesis) (2)

Nitrogen Fixation

$N_2 + 2H_2O + \text{Energy} = NH_3 + O_2$ (in soil) (3)

$N_2 + 2H_2O + \text{Light} = NH_3 + O_2$ (in water) (4)

Acidogenesis

$4C_3H_7O_2NS + 8H_2O = 4CH_3COOH + 4CO_2 + 4NH_3 + 4H_2S + 8H^+ + 8e^-$ (5)

Methanogenesis

$8H^+ + 8e^- + 3CH_3COOH + CO_2 = 4CH_4 + 3CO_2 + 2H_2O$ (6)

Adding 5 and 6 give overall biomethanation chemistry

$4C_3H_7O_2NS + 6H_2O = CH_3COOH + 6CO_2 + 4CH_4 + 4NH_3 + 4H_2S$ (7)

Mineral weathering

$CO_2 + H_2O = HCO_3^- + H^+$ (8)

$\text{Primary Mineral} + CO_2 + H_2O = M^{+n} + nHCO_3^- + \text{soil/clay/sand}$ (9)

Nitrification

$NH_3 + CO_2 + 1.5O_2 = \text{Nitrosomonas} + NO_2^- + H_2O + H^+$ (10)

$NO_2^- + CO_2 + 0.5O_2 = \text{Nitrobacter} + NO_3^-$ (11)

Denitrification

$4NO_3^- + 2H_2O + \text{energy} = 2N_2 + 5O_2 + 4OH^-$ (12a)

$NO_2^- + NH_4^+ = N_2 + H_2O + \text{energy}$ (12b)

Figure 1: Process Chemistry of Soil Biotechnology. Source: Presentation by Vision Earthcare

ii) Components

a. Media: It is formulated from soil with primary minerals of suitable size and composition.

b. Culture: Geophagus worms (*Pheretima elongata*), nitrifying and denitrifying organisms and bacteria capable of processing cellulose, lignin, starch, protein and anaerobic bacteria for methanogenesis. The bacterial culture is extracted from excreta of ruminant animals.

c. Additives: Formulated from natural materials of suitable particle size and mineral compositions to provide sites for respiration and CO_2 capture.

d. Plants: Green plants particularly with tap root system act as bio-indicators and add aesthetic value.

e. Under drain: Stone rubble of various sizes ranging from fine sand to gravel.

1.3 Wastewater treatment process

The wastewater is first collected in a holding tank after which it is pumped into a trapezoidal-shaped bioreactor. The bioreactor is constructed by excavation and made waterproof. The underdrain is laid at the base. The tank is then filled with layers of media and culture. The surface of the bioreactor contains rows of plants. A network of perforated pipes is constructed on the surface that spreads the incoming wastewater evenly over the surface of the bioreactor. Another set of pipes is also laid vertically extending into the bioreactor for aeration.

Water is pumped over the bioreactor through the perforated pipe network and begins to trickle down the filtering media. The suspended solids in the wastewater are held back by the top media. As the water seeps through the rest of the layers, dissolved pollutants are removed, and finally treated water passes through an outlet at the bottom of the tank and is collected in a treated water storage tank constructed alongside.

If required, recirculation pumps can be added to transport the water back into the bioreactor. This creates a second round of purification, obtaining the desired hydraulic retention and improved output water quality to the desired level. Shrubs and trees are planted on top of the bioreactor to act as bio-indicators, organisms used to monitor the health of the environment. In this case the growth of these plants will determine their ecological health thereby indicating the quality of the recirculated water.

This entire treatment process can be operated on a batch or in continuous mode and is based around three fundamental reactions (refer to Figure 1 for more detail):

a) Respiration

b) Mineral weathering

c) Photosynthesis

iii) Significant features

The technology has the capacity to reduce rates of Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), Total Suspended Solids (TSS), Turbidity, Nitrogen and Phosphorus.

According to Vision Earthcare, this technology also offers several attractive features:

- Minimal maintenance
- Less mechanical equipment
- Low sludge
- Tunable output quality
- No odour

2. SBT at ACCEPT Society

2.1 Project location

ACCEPT Society is an AIDS-care hospice located near Hennur Cross (Bangalore). This 5-acre campus provides inpatient and outpatient care and counseling for AIDS-affected people and has a children's home for HIV+ orphans. Additionally, ACCEPT Society engages in horticulture and agricultural activities as a source of food as well as income.

The hospice's water supply comes from a borewell on campus. The supply is not adequate and is often supplemented through a water tanker service, twice a day during the summer months and once a day for the rest of the year. In order to increase their water supply, ACCEPT Society recently installed a rainwater harvesting (RWH) system. However due to various issues, the system is not being fully utilised.

Sewage was originally draining into a main septic tank from a secondary tank and soak pit on the campus. However due to the clayey properties of the soil in the campus, the tanks encountered severe flooding problems for which they had to be emptied very frequently. In addition, inadequately treated greywater was disposed of in dug and recharge wells which could be affecting groundwater quality.

Hence, the hospice was searching for a solution for their wastewater treatment problems. This provided Arghyam an excellent platform to test and validate SBT as a technology and at the same time support a charitable initiative.

2.2 Design and construction

i) Key design facts

Volume of wastewater generated: The average daily fresh water consumption at a typical residential dwelling varies widely between 100-250 litres per capita per day (lpcd), a range covering most urban dwellings in India. A common heuristic is that wastewater constitutes 80% of the incoming water supply.

There are large diurnal variations in the wastewater flow due to the time-specific nature of wastewater generating activities, with a typical peak in the morning and the late evening. The total population at ACCEPT Society is 60-80 people, but being a hospice there is also a floating population and a staff contingent present only during the day. Seasonal variation is also observed as water consumption drops during the winter because patients reduce their bathing frequency.

This variation combined with no metering at the campus, made it hard to estimate the wastewater volume, a fact which is crucial in order to design an appropriate treatment plant. Taking this into consideration, Arghyam worked with the ACCEPT Society staff to estimate their wastewater generation. The average wastewater volume was estimated to be 15 KLD and thus a bioreactor of this volume was designed (BR1).

In order to test this technology further, an additional 1 KLD bioreactor (BR2) was constructed. This bioreactor would treat 1 KLD of water leaving BR1. The operation doubled the treatment of 1 KLD of water and was expected to result in a higher standard of treated wastewater quality which could be then used for groundwater recharge. Overall the total area of the plant built is approximately 120m^2.

Following construction of the plant and metering over an extended period of time, it was found that the actual average wastewater volume was 6 KLD. Since this is significantly less than the figure taken into consideration during the design phase, the SBT plan operates well below capacity.

ii) Stakeholder involvement

Hinren Technologies (www.hinren.com) carried out the civil construction work based on parameters set by Vision Earthcare (VEC). Meanwhile VEC carried out installation of all mechanical and electrical works.

iii) SBT construction components

Construction began in June 2010 and the plant was commissioned three months later with the following components:

- Expansion of existing septic tanks and soak pits to allow for mixed black and grey water. This extension incorporated a buffer storage space to account for any failures in the operation of the sewage treatment plant (Figure 14 at end of report)
- Two bioreactors of 15 KLD and 1 KLD capacities (Figure 2 for engineering drawing and Figure 16 for photograph, at end of report)
- An output tank for treated water constructed with a deeper compartment at the centre for the submersible pump to reside (Figure 18 at end of report)
- A PVC piping network connecting all SBT components
- Electrical equipment to pump the water

Photos of all the SBT plant components can be found at the end of this report.

