Treatment technologies in practice

On-the-ground experiences of faecal sludge and wastewater treatment

SNV

UTS Institute for Sustainable Futures

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This compilation of case studies was produced as part of SNV's Urban Sanitation and Hygiene for Health and Development (USHHD) programme, which is currently implemented across 20 cities in the world. It documents real-life faecal sludge and wastewater treatment practices narrated by plant owners, operators, and SNV staff in Bangladesh, Indonesia, Kenya, and Zambia. Accounts from Malaysia, India, South Africa, and Benin are also shared.

Each case study was reviewed by Antoinette Kome and Rajeev Munankami (SNV). Contributors from countries are acknowledged at the back of each case study. This publication was edited and managed by Anjani Abella (SNV). It was designed by ThompsonStenning Creative Group.

For more information on SNV's USHHD approach:
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Kushtia municipality-owned and operated vacutug (Photo: SNV)

Foreword

Urban sanitation is one of the biggest challenges of the Sustainable Development Goals (SDGs). With more than half the world's population now living in urban areas, coverage is barely keeping up with population growth. With the growing realisation that only a minor part of that coverage is safely managed, an environmental health emergency is staring us in the face. The effects of climate change will make this challenge even bigger.

This means that making the 'right' decisions on urban sanitation investments is becoming more important than ever. Clearly, our infrastructure needs to be designed for a broader range of extreme events. But in parallel, we need to recognise that the adaptive capacity of our management structures and government systems will be stretched.

For a long time, sewers were seen as the main, often only, option to address the management of human waste (faeces and urine) in urban settings. Yet, construction of sewers and related treatment is highly capital intensive. So, in the absence of the requisite funding, many cities simply continued with the status quo of unregulated, informal emptying and unsafe disposal. Recently, interest in non-sewered and low-cost sewer solutions has increased. There is a growing recognition that, in most settings, citywide sanitation services will need to involve a mix of sewered, decentralised, and non-sewered options. Developing and integrating these operationally, financially, and in technically appropriate ways is a priority in these contexts.

SNV has been working in urban sanitation for almost 10 years; striving to develop an approach that addresses the whole sanitation value chain, all people, and all areas of a city in an integrated, sustainable way.[1] ISF-UTS has been our knowledge partner and together, we have been developing a range of knowledge outputs,[2] spanning topics from sanitation planning and financing, to enforcement and slums, and others. We have also been organising a range of learning events.[3] However, we felt that there was a gap around treatment of wastewater and faecal sludge. This was not so much in terms of technical guidance on treatment options, but rather information on the day-to-day reality and perspectives of people involved. Factors which we believe could help local governments and/or utilities reflect on the different options available.

Discussions on urban sanitation investments are very treatment plant centred. Funding and construction of treatment plants is often perceived as the intervention that will solve the urban sanitation problem in a city; too little thought is given to getting all waste to the treatment plant (whether for wastewater, or for faecal sludge). Where treatment plants do get built however, functionality rates are low – this is particularly the case with faecal sludge treatment plants. I have seen more non-functional and abandoned faecal sludge treatment plants than operational ones.

In seeking out cases for this book, we wanted to include some of the success stories on faecal sludge re-use that we saw presented at multiple international conferences. We asked our country teams to drive to the sites and were saddened to find that some of these projects had completely disappeared.

This makes me wonder whether we are at risk of creating parallel realities in our sector – one reality with fabulous success stories about innovation and circular economy, being financially viable, and environmentally and socially sustainable; the other reality being the one in which most of the urban sanitation infrastructure is struggling. Isn't it time for us to take stock and ground all these expectations in order to come up with a more realistic narrative around treatment and re-use?

While a narrow focus on 'treatment only,' re-use and disposal rarely results in sustainable solutions, this is no doubt an important part of the urban sanitation puzzle. We need to understand better how decisions were made around the building of all these plants, and why there are so many problems today.

There are tools and compendiums describing different technology options, but when speaking to municipalities or utilities, decision-making on their infrastructure has not always been made as an 'informed choice'. Rather, decisions were based on recommendations by a consultant or designs pre-defined by a multi-lateral development bank or NGO; replicated from a neighbouring city or built because it fit within one municipal budgeting cycle. While municipalities and utilities were happy to secure investment for their treatment plants, they were less aware of what it would entail to keep these plants operational. Yet, these are the very same people who are expected to operate and maintain that infrastructure for 20 years or longer, and with the expectation of seeing the benefits this would bring to their cities or towns. They are also the very same people expected to bear the burden of repaying any loans via which the infrastructure may have been funded.

SNV's mission is to contribute to a society in which all people have the freedom to pursue their own sustainable development. That means that we do not promote one specific technology

[1] SNV, "Urban Sanitation and Hygiene for Health and Development (USHHD)", *Capability statement*, The Hague, SNV, 2020, https://snv.org/cms/sites/default/files/explore/download/ushhd-capability-statement_0.pdf, [accessed 3 May 2021].
[2] View some of SNV and ISF-UTS' collaborative learning papers and briefs here, https://interactive.snv.org/snv-urban-sanitation-publications#196515 and https://interactive.snv.org/snv-urban-sanitation-publications#195070.
[3] Documentation on SNV-organised USHHD learning events available for download here, https://interactive.snv.org/snv-urban-sanitation-publications#257720.

over another, but rather facilitate a process of 'informed choice' that explores several relevant technologies. As a rule of thumb, this means that more than one technology option should be explored. Presenting only one option leaves city authorities with no comparison and no alternative(s) to choose from.

While comparing options has the benefit of deepening people's understanding, it should of course also be done (a) in consideration of the service delivery system for the entire city (or region if it concerns a regional utility), and (b) while incorporating relevant data and possible scenarios over time. These are complex considerations which, in the absence of any additional efforts, risk becoming technical discussions among a restricted group. Thus, informed choice is also about translating data into accessible information, so that stakeholders can participate meaningfully in both discussions and decision-making.

Facilitating informed choice for decision-making by an individual is complex enough. However, facilitating informed choice by a local authority intersects with their duties of realising rights, good governance and accountability. They are not making these informed decisions for themselves, but for the population of their city; those who will benefit from the service; those who pay the taxes that repay the loan; and those who live in the surroundings of the treatment plant and may be affected by it. This is an added complexity. Moreover, city authorities are responsible, directly or indirectly, for the working conditions of sanitation workers at the plant. Hence, in addition to understanding the treatment options, informed choice in this context means understanding and weighing up the implications of treatment options for different stakeholder groups within their cities.

Unfortunately, the understanding and also the interest of city authorities and other stakeholders in treatment technologies is generally limited. The information is considered too technical and the stories presented either too theoretical or miraculous in their success.

The day-to-day reality in both faecal sludge and wastewater treatment plants is less clean and rosy. The learning curve is often much steeper and creating the enabling conditions requires a lot of hard work. What we need are real-life stories that help stakeholders to reflect on these aspects. Only then will the much-needed innovation in the urban sanitation sector become a reality. In this book, we present a collection of these day-to-day stories. I hope you will read it, share it, use it, and that you will commit to ensuring more informed choices about treatment and re-use. If you only take away one message, remember that functional treatment is hard work and that there is no magic bullet.