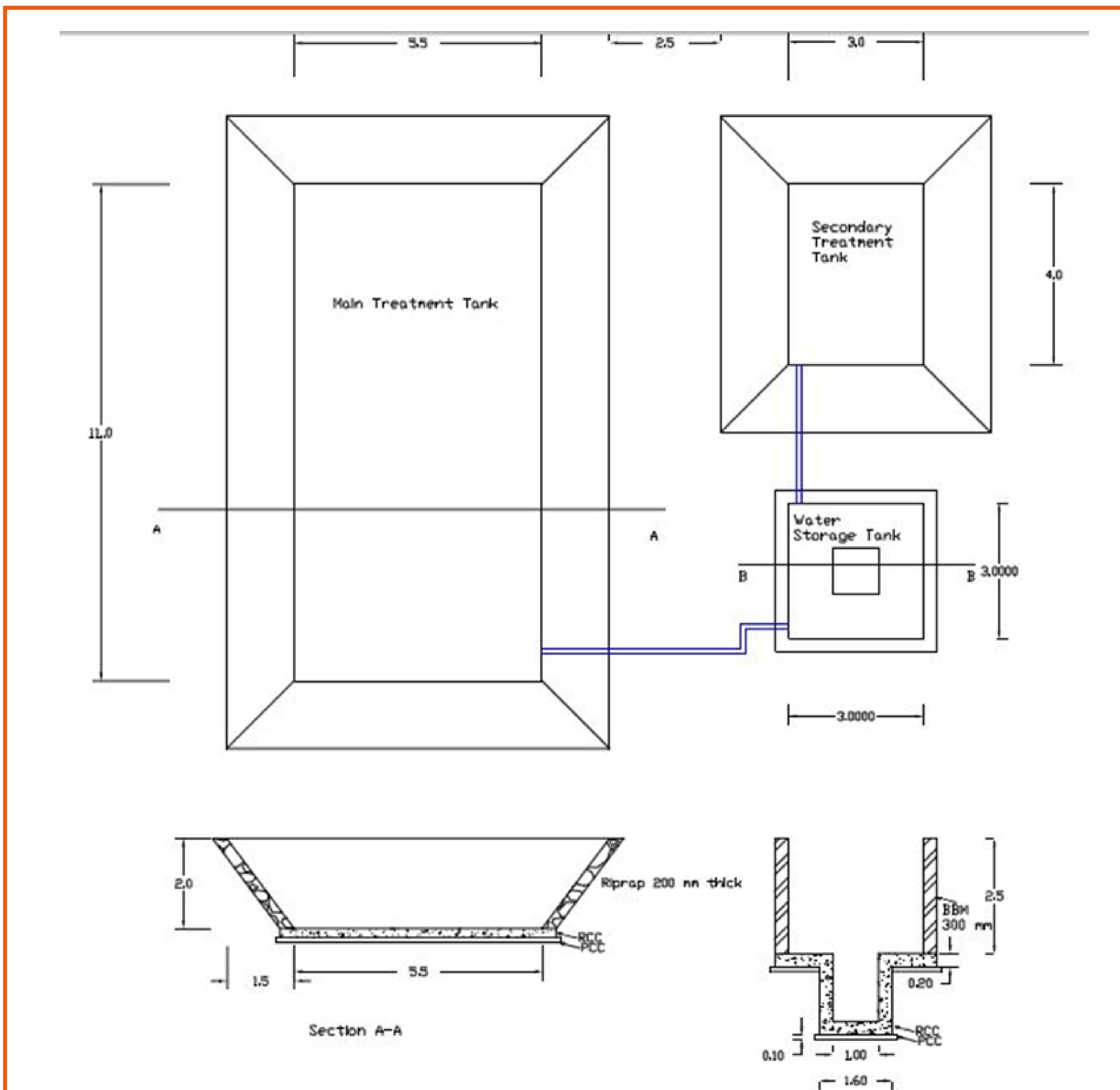


Figure 2: Engineering drawing of civil bioreactors

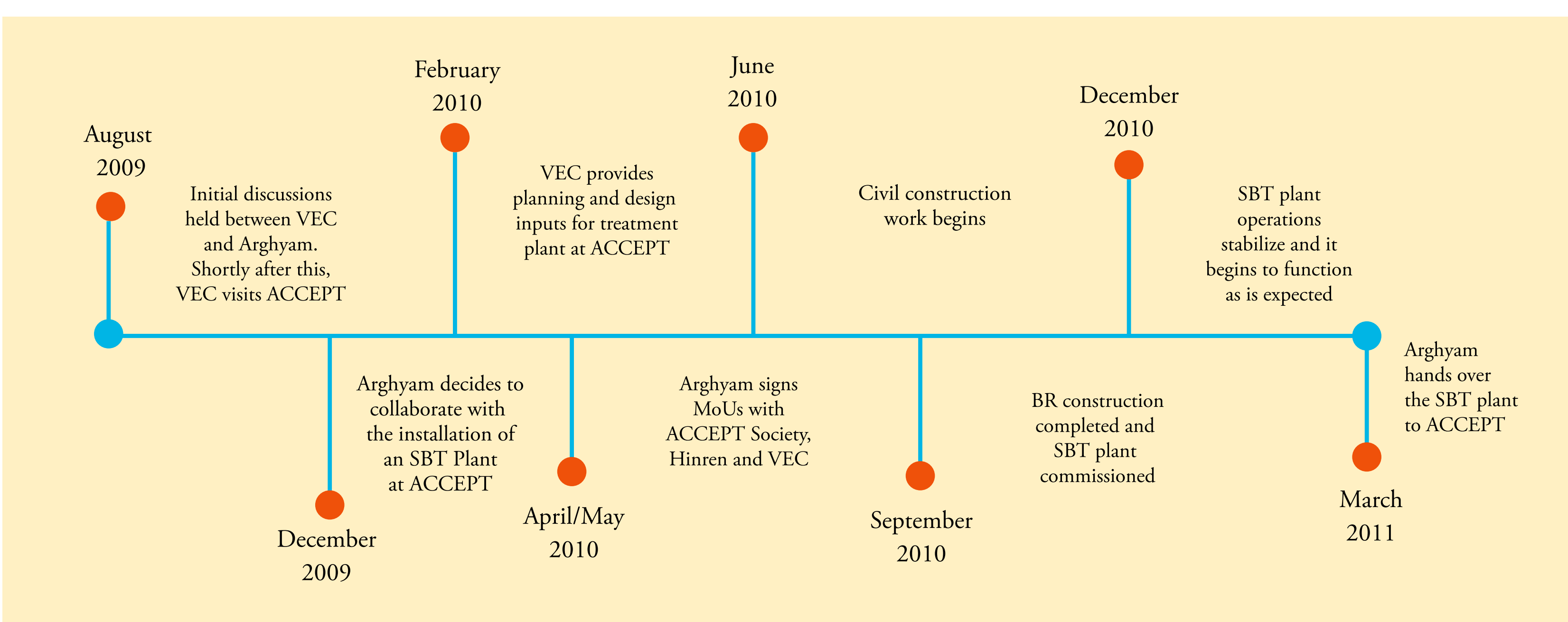
2.3 Treated water specifications

Following discussion with VEC, Arghyam put forward a set of desired treated water quality standards (Table 1). These are based on standards set by KSPCB/CPCB, USEPA-GWR, WHO and BIS.

Parameters	Desired treated water quality of 1KLD plant	Desired treated water quality of 15 KLD plant
pH	7-8	6-8.5
Turbidity	10	10
TDS	Same as input	Same as input
TSS	<10ppm	<30ppm
DO	>5ppm	>5ppm
COD	<20	<30
BOD	<5ppm	<10ppm
O & G	<2ppm	<2ppm
N as nitrate	<45ppm	----
Ammoniacal–N	----	<10ppm
Phosphate as P	< 5ppm	----
Total coliform	<10^4cfu/100ml	10^5cfu/100ml
Faecal coliform	10^3 - 10^4 cfu/100ml	10^4cfu/100ml

Table 1: Desired treated water quality standard mutually set by Arghyam and VEC

2.4 Project timeline



2.5 Monitoring

After construction and commissioning in September 2010, Arghyam has been regularly monitoring the SBT plant. Water samples have been periodically tested by an external laboratory for all relevant parameters (Annexure 1).

3. Construction Experience and Operational Observations

3.1 Challenges faced during construction

The construction phase presented numerous challenges.

Firstly, in order to channelise the wastewater of the entire campus from its 2 septic tanks, 1 soak pit and numerous grey water outlets, a pipe network had to be laid.

In addition to this, due to extreme waterlogging in the soil around the septic tanks, the construction planned in order to extend the tanks needed to be undertaken a significant distance away from the original to avoid the waterlogged area (Figure 14 at end of report.)

The waterlogging also had an impact on labourers who felt uneasy about the work conditions leading to a high labour turnover. Lastly, in order to avoid the use of pumps, a gravity flow system was installed joining soak pits to the main septic tank. Wastewater backflows were observed during heavy flows as the slope was insufficient. Thus, the slope was increased by lowering the inlet pipe into the main septic tank.

Figures 12 & 13 at the end of the report reflect progress during the construction of BR1.

3.2 Pumps and energy consumption

A total of three pumps were installed:

- 1HP sewage pump: to transport water from septic tank to bioreactor 1 (BR1)
- 1 HP recycling pump: to recycle treated water into bioreactor for further treatment and pump water from bioreactor 2 (BR2)
- 0.7 HP discharge pump: to transport water from the treated water tank for use in the agricultural area at the campus.

Based on the operation schedule (Annexure 3) and considering the daily electricity consumption for pumping is approximately 6.4 units, the energy cost is about Rs 7.5/KL of wastewater treated.

3.3 Input quantity

Raw water volume into the system was measured from December 2010 to July 2011. It showed a variance between 2 KLD-11 KLD, averaging out to 6 KLD. Since sewage meters were observed to be expensive, an analog high-end water meter capable of handling solid particles to a certain degree was used instead.

3.4 Operational challenges post construction

i) Solid settling in the septic tanks:

It was observed that there were a lot of inappropriate solids entering into the septic tank including soap sachets, plastics, paper, sanitary napkins, etc. In order to intercept this solid waste, a plastic basket was suspended in the overflow area between compartments of the septic tank. This solution did not work and three months into the functioning of the plant, the submersible pump choked and stopped functioning. Taking into consideration the stigma attached to both HIV/AIDS as well as working with raw sewage, finding labourers who were willing to repair the pump was a difficult task. The problem was eventually resolved using a backup pump which was purchased online. This pump included a protective mesh which prevented solid waste from entering and clogging it. In order to avoid this problem in the future, a new chamber and mesh was placed prior to the settling tank so as to intercept solid waste. This is now functioning well.

ii) Pump capacity:

Since the volume of water requiring treatment at ACCEPT is relatively low, a low capacity pump would have been ideal to allow the water coming into the bioreactor to trickle through slowly, thereby maximizing the reaction time. However, due to unavailability of low capacity pumps in the market, a pump of higher than optimum capacity was installed. The plant is still operating at a non-optimal input rate.

To address the above problem, water is recycled twice through BR1 in order to increase contact time with the media thereby improving the water quality.

3.5 Manpower requirement

Considering the reduced volume of wastewater and the automatic functioning of pumps, a total of 12 man days/month of unskilled labour was identified in order to manage the plant. The main activities involve weekly maintenance of pumps and pipes and monthly supervision and cleaning of tanks.

3.6 Reuse of treated water

75% of ACCEPT Society's 5-acre campus is used for agricultural activities. Treated water from the SBT plant is pumped directly through pipelines to the field and is used to irrigate a variety of vegetables and horticultural crops such as banana, mango and grapes.

3.7 Analysis of residue

Promoters of this technology emphasise that the residue accumulated on the surface of the bioreactor can be used as fertilizer. This is not possible at ACCEPT since most suspended solids settle in the septic tank prior to reaching the bioreactor. Thus there is no potential for biofertilizer from the residue in this plant.

3.8 Video documentation

Experiences with construction and running of the SBT plant at ACCEPT Society and also the broader water management experiences have been captured in two short films:

http://www.youtube.com/watch?v=p4vU5XluqOw

http://www.youtube.com/watch?v=ssWutuZ5Cug

4. Water Quality Parameters

This section discusses the status of water quality parameters following treatment through the SBT plant at ACCEPT Society. The water quality tests were conducted periodically since October 2010.

4.1 Input quality

The input water quality was tested during every set of water quality measurements made on the plant (Table 2).

Wastewater parameters	Normal range for sewage	Range seen at ACCEPT
pH	6.5-7.5	7-7.8
BOD	100-300 mg/L	60-150 mg/L
COD	200-600 mg/L	160-400 mg/L
Ammoniacal Nitrogen	12-50 mg/L	21.8-112 mg/L
Phosphates	6-24 mg/L	5-7.3 mg/L
Total Suspended Solids (TSS)	200-290 mg/L	18-150 mg/L

Table 2: ACCEPT Wastewater Characterisation

4.2 Output quality

Following a first set of tests, it was observed that the flow rate of wastewater through BR1 was substantially higher than that required to achieve the most effective treatment. Additionally, although BOD and COD values were in line with standards, ammoniacal nitrogen was observed to be substantially higher. These test results highlighted the need for recycling water through a second bioreactor (BR2). Thus in order to attain a higher residence time for more effective treatment as mentioned above, a further round of recycling was considered to be essential.

Below is an analysis of chemical parameters in the primary (BR1) and secondary bioreactors (BR2), based on standards provided previously in Table 2.

i) Bioreactors

BR1: The primary reactor is observed to perform well and meets the desired output specifications. This is mainly due to the fact that wastewater is passed through this tank multiple times in order to achieve better water quality results. It must however be noted that the primary bioreactor is not operating at its most optimal capacity due to the lack of a lower capacity pump.

BR2: The performance of BR2 is not substantially better than BR1. The reason VEC offered for this was the lack of a better pump. The one in use inside BR2 has a power of 1 HP, making the water flow at a faster rate than that required to appropriately treat the water.

ii) Chemical parameters

The following data refers to a compilation of 9 treated wastewater quality tests carried out from November 2010 to March 2013 (Annexure 1).

Total suspended solids (TSS): In the SBT the input TSS in sewage ranged from 18-152 mg/L (Figure 3). Following treatment all the TSS output values were found to be within the standard.

Overall, TSS reduction in this plant is 87% for both BR1 and BR2.

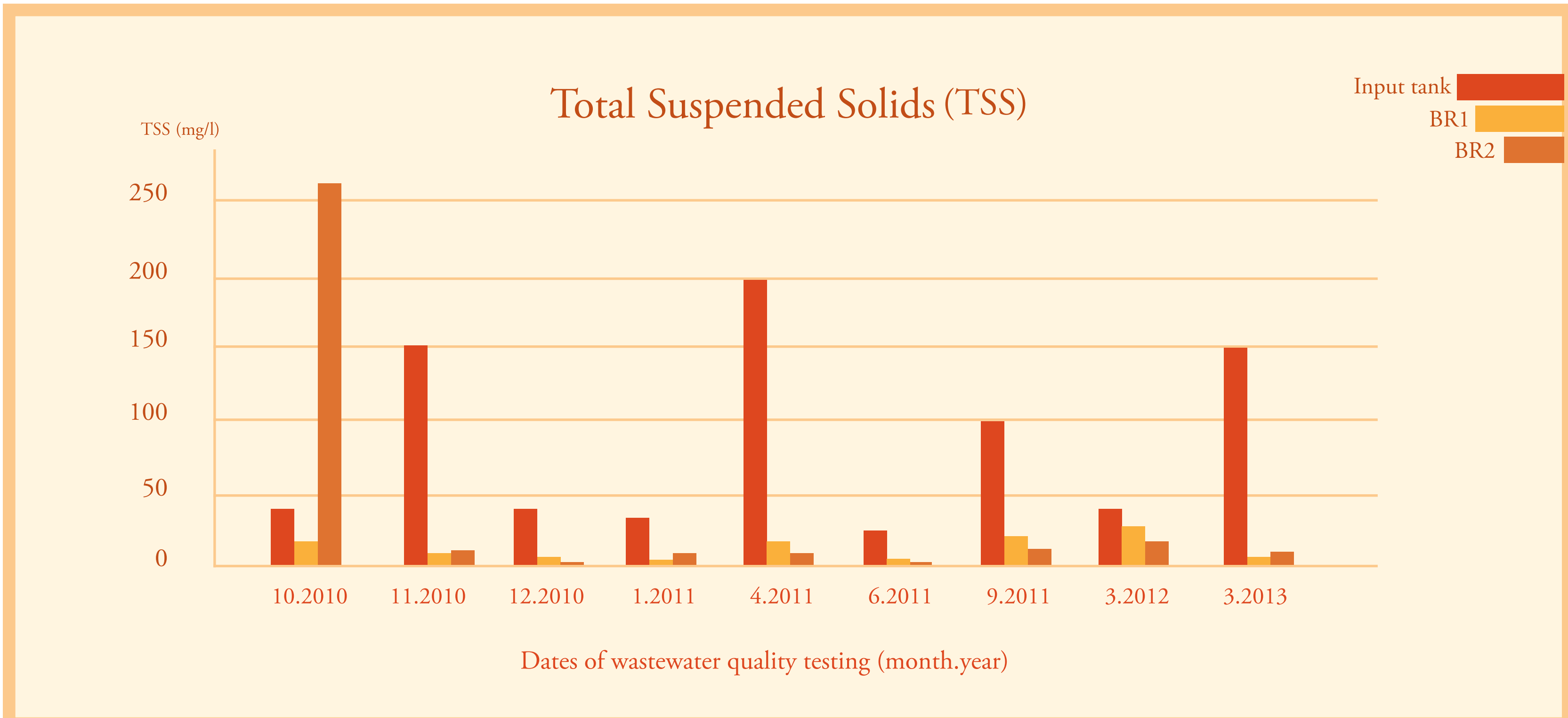


Figure 3: TSS values from 2010-2013 in input tank, BR1 and BR2

Chemical oxygen demand (COD): COD measures the oxygen consumed to oxidise all organic and inorganic matter. The BOD:COD ratio is typically 0.5:1 for raw domestic wastewater and may drop to as low as 0.1:1 for well-stabilised secondary effluent.

In the SBT plant, COD in input sewage varied from 162-405 mg/L (Figure 4). Following treatment, it can be observed that BR1 produces water above the standard (30 mg/L); however the water from BR2 marginally misses the second standard of 20 mg/L more often than not. These values overall conform to the standards expected and thus the plant is seen to operate well with regards to COD removal.

The average COD reduction for BR1 and BR2 over the course of the observation period is 91% and 93%, respectively.