Antoinette Kome

SNV Global Sector Head, WASH

Introduction

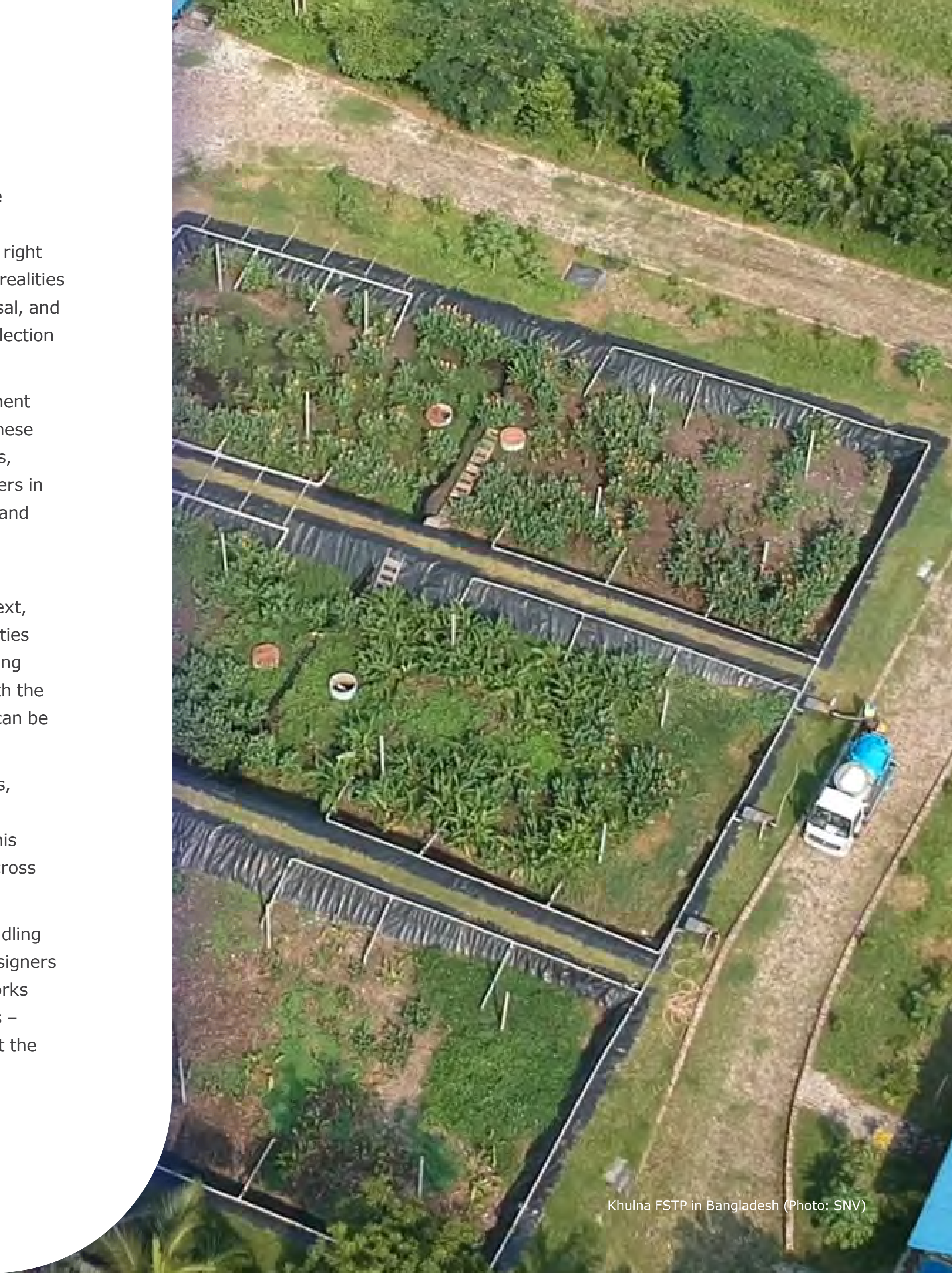
The operation of faecal sludge and wastewater treatment plants rarely plays out as they are described in a manual or textbook. Yet little has been documented on the real-life practical challenges involved. This gap limits the ability of planners and decision-makers to make the right investment choices. This compilation of case studies makes accessible the experiences and realities faced by people involved in the operation of faecal sludge and wastewater treatment, disposal, and reuse facilities, and the decisions that they had to make. Such knowledge can inform the selection of treatment technologies that are appropriate for expected contextual realities.

The compilation presents nine case studies of selected faecal sludge and wastewater treatment technologies, and disposal and reuse options from eight countries across Africa and Asia. These include: conventional sludge drying beds, mechanical screw presses, rotating bio-contactors, and Anaerobic Baffled Reactors (ABR) in Indonesia; constructed wetlands and coco peat filters in Bangladesh; Black Soldier Flies (BSF) and briquettes in Kenya; biogas digesters in Zambia; and deep row entrenchments in India, Malaysia, South Africa, and Benin.

The compilation is intended to be illustrative and is not comprehensive across all available technologies. Each case study outlines a system, its treatment purpose, its regulatory context, and the process that led to its selection. In addition, the realities, challenges, and opportunities of operating and maintaining each technology are described. The studies complement existing technical, process-oriented documents by providing accounts of field-based experiences with the treatment technologies. It is not a manual for informed choice; rather, it is a resource that can be drawn upon during informed choice processes.

The target audience for this document are faecal sludge and wastewater treatment planners, decision-makers, and practitioners. This can include those working in government, non-governmental organisations (NGOs), research and learning institutions, or private sector. This compilation can be used at a broad level to get a sense of the different options described across the various technologies, or at a detailed level, to examine specific technologies.

The deliberate selection of case studies presents a mix of faecal sludge and wastewater handling technologies implemented at full scale over an extended time period. The operators and designers of each technology interviewed for this research were identified and accessed via the networks of the SNV Netherlands Development Organisation and the Institute for Sustainable Futures – University of Technology Sydney (ISF-UTS). The following sections of this document present the nine case studies in detail.



Khulna FSTP in Bangladesh (Photo: SNV)

Key insights emerging from the case studies

From these nine case studies, a number of key issues and considerations emerged that planners, decision-makers, and practitioners may consider when designing or operating faecal sludge and wastewater treatment technologies outlined in this document. These are presented below.

Matching intended capacity with demand realities is challenging. Designing treatment capacity to match unfolding demand for faecal sludge emptying and wastewater treatment can be a challenge. Several faecal sludge treatment plants were found to be operating below capacity. Low demand for regular desludging, or for connection to piped wastewater networks, were the primary reasons for this underutilisation. In all cases, to increase demand, promotion and communications campaigns were undertaken to inform households of the benefits of regular desludging or of joining piped networks. It is important to note that it takes time to develop demand as well as emptying service capacity. Until faecal sludge treatment plants are fully operational, safe disposal options are still needed. Options such as deep row entrenchment can offer interim solutions to the problem of faecal sludge disposal. In some cases, deep row entrenchment can provide a longer-term strategy, and in one case sludge was reused for agroforestry.

Sludge characteristics and variability of waste input are key but often omitted considerations. Sludge characteristics are important considerations when choosing a technology, and when making operational decisions; for instance, in the face of variable sludge quality. However, sludge characteristics are often poorly documented, or no analysis is done. This results in a lack of local data to make informed decisions. When sludge from septic tanks contains rough sand or trash, and/or when grease is thrown into latrines, sludge can block and damage screening equipment and delay the treatment process. Foreign objects mixed in the sludge can be an occupational health and safety issue for staff. For example, sharp metal items can injure workers when they are manually sorting organic matter. Strengthened early consideration of input characteristics would facilitate better choices and proactive mitigation efforts during operation.