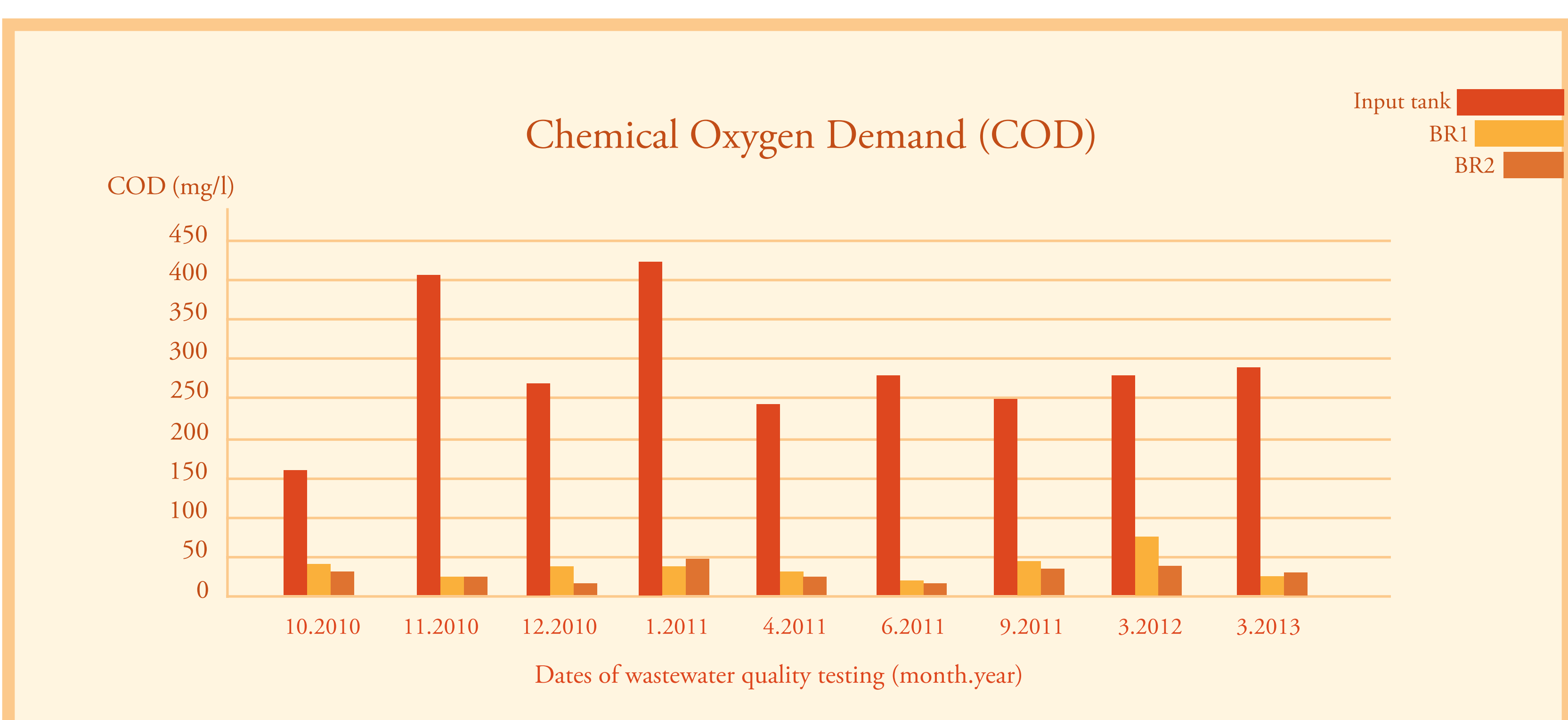


Figure 4: COD values from 2010-2013 in input tank, BR1 and BR2

Biological oxygen demand (BOD): This is the rate at which organisms use oxygen to stabilise or break down organic matter in wastewater where high levels of BOD indicate high levels of organic matter in wastewater.

In the SBT, BOD in sewage varied from 60-150 mg/L (Figure 5), comparatively lower in comparison to any other domestic sewage. Following treatment, BR1 produced water with BOD values within the standard (10 mg/L). However BR2 failed to do so, reflecting BOD values above 5 mg/L. Overall, BOD removal in the SBT plant met the desired quality.

The average BOD reduction for BR1 and BR2 over the course of the observation period is 92% and 93% respectively.

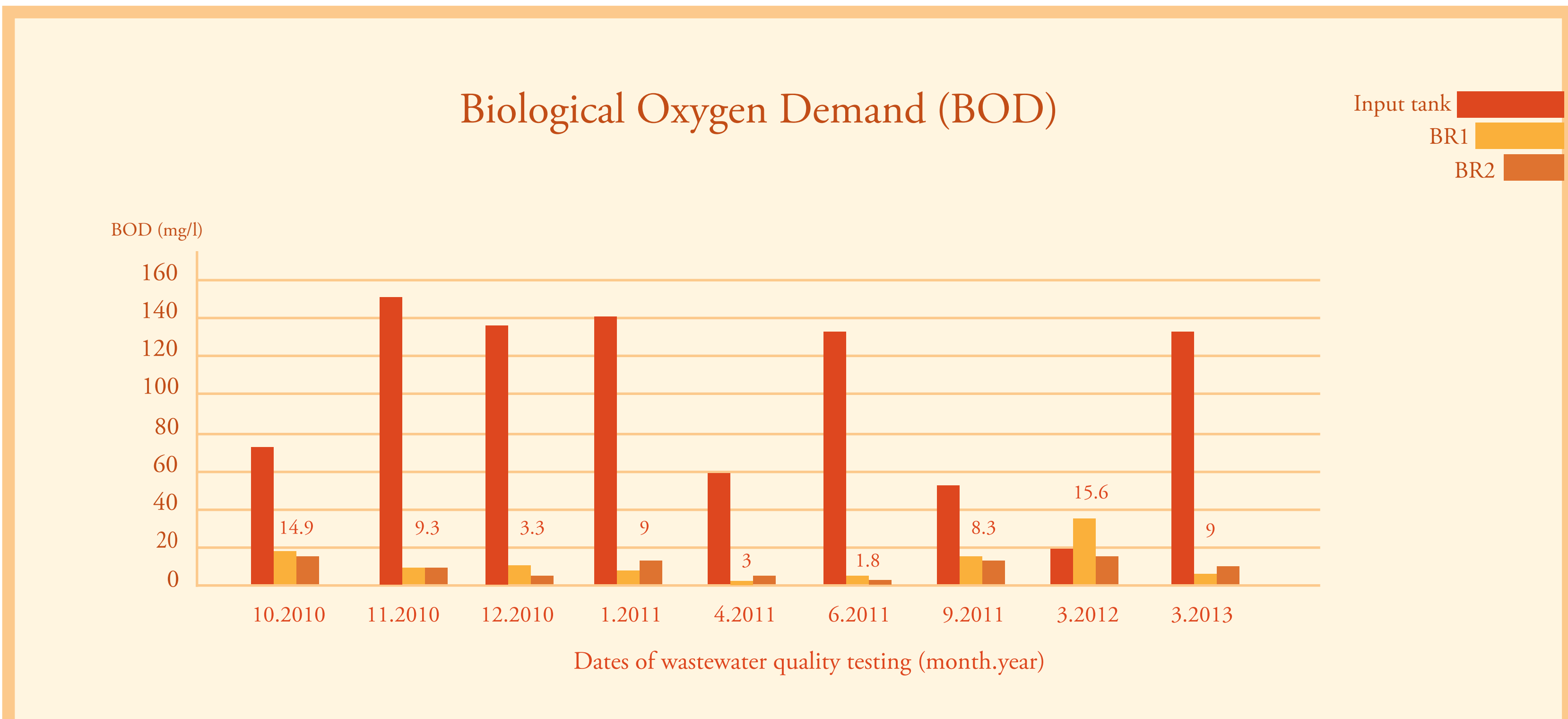


Figure 5: BOD values from 2010-2013 in input tank, BR1 and BR2

Nitrogen: Nitrogen in the wastewater effluent can be found in both inorganic and organic forms. Inorganic nitrogen includes ammonium (NH_4^+), ammonia (NH_3), nitrite (NO_2^-) and nitrate (NO_3^-) whilst organic nitrogen includes natural materials such as proteins and peptides, nucleic acids and urea and numerous synthetic organic materials. The total nitrogen is the sum of organic nitrogen, ammonia, nitrite and nitrate.

In the SBT plant, the average output nitrate (as N), is 23 mg/L (Figure 6) which is meeting our standard of 45 mg/L[1] . Similarly, the output ammoniacal nitrogen level is also low and comfortably meets our standard of 10 mg/L on average (Figure 7).

We note that something interesting is going on here; as is seen in the graph, nitrate level in the output water is often higher than in the input water. Other forms of nitrogen (ammonia, nitrogen in organic compounds) are being converted into nitrates (nitrifying reaction), but the follow up reaction (de-nitrification) where the nitrate is converted to nitrogen gas, is not happening sufficiently. This is resulting in an overall increase in the nitrate level in the water. The explanation offered for this by the service provider (VEC) is an insufficient organic load (COD or BOD) in the input wastewater. This organic load is necessary for the de-nitrification reaction to take place.