Nearby communities need to be consulted on local impacts. Gaining community support for a treatment plant can be crucial for its long-term sustainability. Where possible, communities should be consulted and their concerns considered and addressed during the planning and design stages. Community concerns may include odour, leakage into groundwater wells, or disruptions to local traffic during the construction stage. Lack of community buy-in can threaten a plant's operation, as community members may refuse to use the service, leading to underutilisation and financial shortfalls.

Understanding all the input costs is critical to develop sound financial arrangements for reuse. Reuse options (e.g., briquettes, co-compost/fertilisers, and insect-based animal feed) are increasingly being trialled and used to ensure safe disposal in the last step of the chain *and* to recycle resources and generate income. However, the cost-effectiveness of these options is not always initially clear. High input and operational costs (such as energy) may in some cases mean that a scheme is not financially viable, or it may need external support.

Potential contamination of the surrounding environment may require mitigation measures. During site selection it is important to be aware of the risk of contaminating the surrounding land and groundwater resources. Strict controls are needed to ensure that treated effluent is responsibly managed to avoid local and downstream impacts. This was particularly noted for deep row entrenchments where it is not possible to use trenches in areas that experience flooding or inundation, or that have sandy soil. The risk of contamination should be considered for all types of treatment systems.

Power security and continuity can affect successful operation. Back-up or alternative sources to mains electricity may be needed to ensure continuity of operation, or alternative options that do not require power might be needed. Power outages and lack of back-up generators can interrupt faecal sludge *and* wastewater mechanical treatment. Technologies that rely on solar power may be unreliable due to their dependence on sunny weather.

Weather conditions should be factored in to selection choices and design. The chosen treatment technology should match local weather conditions. Rainy weather, for example, can affect the rate of drying in sludge drying beds and the drying of briquettes. This is particularly important in the context of climate change and potential increases in dry spells or extreme rainfall events in many locations.

The need for highly technical knowledge and a lack of locally available spare parts may make certain technologies undesirable. A lack of the technical skills needed to maintain some technologies, and an inability to obtain spare parts locally, can lead to stoppages, or they can mean that some technologies are out of operation for long periods. Appropriate recruitment and training are therefore important.

Overarching considerations

This case study compilation can help planners, practitioners, and decision-makers to improve contextualised choices of treatment technologies and address local operational challenges. They can consider the technologies presented in this compilation, or they can apply the informed choice considerations outlined here to evaluate other technologies beyond those presented here.

When selecting the most appropriate treatment options, technologies should be considered in short, medium, and long time frames. This includes how best to match the generation or input of waste with appropriate investment in viable treatment technologies. The quantity of waste will depend on community demand, desludging practices, and wastewater infrastructure. The viability of treatment technologies will depend on the availability of human resources and the context in which the technologies will be operating, as well as wider factors including climate, power supply, and environmental considerations.

Finally, it is important to reflect on how technologies work in practice in specific country contexts. Theoretical textbook instructions may seem straightforward, but this impression can be misleading. This case study compilation provides insight to the realities and challenges of operating and maintaining technologies on a daily basis, which can serve as a starting point for increased documentation and sharing of such knowledge across different countries and contexts.

Round-shaped carbonised briquettes in drying beds (Photo: SNV)

CASE STUDY 1

Mechanised and conventional faecal sludge treatment

Duri Kosambi, Indonesia

Background

Treatment selection and purpose

The Duri Kosambi Faecal Sludge Treatment Plant (FSTP) is one of two FSTPs operating in Jakarta. The other plant is the Pulo Gebang FSTP. Both are managed by PD PAL Jaya, a city-owned sewage management company.

The Duri Kosambi FSTP consists of a conventional system (non-mechanised) built in 1983, and a mechanised system built in 2013. The plant treats faecal sludge from septic tanks. The main criteria for the selection and design of the FSTP were cost and land availability. When the conventional system was built, the technology was chosen because of its lower operating costs. When the plant needed expansion, land availability was limited, and so a mechanical system which needed less space was chosen. PD PAL's former Director explained that the municipality paid for the construction of the treatment plant, but PD PAL has had to make additional investments since it took over management and operation in 2016 (i.e., faecal sludge trucks, vacuum trucks, computers and related systems, pump, screen, etc.). PD PAL self-finances all operation and maintenance (O&M) costs.

> *The main reason for selecting the technology is the operating cost. The conventional system has the cheapest operating cost - so we built one in 1983. By 2013 we needed to increase the treatment capacity. Because conventional systems require a large area, we decided to use the mechanical system as an alternative to cope with the low land area availability.*
>
> **FORMER PD PAL JAYA DIRECTOR**

Mechanical sludge screening from vacuum trucks

Description of the system

A flow diagram of the treatment plant is shown in Figure 1. Trucks transport septage from septic tanks to the treatment plant. There are two sludge receiving areas – one for the conventional system and one for the mechanical system.

Table 1 shows Duri Kosambi FSTP's design and operational capacity. PD PAL spends approximately 50% of its operational costs on labour, with other major costs including electricity and chemicals for the treatment system. The remaining costs are for water, meals, vitamins, health insurance, employment insurance, uniforms, and safety equipment.

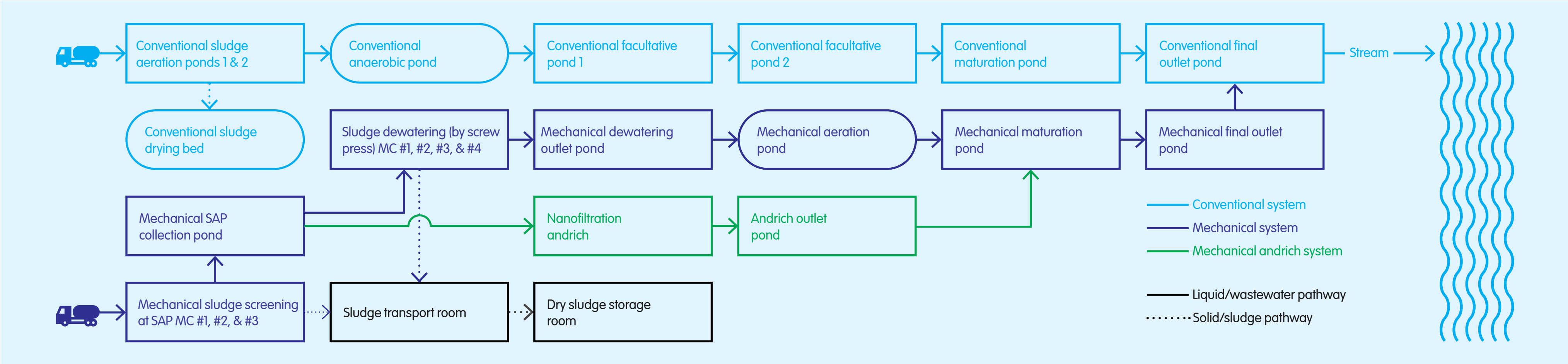
Table 1. Capacity and operating costs of Duri Kosambi FSTP

	Conventional system	Mechanical system
Design capacity	300 m^3 of sludge/day	600 m^3 of sludge/day
Operating capacity	140-200 m^3 of sludge/day	

Conventional maturation outlet

Mechanical sludge screening using Huber acceptance plant

Figure 1. Block flow diagram of Duri Kosambi FSTP[1]



[1] Block flow diagram drawn by SNV based on site visit interviews.