When assessing this SBT plant's efficacy in getting rid of all the nitrogen in various forms in the wastewater, results showed a reduction of 60%.

[1] However these numbers (45 mg/L, 23 mg/L) are not in the same units as the 45 mg/L standard for nitrate in drinking water according to Bureau of Indian Standards. This is because one set of units measures just nitrogen and the other measures NO_3^-. So the SBT plant is not able to create output water that meets the drinking water standard for nitrates.

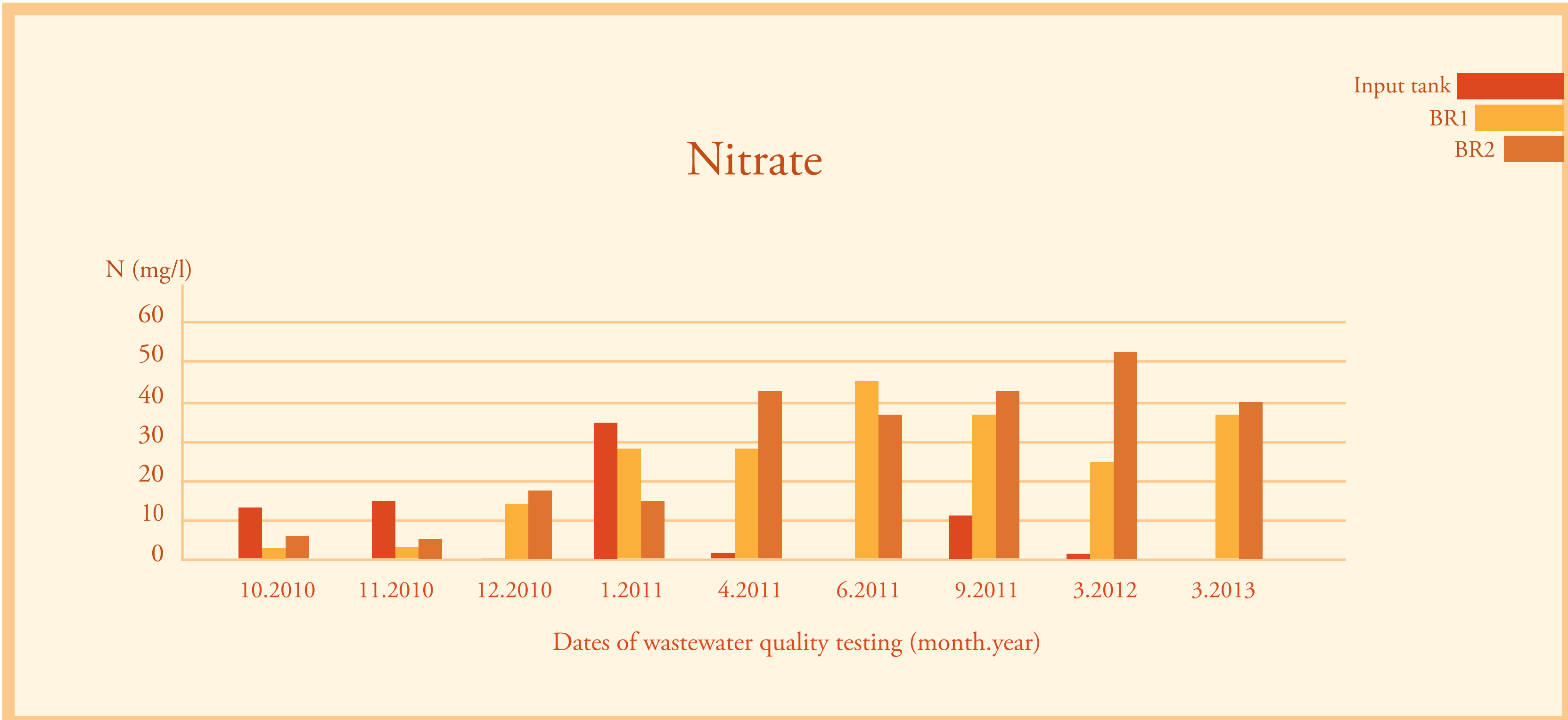


Figure 6: Nitrate values from 2010-2013 in input tank, BR1 and BR2

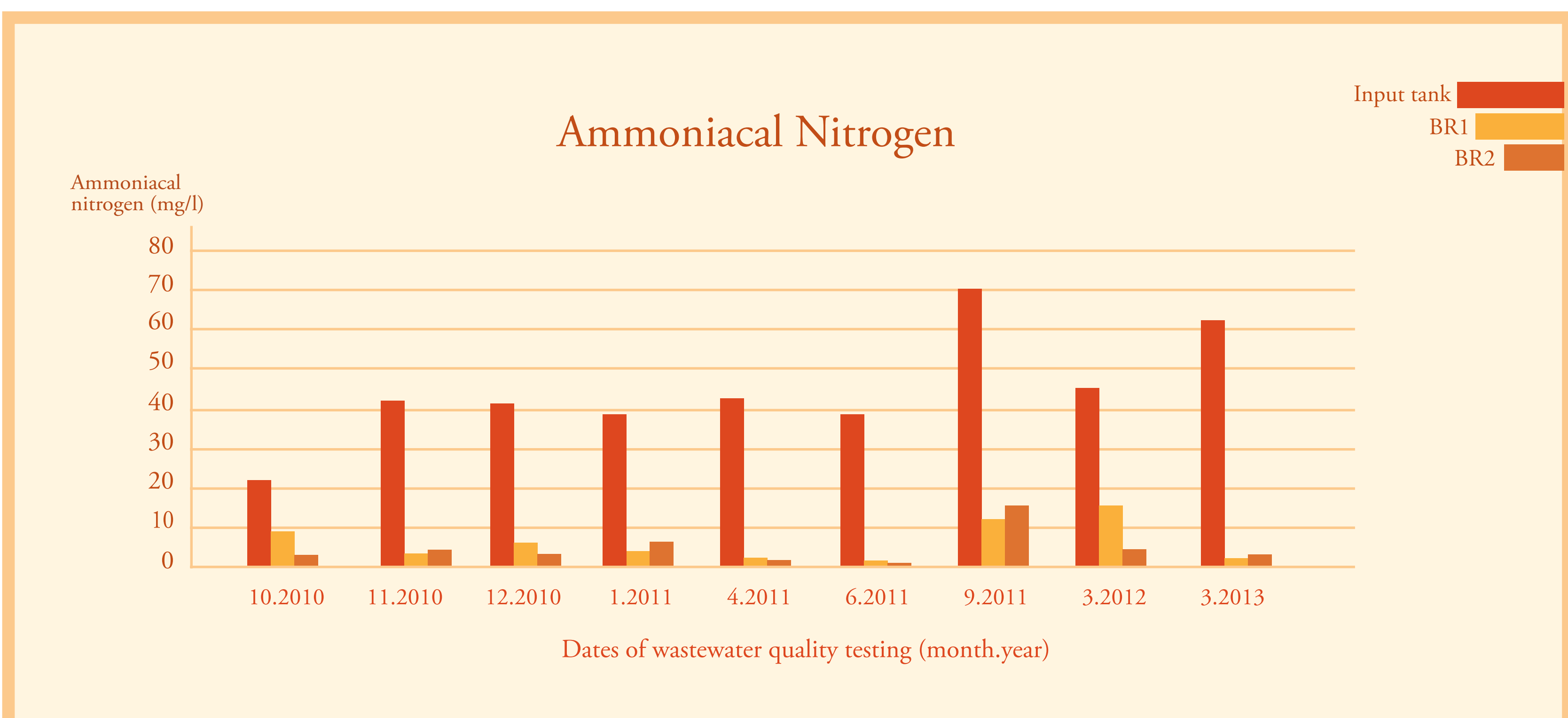


Figure 7: Ammoniacal nitrogen values from 2010-2013 in input tank, BR1 and BR2

Pathogens: Microbial pathogens in wastewater can be divided into three separate groups – viruses, bacteria and pathogenic protozoan/helminthes. Since the detection, isolation and identification of many of these is a difficult, time-consuming and hugely expensive task if undertaken on a regular basis, a class of bacteria called coliforms and a subclass known as faecal coliforms are used as an indicator.

The SBT plant did not have a defined standard for Faecal (FC) and Total Coliforms (TC) as the technology is not geared towards reducing bacterial contamination. However, test results show significant reductions in TC and FC values.

Moreover, differences are observed between BR1 and BR2 with the latter achieving the lowest FC values (Figures 8 & 9).

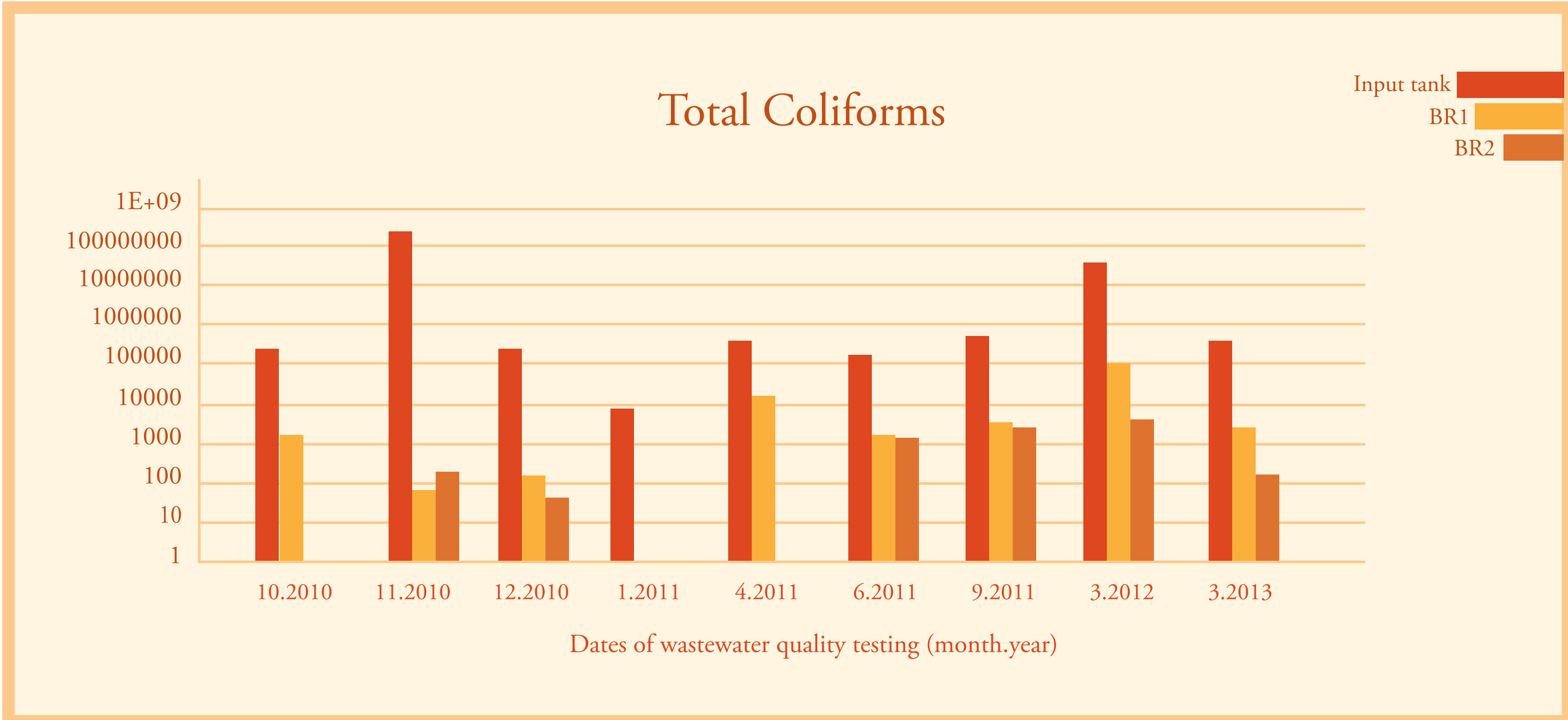


Figure 8: Total coliform values from 2010-2013 in input tank, BR1 and BR2

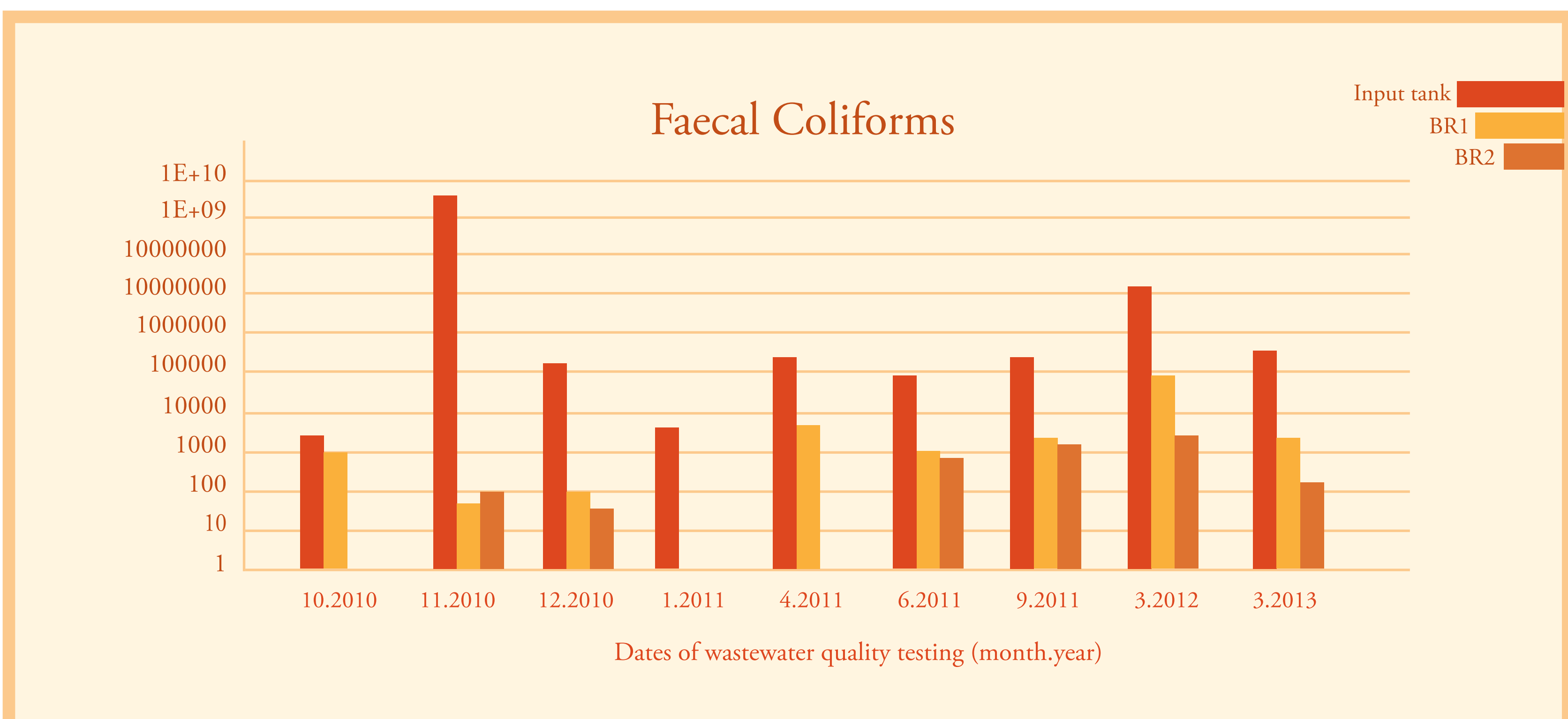


Figure 9: Faecal coliform values from 2010-2013 in input tank, BR1 and BR2

4.3 Borewell water quality

The borewell water quality was measured on 8th October 2010 from one of the borewells on campus before the wastewater treatment could have any significant effect on the groundwater and once again on 16th June 2011. The differences in amounts of various parameters were small and not enough to arrive at any conclusions regarding the effect of the wastewater treatment plant on the borewell water quality. Of particular mention was the nitrate level which increased from 0.23 mg/L to 1.6 mg/L and TC which went up from 24 MPN/100ml to 161 MPN/100ml. Further tests over a period of time are needed to gauge if the plant is having a tangible effect on the quality of the borewell water.

4.4 Limitations

When carrying out water quality testing, substantial variation was noted in the results obtained from different testing labs. This was resolved by working with the lab we evaluated as being of best quality and reliability. As a general observation, this lack of consistency between labs is a matter of some concern.

5. Cost-benefit Analysis

5.1 Factors

Capital cost and land requirement: Land requirement for the 15 KLD ACCEPT plant was 120 square meters. Cost of construction for the plant was about Rs 19 lakhs (2010). This includes the cost of piping and electrical equipment to bring water in and out of the plant but it does not include the cost of retrofits that were done to some of the equipment on campus or the cost of the 1 KLD test plant. This is because these two components were specific to this particular project. The plant was installed as an experiment and the retrofitting was completed in order to adapt the plant to already existing infrastructure.

Annual power cost: As discussed earlier, the daily water and power consumption were monitored over an extended period of time and the power requirement was found to be 1.06 unit/KL. Taking the 2010 cost of one unit electricity as Rs 7, the per day cost for treating 15 KL was calculated as Rs 111, which meant an annual power cost of Rs 40,624.

Other operation and maintenance cost: The manpower required to handle the system is 3 hours per day. Taking the cost of an unskilled worker to be Rs 4,000 per month, per day cost for manpower comes to approx Rs 50 per day. The annual cost would then be Rs 18,250.

Total annual O&M cost: Taking into consideration the above, the total O&M cost is Rs 58,874.