Regulatory environment and compliance

During the design and planning of the Duri Kosambi FSTP, the main regulatory and compliance standard followed for effluent quality was the Governor's Regulation (*Pergub*) No. 122/2005 of 2005. Since 2016, a more stringent effluent quality regulation has been applied in Indonesia.[2] The 2016 regulations introduced more stringent standards for Total Suspended Solids (TSS), Biochemical Oxygen Demand (BOD), and oil and grease. The Chemical Oxygen Demand (COD) requirement is now less stringent; potassium manganate ($KMnO_4$) and Methylene Blue active substance (MBAS) are no longer regulated but coliform bacteria monitoring has been introduced. The most recent laboratory results for the Duri Kosambi FSTP showed that in some respects, effluent quality did not meet the standards, and there were no reports on concentrations of coliform bacteria, oil and grease, despite being covered by the new regulations.

To comply with the new 2016 effluent standards, PD PAL installed an additional filter at the outlet pipe of the maturation pond before the water enters the final outlet pond. PD PAL installed the new filter to minimise TSS concentrations. PD PAL also installed a blower for additional aeration in the final outlet pond. While these actions have improved Duri Kosambi's effluent quality performance, additional improvements to the treatment process are still needed to comply with the standards.

Table 2. Influent and effluent qualities of wastewater treated at Duri Kosambi FSTP plant in 2019, as compared to effluent standards

Parameter	Inlet	Outlet	Standard (No. 68/2016)	Method
pH	6, 45-7, 88 pH	7, 12-7, 61 pH	6-9 pH	SNI 06-6989.11-2004
Total suspended solids, TSS	340-8933, 33 mg/L	22, 5-84, 29 mg/L	30 mg/L	SNI 06-6989.26-2005
Biochemical oxygen demand, BOD_5	106, 38-646, 82 mg/L	2, 76-69, 79 mg/L	30 mg/L	Respirometric, 2005
Chemical oxygen demand, COD	687, 9-2780, 37 mg/L	41, 25-127, 67 mg/L	100 mg/L	Spectrophotometric, 2002
Total organic matter, $KMnO_4$	108, 04-568, 72 mg/L	54, 21-150, 50 mg/L	85 mg/L	SNI 06-6989.22-2004
Ammonia, NH3-N	108, 75-239, 25 mg/L	0, 45-29, 81 mg/L	10 mg/L	Spectrophotometric
Methylene blue active surfactant, MBAS	0, 74-2, 69 mg/L	0, 13-0, 78 mg/L	2 mg/L	Spectrophotometric

Operation and maintenance: realities, challenges, and opportunities

Realities of running the treatment plant

Distribution of sludge at acceptance

The distribution of the incoming sludge into the two systems (conventional and mechanical) is determined by the number of trucks and the amount of sludge received. If, for example, five trucks arrive simultaneously, the sludge is distributed between the conventional and mechanical systems to facilitate a speedy acceptance process. If fewer trucks arrive on any given day, then all the sludge is directed towards the conventional system, as the operating costs of energy and chemical requirements are much lower than for the mechanical system.

The distribution of sludge also depends on maintenance and operation schedules. If the mechanical system is under maintenance, all sludge goes to the conventional system, and vice versa. Furthermore, sludge can only be discharged into the mechanical system in the morning as the trained machine operators required for this task are only present in the mornings, whereas the conventional system requires hardly any supervision.

[2] *Regulation of Ministry of Environment and Forestry of the Government of Indonesia* (2016) Permen LHK No. 68/2016

Staffing requirements

Sixty people work at the Duri Kosambi and Pulo Gebang FSTPs. There are eight permanent staff who manage both FSTPs and 26 non-permanent staff working at Duri Kosambi only. The 26 staff include 13 operators (two for the conventional system, four for the mechanical system, one for an Andrich pre-treatment system currently being trialled, and six recording inflows) and 13 workers responsible for security, administration, driving, and cleaning. Most operators have a high school or vocational school qualification. Since staff and operators do not work after hours, PD PAL relies on the security guard to prevent after-hours entry to the facility, handle emergency issues, and report any problems (such as power outages) or technological disruptions (such as the blower ceasing to function).

Staff at the facility have all received training on Occupational Health and Safety (OHS), asset management, and general operation of the treatment plant from the Ministry of Public Works. The operators received training in the operation of the treatment plant from a USAID-funded water and sanitation urban development programme, with some receiving additional administrative training as well. Operators are all equipped with safety uniforms, helmets, boots, and gloves, and are trained in using the safety equipment. However, no specific OHS Standard Operating Procedure (SOP) exists at the facility for the handling of untreated and treated effluent and sludge.

> *If there is any power failure here, the mechanical system will be disrupted since it requires electricity to function. We are fortunate that we also have the conventional system in Duri Kosambi STP which does not require electricity. However, when the blower dies in the aeration tank during an electricity outage it will interrupt the aeration process.*
>
> **HEAD OF IPLT DURI KOSAMBI**

Operating costs vs. revenue

At present, the Operation and Maintenance (O&M) costs for both the Duri Kosambi and Pulo Gebang FSTPs exceed the revenue produced by the two facilities. The revenue that PD PAL earns from private desludging companies discharging faecal sludge into their facilities is US$ 1.80/m^3 of sludge. For its PD PAL-managed desludging service, PD PAL charges households US$ 11/m^3, with an average charge of US$ 22 per household. To cover the current income gap, PD PAL uses funding from its other business units, namely a sewerage service in central Jakarta.

The income gap is primarily due to the facilities operating below capacity. At the Duri Kosambi FSTP, 140-200 m^3/day of sludge is currently being processed, while the facility's capacity is 900 m^3/day. The facility is not expected to reach 100% capacity until 2050.[3] The underutilisation is being addressed through promotion and communications campaigns to inform households of the benefits of regular desludging. This is challenging, as many households prefer septic tanks that seep effluent into the ground over those that require desludging, and awareness of any need to empty their tanks is generally low.

Electricity supply and continuous maintenance

A constant power supply and continuous maintenance are crucial for ensuring that both the mechanical and conventional treatment systems function properly. A generator has been installed as a back-up for potential power failures. However, according to the former PD PAL Director, the generator is hardly required as power outages rarely occur in Jakarta. Power is quick to come back when they do occur.

Continuous maintenance of equipment and facilities requires significant financial and human resources to ensure optimisation of the treatment process. When PD PAL took over management and operation in 2016, interviews with staff and operators revealed that significant maintenance and repair work was required to restore the facility to its well-functioning condition. A current trial with an Andrich (mechanical) pre-treatment system is part of the optimisation and improvement efforts of PD PAL.

Challenges of operation and maintenance

Contamination of sludge received

One of the main operational challenges faced by the Duri Kosambi facility is the contamination of the received faecal sludge with oil and grease, likely discharged by restaurants into their septic tanks, as well as coarse sand and trash from household septic tanks. The facility sometimes also receives sludge containing artificial dyes, which operators are only able to detect after final treatment. As the facility is not designed to treat restaurant or industrial wastewater, these contaminants negatively affect the treatment plant's performance.