Total cost of wastewater treatment over the plant life: If the plant runs to full capacity the cost of recycling 1KL comes to Rs 24.54 (Figure 10).

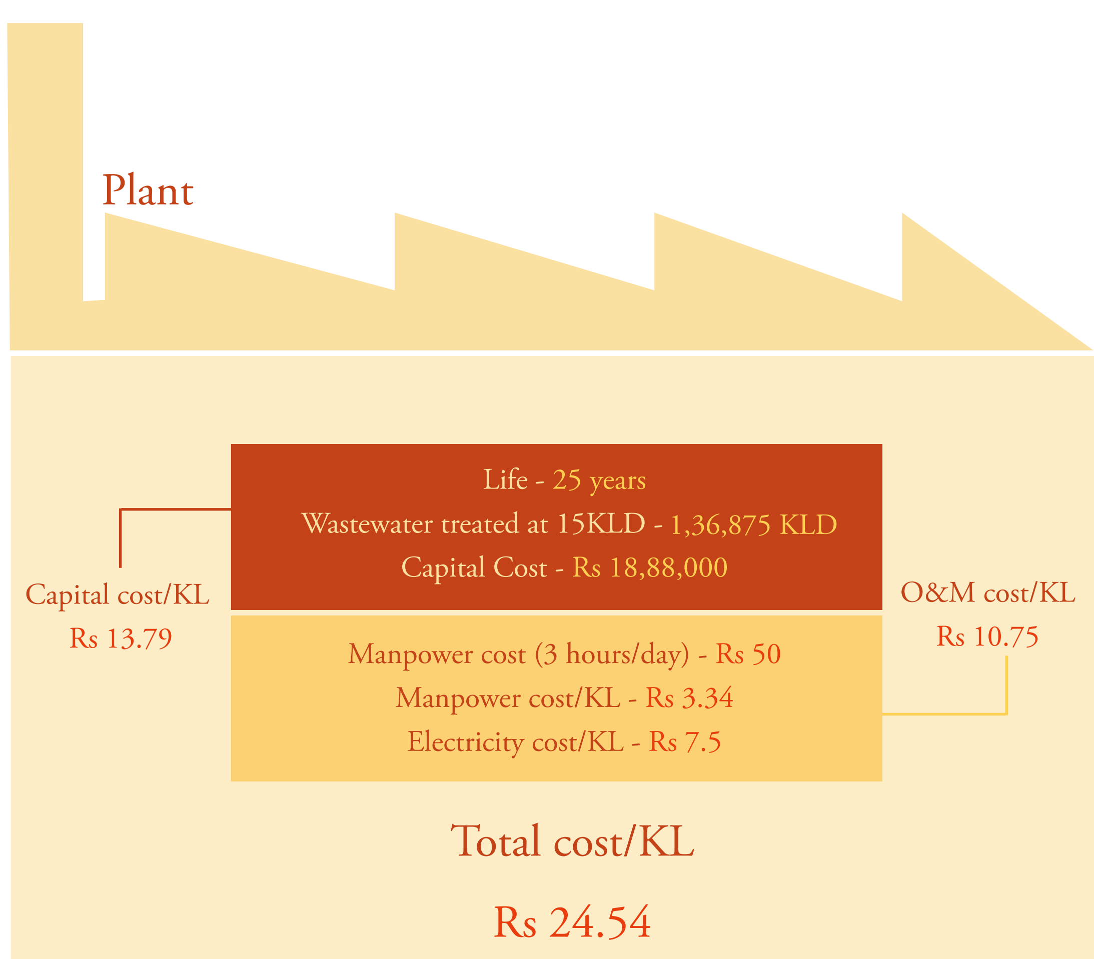


Figure 10: Wastewater treatment cost per KL

Return on investment: Looking at the O&M cost alone, if the cost of buying water is Rs 50/KL (which is the case for the ACCEPT campus), a saving of Rs 39/KL is possible by treating wastewater and reusing it rather than buying it from outside. This can be used to calculate the time taken for the plant to pay for its capital cost: 9 years.

Currently the SBT plant at ACCEPT is running at only 6 KLD. If we assume that this rate continues, the calculation for the payback time yields 22 years.

5.2 Other benefits of SBT

The SBT plant plays a significant role in the conservation of freshwater since it encourages reuse through the treatment of wastewater. Moreover, since the output wastewater quality is improved, the operation of a SBT plant reduces groundwater pollution.

More specifically:

a) There is no sludge generation and thus no requirement to dispose of any sludge. According to technology providers, the residue on the surface of the bioreactors can be directly used as biofertilizer.

b) SBT has very little odour problems.

c) It is aesthetically appealing and adds to the landscape rather than consuming land to build up a STP.

6. Discussion and Conclusion

The installation of SBT at ACCEPT Society has largely served its purpose, enabling Arghyam to understand SBT better and verify the technology claims. Barring a few problems mentioned in this report, the installation has worked as claimed by the technology providers and does a good job of wastewater treatment.

6.1 Comparison of SBT with other treatment technologies

Comparing wastewater treatment technologies is not a simple task. There are competing wastewater treatment paradigms between the large centralised treatment systems and smaller decentralised plants. These models come from different philosophies of urban management and thus direct comparison in order to make a particular wastewater treatment technology decision may not be appropriate.

Our understanding is that a basket of solutions can provide cities/towns with the necessary information to choose technologies from. In this basket the decentralised, low-tech, 'green' solutions like SBT play an important role.

The following factors are normally of interest when comparing wastewater treatment technologies:

- Capital cost
- O&M cost
- Land footprint
- Power requirement
- Quality of treated water

When considering the above factors in the Indian context, a lack of electrical power, trained manpower and spares are significant problems. Many STPs have become dysfunctional or are functioning sub-optimally due to these problems, thereby reducing or nullifying their expected cost-effectiveness. Hence it may be appropriate to pick a solution that is not the lowest cost if the risk from limiting factors such as availability of power and skilled O&M, spare parts, etc. is high. These points support SBT despite it not doing so well against parameters like cost or land requirement.

SBT scores very high in having minimal power requirement. Power is needed only to pump water in and out of the plant. This requirement can be reduced further if the flow can be transported by gravity. Further, the plant does not require uninterrupted operation and is meant to be run for a few hours a day. Thus SBT is a strong candidate where uninterrupted power supply is problematic or not possible.

Additionally, when compared to technology-based approaches, SBT scores significantly higher for O&M expenditure. In smaller towns this factor could make SBT a better choice over less expensive options.

Comparisons were made between SBT and other major mainstream and alternative technologies (ASP, MBR, UASB+EAS, TF, DEWATS) at two scales, 15 KLD (summarised in Figure 11) and 1 MLD (Annexure 3).

Total Cost of Ownership (TCO) for 15KLD plant, with a lifetime of 25 years and land cost of Rs 2,200/m^2 (Rs lakh)

Figure 11: TCO comparison for various wastewater treatment technologies

SBT, DEWATS and UASB + EAS are comparatively good options when considering this particular analysis. The final decision between these three could be made on the basis of cost and any of the limiting factors mentioned above.

6.2 Comparing DEWATS and SBT

Since DEWATS is one of the prominent decentralised technologies in the market it is worthwhile to compare it with SBT. When considering the above factors, DEWATS in general scores better than SBT in capital cost. For other parameters such as land requirement, O&M and power requirement, DEWATS is mostly at par with SBT.

SBT holds a significant advantage when considering the quality of treated wastewater. Based on the results of the installation of this SBT, it is capable of showing quite high levels of BOD/COD reduction, as well as nitrate and phosphate reduction. Therefore SBT may have a stronger case when a facility wants to reuse the water and has very definite and stringent output water quality requirements.

6.3 SBT in particular contexts

Below we consider some of the specific situations:

Apartment complexes and gated communities: In places like Bangalore it has become a requirement for large apartment complexes, gated communities and similar campuses to treat their wastewater to some level before discharging into a sewer or to the environment. Where finance and space are serious constraints as is often the case with these installations, none of the available technologies really work well, as reflected in an epidemic of malfunctioning wastewater treatment plants in apartment complexes.

The lack of interest and knowledge from home buyers in the STP means that real estate developers do not do a good job on the STP. They are sometimes installed underground to save on space which causes operational problems in aeration. We conclude that in apartment complexes where land is not too much of a constraint, SBT will be a good competitor due to its low O&M cost, competitive Total Cost of Ownership and non-requirement of skilled manpower.

Moreover, the fact that the SBT plant simulates a garden-like environment means that the land requirement is somewhat 'softened' since the land use can be integrated into landscaping.

Since the plant is open air, concerns regarding smell are often brought up. In practice however, we observed that the plant created very minimal smell.

Large cities: Large cities in India are in the process of increasing their wastewater treatment capacity significantly and this trend will continue. In existing large cities, space could be a constraint that pushes the decision towards solutions that have a smaller space requirement. Currently, the SBT providers are working on models where SBT can be installed in multistoried buildings so that space requirement is not such a constraint.

Smaller towns: The lower land cost in smaller towns, and non-availability of skilled manpower and continuous electrical power make SBT a competitive option. To manage the larger initial capital requirements, SBT can be considered in a decentralised, phased installation approach.

Institutions in peri-urban areas: Here land and capital costs are typically not a constraint, thus making SBT a very competitive solution.

Rural wastewater treatment: None of the technologies mentioned above including SBT seem to be appropriate in a rural context due to various reasons (power, manpower, cost, low volume of wastewater generated). There is no significant move away yet from pit toilets in rural areas, and perhaps these along with septic tanks continue to be acceptable in most situations. Grey water management is unsatisfactory in most rural areas and constitutes a potential health hazard, reducing the quality of life. Soak pits are a simple and low cost option for many cases, and other solutions also need to be developed and mainstreamed.

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Annexure 1

Wastewater quality treatment samples

	October 2010			November 2010			December 2010		
	Input	BR1	BR2	Input	BR1	BR2	Input	BR1	BR2
pH	7.52	7.57	10.88	7.55	7.85	7.62	7.78	7.35	7.8
BOD	74	18.6	14.9	150	9.6	9.3	138	9.4	3.3
TSS	42	16	262.0	150	8	10	40	6	4
Ammoniacal N	21.8	8.7	2	42.2	2.8	3.5	41.3	5.8	2.3
COD	161.9	42.4	26.9	404.8	24.3	24.3	267.1	39.3	15.7
TDS	560	504	346	730	548	580	664.0	610	604
TC	220000	2400	<1	161000000	92	161	240000	161	54
FC	2400	1100	<1	5400000000	54	92	170000	92	43
Turbidity	34.6	28.2	74	124	3.7	3.8	45	4.2	1.8
Phosphate as P	7.3	3.2	0.58	1.05	1.1	0.64	6.7	1.4	1.4
Nitrate as N	11.8	2.4	5.3	12.6	2.3	3.9	0.15	12.8	16.7
Oil and Grease	40	<1	<1	82	<1	<1	<1	<1	<1
TKN	32.9	13.1	3	106.3	4.2	5.6	60.7	9	3.9
Hardness ($CaCO_3$)				217.8	188.1	257.5	242.4	141.4	141.4
Sulphates	8.8	16	31.5	32.4	36.3	30.5	16.1	35.1	34.6
Iron (Fe)	0.59	0.35	0.32	0.15	0.12	0.18	0.5	0.24	0.09
Total chlorides	125.6	107.6	116.6	29.6	111	12	123.5	133	133
Fluoride	<0.02	<0.02	0.34	<0.02	<0.02	0.04	0.4	<0.02	<0.02

	January 2011			April 2011			June 2011		
	Input	BR1	BR2	Input	BR1	BR2	Input	BR1	BR2
pH	7.54	7.44	7·57	7.37	7.12	7.33	7.12	7.05	7.02
BOD	140	5.1	9	60	1.5	3	135	3	1.8
TSS	32	4	8	200	12	6	18	4	2
Ammoniacal N	39.3	2.7	4.1	41.9	1.3	1	39.3	0.9	0.6
COD	414.4	37.3	49.7	240	24	20	277.1	16	13.7
TDS	616	540	546	686	748	860	640	756	708
TC	9200	<1	<1	380000	16100		140000	1800	1300
FC	5400	<1	<1	170000	5400		80000	1100	800
Turbidity	90	2.7	5.4	135	2.6	1.8	175	2	1.5
Phosphate as P	0.5	0.44	1.48	3.6	0.77		10.5	1.7	1.3
Nitrate as N	34.3	27.8	15.8	1.3	27.2	41.9	0.3	45.8	37.1
Oil and Grease	8	<1	<1	<1	<1	<1	18	<1	<1
TKN	47.3	4.1	6.5	60.3	2.9	2.3	58.8	1.5	<1
Hardness ($CaCO_3$)	240	220.8	240	261.0	223.1	252.2	209	209	218.5
Sulphates	37.5	28.9	27.7				17.1	20.3	18.8
Iron (Fe)	0.3	0.26	0.27				0.38	0.08	0.07
Total chlorides	114.4	114.4	114.4				137.2	128	137.2
Fluoride	0.8	0.2	0.15				0.15	0.04	0.11

	September 2011			March 2012			March 2013		
	Input	BR1	BR2	Input	BR1	BR2	Input	BR1	BR2
pH	7.37	7.24	7.27	7.35	7.41	7.19	7.11	6.87	6.91
BOD	54	9.7	8.3	19	36	15.6	132	6.3	9
TSS	100	16	10	34	22	12	152	6	8
Ammoniacal N	69.9	12	14.1	46.1	17.5	4.5	61	1.8	2
COD	248.3	41.2	33	277.7	75.7	40	286.8	17.6	21.6
TDS	824	806	626	610	744	804	702	944	970
TC	540000	3500	2400	24000000	110000	5400	540000	2400	161
FC	240000	2400	2200	13000000	80000	3500	350000	1800	161
Turbidity	58	10.8	3.9	55.5	24.4	10.2			
Phosphate as P	18.3	6.4	5.6	19.3	6.5	3.4	9	0.08	0.1
Nitrate as N	10.6	37.4	42	1	25.3	51.3	0.13	37.8	40.3
Oil and Grease	20	<1	<1	24	<1	<1	34	<1	<1
TKN	106.5	18	21.5	49	26	6.5	65.5	2.8	3.3
Hardness ($CaCO_3$)	171.7	212.1	191.9	262.6	282.8	292.9	313	343.4	323.2
Sulphates	16	14.6	10.8	58.5	29.9	142.1	29.2	46.8	48.4
Iron (Fe)	1.8	0.57	0.65	7.9	5	3.1	2.4	0.7	0.51
Total chlorides	110.2	101.0	101.0	149.7	159.1	177.8	153.1	181.9	181.9
Fluoride	0.21	<0.02	<0.02	1.3	1.2	0.55	0.08	0.13	0.02

Annexure 2

Pump operation schedule

Operation Timings				
Pump	From	To	Duration	Switch Off
Discharge Pump	08.30 AM	09.45 AM	75 Minutes	09.45 AM
Sewage Pump	10.00 AM	11.00 AM	60 Minutes	11.00 AM
Recycling Pump	10.00 AM	12.30 PM	150 Minutes	12.30 PM
Discharge Pump	01.30 PM	03.00 PM	120 Minutes	03.00 PM
Sewage Pump	03.00 PM	04.00 PM	60 Minutes	04.00 PM
Recycling Pump	03.00 PM	05.30 PM	150 Minutes	05.30 PM

Annexure 3

Comparison of treatment technologies

Treatment technology	Size	Land Req in sqm	Land Cost in Lakh Rs	Capital cost in Lakh Rs	Annual power cost in Lakh Rs	Total O&M cost in Lakh Rs	Total Cost for 25 years including land	Output quality (BOD, COD, TSS, FC-log unit)
ASP	15KLD	27.3	0.6006	9.01	0.063	2.6394	75.5956	
	1MLD	1820	40.04	34	4.2	9.96	323.04	85-95%, 80-90%, 85-90%, upto 3<4
TF	15KLD	24.3	0.5346	7.95	0.0534	1.96895	57.70835	
	1MLD	1620	35.64	30	3.56	7.43	251.39	80-90%, 85-90%, 75-85%, upto 2<3
MBR	15KLD	12	0.264	22.525	0.08415	5.18075	152.30775	
	1MLD	800	17.6	85	5.61	19.55	591.35	95-98, 95-100, 98-100, upto 6<7
UASB+EAS	15KLD	21.75	0.4785	9.01	0.02265	0.9487	33.206	
	1MLD	1450	31.9	34	1.51	3.58	155.4	80-95, 80-90, 85-90, upto 2<4
DEWATS	15KLD	52.5	1.155	10.5	0.05	0.5	24.155	
	1MLD	3500	77	180	1		257	70-90,xx
SBT	15KLD	120	2.64	18	0.05	0.5	33.14	
	1MLD	4675	102.85	172	1	8.95	498.6	90-97, 92-97, 85-97, upto 5

Compiled from:

'UASB Technology for Sewage Treatment in India: Experience, economic evaluation and its potential in other developing countries', communications with personnel of the Coalition for Dewats Dissemination Society, www.cddindia.org and Mr M. N.Thippeswamy, Retd. Chief Engineer, Bangalore Water Supply and Sewerage Board.

Photographs

Figure 12: Construction progress, laying the concrete floor and linking the walls with riprap for BR1

Figure 13: Construction progress, bioreactor walls lined, and media being filled into BR1

Figure 14: Septic tank extension compartments

Figure 15: Septic tanks

Figure 16: Bioreactor 1 (BR1) in the foreground with Bioreactor 2 (BR2) and treated water tank in the background

Figure 17: Bioreactor 2 (BR2)

Figure 18: Output water tank

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