[3] JICA, *Masterplan of Wastewater Management in DKI Jakarta*, Jakarta, JICA, 2012.

Conventional aerobic pond

A Huber screw press unit in operation

To overcome these challenges, the SOPs state that operators should add 'chemicals' to the system, but the types of chemicals are not known. The SOPs also say that contaminated sludge should be isolated for mechanical treatment. Using the mechanical treatment ensures that oil and grease do not settle in the conventional pond system or clog the connecting pipes. At present, there is some discussion on whether fees for sludge disposal could be charged, not just on the basis of the quantity of sludge received, but also on the quality, given the impact of poor-quality sludge that flow into the system. However, PD PAL is reluctant to increase prices as doing so may further reduce the amount of sludge received.

Technological breakdowns and related capacity challenges

The most common operation and maintenance issues include failing pumps, blowers, and surface aerators; leaking and corroded pipes; ineffective conventional screening processes; and limited capacity to repair technologically demanding treatment units.

Sludge containing rough sand and gravel, which are not removed in the conventional screening process, causes damage to the piping and structures as it slowly scours the concrete in the conventional system. The treatment plant manager explained that ideally, the inlet system is re-designed to screen rubbish and settle out rough sands more effectively, and to take up less space. If these adjustments are made, the mechanical sludge acceptance plant would not be needed. All the processing could then be done by the conventional system. This would require fewer financial resources.

The most demanding treatment units to operate are the mechanical Huber's Screw Press Dewatering Units. The operators do not have the technical capacity to troubleshoot issues or repair damage, as operation and control are performed through an electrical control panel. Technicians from Huber's distributor office in Jakarta are required for these tasks, and all spare parts have to be ordered from Malaysia. Despite these challenges, the dewatering system has never been out of service as there are three units at the facility, each with a capacity of 150 m^3/day. So, if one unit is out of service, the other two can be relied on.

> *We often receive sludge from the restaurant or food industry that contains high fat, grease, and oil which causes a bad smell throughout the system and clogs the pipes. We have to add some chemicals so that it won't cause a smell. Also, we are forced to operate the mechanical system on weekends rather than only the conventional system, to treat the sludge faster so that the fat, grease, and oil are not settled in the system.*
>
> **HEAD, DURI KOSAMBI FSTP**


Fuel briquettes

Opportunities for reuse and optimised treatment

Piloting the production of briquettes

At present, treated sludge from the Duri Kosambi FSTP is collected and stored at the facility. Pilot research is underway with the State Electricity Company to convert the treated sludge into briquettes for reuse as fuel. Two types of briquettes are being trialled. One consists entirely of treated sludge, and the other is a mixture of treated faecal sludge (80%) and organic waste (20%). The pilot research suggests that 12 kg of briquettes could produce 3,500–4,500 watts of electricity, which is approximately half of coal's calorific value. PD PAL is considering to sell these briquettes to a power plant based in Bogor, but the distance from Duri Kosambi to the power plant (more than 70 km) means that this is not currently financially viable, due to the significant transport costs. Furthermore, the low quality and calorific value of these briquettes, as well as the abundant supply of cheap Liquefied Petroleum Gas (LPG), means that the current market value of briquettes is low.


Andrich unit being operated

Andrich treatment system

In an effort to optimise and improve treatment performance at Duri Kosambi, an Andrich treatment system is currently being trialled as a pre-treatment system. Andrich is named after two Indonesian engineers who developed the system, Andri Oba and Chariunnas. The system consists of a nanofiltration membrane unit, which is equipped with a Dissolved Air Flotation (DAF) system. Water from the Sludge Acceptance Unit (SAP) effluent collection pond is pumped into a conventional DAF system and then filtered in the nanofiltration membrane unit. The effluent is then discharged into the Andrich outlet pond. From the outlet pond, the overflow enters the mechanical maturation pond and mixes with overflow from the mechanical aeration pond. The operating cost for the Andrich system is US$ 1.50/m^3 of sludge, with US$ 1 of this amount required for skilled labour. Besides its cheaper operating costs as compared to the existing two systems, the main benefit is the far superior quality of the effluent that is produced.

Informed choice considerations	Duri Kosambi FSTP in Jakarta, Indonesia, PD PAL Jaya (government-owned wastewater company)
Operating & design capacity	Design capacity = 900 m^3/day Operating capacity = 140-200 m^3/day
Revenue	Combined revenue (Duri Kosambi and Pulo Gebang FSTPs) = US$ 366,686/year (gap with operational expenditure [OPEX], met through PD-PAL offsite sewerage tariffs)
Energy requirements	Mechanical and conventional natural systems – the natural (or conventional system) is preferred, as the energy and chemical requirement costs are lower
Input characteristics	Sludge with pH = 6.9; TSS 2,100 mg/L; BOD 800 mg/L; COD 900 mg/L
Output characteristics	Effluent liquid quality (*Effluent limit as per environmental compliance standard Permen LHK 68/2016*): pH = 7.4-7.7 (*6-9*); TSS = *60-70 mg/L* (30 mg/L) (does not meet standard); BOD = 35-60 mg/L (*30*mg/L) (does not meet standard); and COD = 90-160 mg/L (*100* mg/L) (does not always meet standard) Coliform bacteria and oil and grease not reported on despite being regulated in the new regulations
Land requirement	Land area was a constraint therefore a mechanical system with a small footprint was chosen to complement the conventional natural system
Reuse	Currently piloting briquette production as an alternative fuel source; income potential is limited due to low quality of the briquettes and high transport costs, although doing so will avoid sludge disposal costs
Skills & human resources requirements	60 people total (Duri Kosambi and Pulo Gebang FSTP): 8 permanent staff at both FSTPs; 26 staff at Duri Kosambi FSTP; 13 operators (2 for the conventional system, 4 for the mechanical system, 1 for the Andrich system and 6 recording inflow); and 13 workers responsible for security, administration, driving, and cleaning
Technology/material (local) availability	Mechanical Huber's Screw Press Dewatering Units' spare parts not locally available in Indonesia, must be ordered from Malaysia

References

JICA, *Masterplan of Wastewater Management in DKI Jakarta*, Jakarta, JICA, 2012.

Regulation of Ministry of Environment and Forestry of the Government of Indonesia (2016) Permen LHK No. 68/2016

Contributors: Lena Ganda Saptalena (SNV in Indonesia) | Dr Teguh Subekti, Hendry Sitohang, Romel Sitompul, and Ir. Erwin Marphy Ali (PD PAL Jaya)

Photos: SNV

CASE STUDY 2

Constructed wetland for faecal sludge treatment

Khulna,
Bangladesh

Background

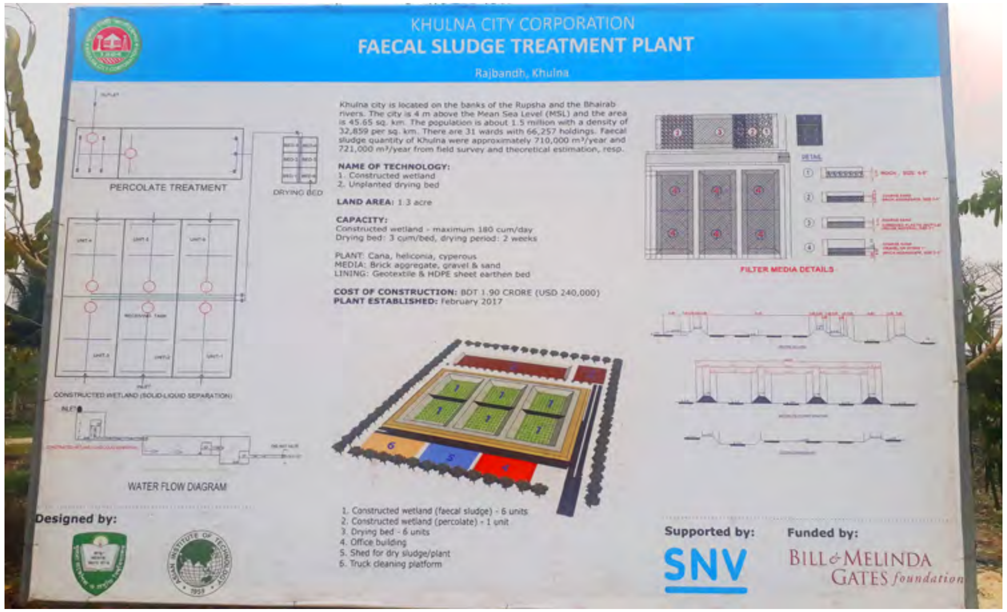
Treatment selection and purpose

The Faecal Sludge Treatment Plant (FSTP) in Khulna, Bangladesh – owned and managed by the Khulna City Corporation (KCC), a local government body – was built in 2016 and began operation in 2017. The constructed wetland (CW) and unplanted drying beds at the FSTP were selected for their low maintenance, operation, and construction costs, and because they offer an environmentally friendly system.

The design and construction of the treatment plant was a collaborative effort. The Khulna University of Engineering and Technology (KUET) and SNV provided technical assistance in design selection by implementing an informed choice process, with KCC making the final decision on the design. Khulna University of Engineering and Technology and the Asian Institute of Technology in Thailand designed the plant. SNV, with financing from the Bill & Melinda Gates Foundation, funded the construction of the plant; with KCC taking responsibility over the plant's construction, and operation and maintenance. To support the effective functioning of the plant, SNV and KUET offer regular trainings and refreshers.

> *We have chosen [this design] because it is more cost effective. It is environmentally friendly also. We have to wear masks at other plants, we all need to wear it here too, but there is no bad smell here. You will also not find any flies here.*
>
> **CHIEF WASTE MANAGEMENT OFFICER, KCC**

KCC FSTP constructed wetlands



Overview of KCC FSTP

Manual bar screen to remove garbage from sludge discharging into vertical flow constructed wetland

Description of the system

The KCC FSTP was built on what used to be a landfill site, which contained close to 15,000 tonnes of solid waste. Prior to construction, a study was conducted to investigate potential risks associated with building the FSTP on a passive landfill site. Once the site was cleared for use, the linear constructed wetland system was built, including six units or basins of vertical flow constructed wetlands, and one subsurface horizontal flow constructed wetland. Treated effluent was designed to discharge into a nearby canal. Six unplanted drying beds were built to collect dry sludge for end-use purposes.

Vacuum trucks (known as vacutugs in Bangladesh) transport sludge to the FSTP, discharging this into a holding-mixing tank that is fitted with a bar screen, which retains coarse material and garbage and prevents the clogging of CW beds. This manual bar screen is fitted at each side of the vertical flow CW in the Khulna FSTP. For the unplanted sludge drying beds, a locally made large plastic container is used to separate sludge from other types of waste.

Table 1. Khulna FSTP capacity and operating costs of constructed wetland and unplanted drying beds

	Constructed wetland (CW)	Unplanted drying beds
Design capacity	180 m³ of sludge/day	3 m³ with a drying period of two weeks
Operating capacity	10-15 m³ of sludge /day	
Operating costs	US$ 2,311/year (salaries and electricity costs)	


BOD levels of treated water are significantly lower than canal water beside the FSTP


Dried sludge in planted constructed wetland

Regulatory environment and compliance

The Khulna FSTP was designed to meet the effluent quality standards set by the Government of Bangladesh's Ministry of Environment and Forests, as per the Environment Conservation Rules 1997. Biochemical Oxygen Demand (BOD) levels at the treatment plant for treated effluent are consistently between 26 mg/L and 33 mg/L, with the allowable disposable limit set at 40 mg/L for inland surface water bodies. The treatment system maintains this BOD level, even with sludge BOD levels of 400-500 mg/L received from household septic tanks.

Operation and maintenance: realities, challenges, and opportunities

Realities of running the treatment plant

Measuring quantities of sludge and maintaining performance

Khulna FSTP has developed a low-technology approach to measure quantities of sludge and to ensure the performance of the treatment plant. To record the quantities of sludge received by the plant, the vacutugs that discharge sludge are used as the measurement standard. The volume is calculated according to the volume of each tanker and the number of trips completed, all of which are registered.

A key activity to maintain performance of the FSTP is to ensure that plants in the constructed wetland are healthy and thriving. Regular weeding and cleaning are required to ensure this. The performance of the treatment plant is measured by closely monitoring the faecal sludge solid matter in the drying beds, as explained by one of the operators. More sophisticated testing is conducted by the Khulna University of Engineering and Technology, as the Khulna FSTP does not currently have a laboratory.

> *We keep an eye on the solid matter at [the] drying bed. We count how many days it needs to dry. From this, we can measure the performance of the filter materials. We measure the moisture also.*
>
> **OPERATOR, KCC**

Vacutug in Khulna city

Sludge drying beds

Construction and operating costs

The largest costs associated with the FSTP have been the capital expenditure and ongoing salary costs. Construction costs for the FSTP alone were initially estimated at US$ 58,930. Due to civil construction works, such as access roads to and around the treatment plant, establishment of testing facility, landscaping needs, and installation of a security system, the final cost was US$ 235,715. The funds were provided through donation by an SNV project financed by the Bill & Melinda Gates Foundation, who have continued to support improvements to the FSTP at an estimated value of US$ 30,000 per year.

The largest ongoing cost for the treatment plant is the salaries of the staff, which consists of one caretaker, the vacutug driver, and helper. Engineers from SNV and KUET provide technical support related to installing or repairing machinery, and monitoring the performance of the FSTP. The operators of the treatment plant have received Occupational Health and Safety (OHS) training from SNV, as well as instructions on operation procedures.

Treatment plant coverage area and future growth

The treatment plant was designed for a 30-year lifespan, with sewerage connections planned to cover the majority of the Khulna population in the future. At present, the FSTP is estimated to cover 13% of Khulna's 1.5 million inhabitants, with the wetland expected to be emptied after seven years to support the intended 30-year lifespan. There are possibilities to expand the treatment plant, if necessary, with additional land that is available and adjacent to the current wetland.

Operators discharging influent directly to planted constructed wetland bed

Challenges of construction, and operation and maintenance

Discharge and screening of sludge

Challenges related to the manual screening of effluent discharge required modifications to the screening systems. Due to the high flow of influent discharge from vacutugs and the insufficient size of filter screens and pipes, the manual screening units in the planted constructed wetland could not handle the inflow rate. This resulted in the spillage of sludge around the units.

To cope with these challenges, operators and vacutug operators have often bypassed the screening units and discharged influent directly to the wetland bed. This practice, however, has led to clogging the constructed wetland filter media. As a result, the plant's filter pipes were replaced with higher quality, larger diameter pipes, and the gate valves were replaced with ball valves. While these changes have improved the performance of the system, according to one of the operators the '*vertical flow constructed wetland is not so sophisticated*'.

Construction challenges

Lack of availability of required materials and reliance on low-cost materials presented challenges to the Khulna FSTP design and construction team. As the treatment plant site was previously filled with municipal garbage, it was not possible to water seal the structure with concrete or locally available materials. Therefore, high density polyethylene sheets were required at the base of the basins. These were not available in Bangladesh and needed to be imported, which involved additional cost and time. The use of compacted soil and rocks to form the walls of the planted constructed wetland also led to structural issues, particularly during rainy season, and due to holes formed by tunnelling rats. This is an engineering challenge that will need to be continuously monitored and addressed.

Treatment plant operating under capacity

The plant is currently operating below its design capacity. This can affect treatment efficiency and requires efforts to increase community demand for emptying. The treatment plant has a design capacity of 180 m^3/day of sludge but is currently receiving between 10 and 15 m^3/day.

The lack of consistency in collected and received sludge could hamper the growth and health of the plants in the constructed wetland and could degrade treatment performance. In discussions, the treatment plant designers and operators acknowledged that the scale was actually too large; development and investment should have been staged and organised incrementally. Increasing the demand for desludging from communities could assist but presents its own challenges in facilitating behaviour change communication initiatives. One of the operators of the treatment plant stated that: '*increasing the demand for desludging is a challenging matter*'.

> *The pipes of this plant were not so wide. The diameter of these pipes was three inches. The quality of the pipes was not good also. After discussing the matter with SNV, we've changed the pipes. Gate valves [have been] replaced by ball valves.*
>
> **CONSERVANCY OFFICER, KCC**

Briquettes on KCC drying racks/trays

Opportunities for reuse

Co-composting and briquette production

Research is currently underway into the possible profitable use of the solid faecal matter from the treatment plant for co-composting, aquaculture, and the production of both non-carbonised and charcoal briquettes. National government funds have recently been secured by KCC and SNV to undertake further research, and to develop and expand briquette production.

> *Solid matter [reuse] is in research level. We want to co-compost it. Actually, we want to do aquaculture. We're researching on the matter. Recently we have made briquettes. And the liquid flows directly to the water body. We have no option to reuse it. We make sure that the liquid is not harmful and is environment friendly, then it flows to the waterbody.*
>
> **CHIEF WASTE MANAGEMENT OFFICER, KCC**

Informed choice considerations		Constructed wetland for faecal sludge treatment in Khulna, Bangladesh
	Operating & design capacity	Design capacity = 180 m^3/day Operating capacity = 10-15 m^3/day
	Operating costs	US$ 2,311 per year (salaries and electricity costs)
	Input characteristics	BOD = 400-500 mg/L
	Output characteristics	BOD = 26-33 mg/L (discharge limit: 40 mg/L)
	Reuse	Investigating options for co-composting, aquaculture, and the production of both non-carbonised and charcoal briquettes
	Skills & human resources requirements	One caretaker, a vacutug driver, and helper; engineers from SNV and KUET provide technical support related to installing or repairing machinery and monitoring the performance of the FSTP
	Technology/material (local) availability	All materials are locally available

Contributors: Sk Shaker Ahmed (SNV in Bangladesh) | Muhammed Alamgir (University Grants Commission of Bangladesh) | Md Abdul Aziz and Anisur Rehman (KCC) | Md Forkan Sarder (Khulna FSTP)

Photos: SNV

CASE STUDY 3

Coco peat filter and reuse production

Kushtia,
Bangladesh

Background

Treatment selection and purpose

The Faecal Sludge Treatment Plant (FSTP) in Kushtia, Bangladesh started operation in 2012. It is owned by the local municipality but is privately operated through a contractual agreement with the Environmental Resource Advancement Services (ERAS), a small-scale private enterprise. The FSTP includes unplanted drying beds to separate solid and liquid waste, a coco peat filter to treat the liquid effluent, and involves a co-composting process for treating dried sludge with organic waste for reuse purposes. These technologies were chosen for their low-cost and simple design for construction, operation and maintenance (O&M). A natural technology was chosen over mechanised options to avoid costly energy bills and the frequent O&M requirements of any mechanised system. However, some mechanised pumps are used as part of the system.

Design selection was done through a consultative process involving several public and private organisations including: (i) the Local Government Engineering Department (LGED) of Bangladesh as the FSTP's funders (through its Secondary Towns Integrated Flood Protection [STIFP] project); (ii) the local Kushtia municipality as the owners of the FSTP; and (iii) a number of international and national consultants as technical advisers. The site was initially developed for the composting of municipal waste, and the faecal sludge management component was added afterwards. It was the Kushtia municipality that made the final decision on the design after discussion and consultation with members of the STIFP project, the municipality, and the technical advisers.

Kushtia municipality-owned and operated vacutug

Description of the system

The Kushtia FSTP uses a linear treatment system to process faecal sludge, which arrives at the facility via municipality-owned and operated vacuum trucks (known as vacutugs in Bangladesh). Figure 1 shows the treatment process. The facility calculates the volume of sludge received according to vacutug size, as each vehicle is marked with its capacity (i.e., 1000L, 2000L and 4000L). Upon reception of the sludge, no screening occurs; rather, it is dumped in the facility's two primary dumping chambers for sludge settling (one chamber on each side of the two drying beds in operation).

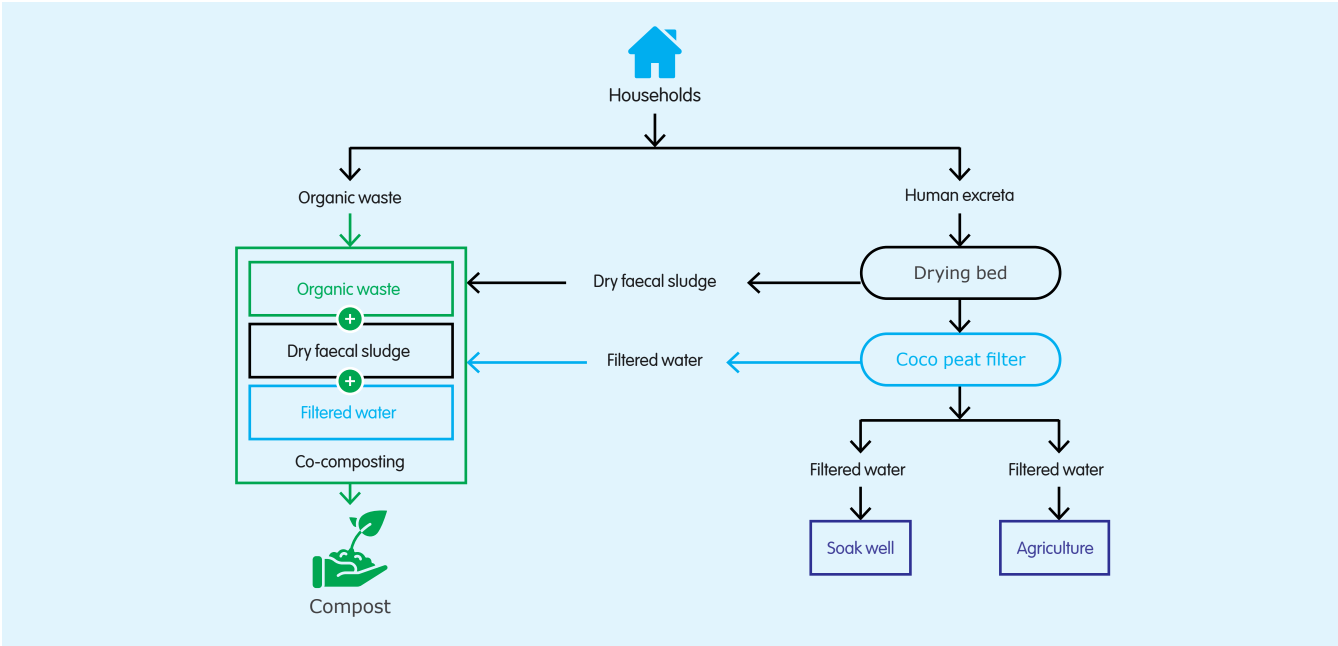
> *We have tried to adapt such a technology to reduce the cost of long-term operations, thinking about operational costing. Because, at the municipal level, capital or earning source is limited. That's why we chose this low-cost technology.*
>
> **ENGINEER, KUSHTIA MUNICIPALITY**

In the two primary dumping chambers, solid waste and other rubbish is sorted using a large perforated drum: the sludge moves through the holes, but the solid waste remains. The remaining sludge moves by gravity to the natural drying beds through the mouth of the chamber. In each drying bed there are three brick rows to distribute the faecal sludge uniformly. The liquid effluent is separated from the solid part in the drying beds through a filter material made up of bricks, sand, stones, and pipes.

Desludging household containment

Settled sludge moves to the natural drying bed via the filtering gate

Figure 1. Treatment flow diagram,[1] adapted by SNV



[1] I. Enayetullah, 'Co-composting of municipal solid waste and faecal sludge in Kushtia Bangladesh', *ISWA Congress 2015*, Dhaka, Waste Concern, 2015, https://www.unescap.org/sites/default/files/Waste%20Concern,%20Bangladesh.pdf (accessed 10 November 2020).


Filtering effluent in coconut dust and coir filtering bed


Discharging sludge into drying beds


Removing dried sludge from the drying beds

The liquid effluent is then accumulated in two reserve tanks and pumped to the coco peat filter. The coco peat filter is a vertical filtering system using coir from coconut processing plants. After filtration through the coco peat filter, filtered water is discharged into a reserve pond. This water is used for farming in the internal facility plant nursery or is discharged into a nearby canal.

The solid part of the treated sludge is combined with organic waste for co-composting in order to produce agricultural fertiliser, which is then sold.

> *The reason the coco peat filter seems good to me is that the water is being filtered twice. Once from the dry bed water goes into the tank. From the tank we upload the water to the coco peat. Water goes to the pond from there. The water has been tested and it has come up to the standard. This is the first time I saw the coco peat system in my life.*
>
> **PRODUCTION MANAGER, ERAS**

Table 1. Capacity and operating costs of coco peat filter and reuse production

	Sludge drying beds
Design capacity	8-9 m^3 of sludge/day
Operating capacity	8-9 m^3 of sludge/day
Operating costs	US$ 115,000 spent in capital expenditure US$ 900/month per staff for salary costs (seven staff at facility)

Regulatory environment and compliance

The Kushtia FSTP follows the environmental and compliance effluent quality standards set by the Government of Bangladesh's Ministry of Environment and Forests.[2] The facility reliably meets government-regulated water quality standards, which require that Biochemical Oxygen Demand (BOD) must be no more than 40 mg/L, and that faecal coliform bacteria must be less than 1,000 per 100 ml. The FSTP is currently meeting these effluent standards and has a laboratory at the facility site to test water quality on a regular basis. For the processed solid waste, no quality standards are followed except to ensure that the waste is safe to dispose of by conducting laboratory testing for pathogens at the facility.

[2] *S.R.O. No. 197-Law/97-Environment Conservation Rules* (1997) Ministry of Environment and Forest, Government of Bangladesh

Sludge drying beds at the Kushtia FSTP

Reserve tanks which drain water from the sludge drying beds

Operation and maintenance: realities, challenges, and opportunities

Realities of running the treatment plant

Costs, training, and support

The facility is leased to ERAS by the municipality, with each entity responsible for different O&M costs. ERAS pays a fee of US$ 590 per year to lease the facility, and the current lease runs until June 2021. As the lease holder, ERAS is responsible for small operational costs. This includes staff salary costs for seven people, which constitutes the largest operational costs. More significant infrastructure costs, such as major repairs and capital expenditure, are the responsibility of the municipality. To date the municipality has invested in connecting the facility to the electricity grid and ensuring proper road access. The municipality is also currently repairing some of the co-compost cells. The seven staff working at the plant have received on-the-job, and practical O&M training from SNV who provide regular technical support. Through the practical training received, staff are aware of and respond to the ongoing O&M needs of the facility.

> *There is no such [O&M] protocol. We take care of it on our own interest. If we understand with our bare eyes, it is dirty, we have to eliminate it or reduce the goods [sludge] if it is more than capacity. Then we make sure the maintenance [is assured].*
>
> **PRODUCTION MANAGER, ERAS**

Cleaning and maintaining treatment units

Cleanliness and maintenance of the coco peat filter and sludge drying beds are the biggest tasks for staff as they require daily cleaning. Frequent operational tasks include lifting the effluent in the coco peat filter several times a week to ensure the filtration system is operating effectively. Desludging or removal of dry sludge occurs weekly to clean the beds and prepare them for new batches of sludge.

Electricity needs

Minimal electricity is needed to operate the FSTP, with the laboratory and pumps operated from the electricity grid, and a fuel-powered generator if power outages occur. The main electricity needs are to power a pump, which moves water from the reserve tanks to the coco peat filter, and to operate the laboratory for effluent quality testing. Additionally, the co-compost facility requires an energy source for the crashing and netting machines.

Lifespan of plant

The FSTP was designed at a small scale to assess the performance of the chosen system, and to gauge the need for future expansion. At the time of the plant's design in 2011, the total population of the city of Kushtia was 102,988. The facility services, including desludging, are available to all, and the lifespan of the facility will be for at least another 20-30 years. With the model treatment system deemed successful, current tendering processes are underway to expand the capacity of the plant to cope with larger volumes as emptying practices increase.

Challenges of construction, and operation and maintenance

Variability of waste input

The plant has experienced variable waste input in terms of quality and quantity, which has led to operational challenges. Poor quality sludge received from households (contaminated with rubbish, or dirt, or with a too high liquid percentage) affects production as it increases the human resources needed to process the sludge, thereby increasing costs.

When the waste input is too low, this affects the amount of fertiliser that can be produced. Equally, as described above, when the input is too high and the plant receives excess quantities of sludge, this excess sludge is discharged into trenches, creating environmental pollution concerns. The municipality agreed to a request by ERAS to expand the capacity of the facility through the addition of two drying beds, with funding from the municipality (80%) and a Bill & Melinda Gates Foundation-financed SNV project (20%). Through a tendering process, the municipality assigned a contractor to construct an additional two beds and a shed. The facility upgrade has been completed, and CCTV cameras for monitoring and security purposes are currently being installed.

> *Earlier, we said, we gave on-the-job training. Now, those who are involved in ERAS or composting look at health [and] safety issues. Gumboots for the legs, gloves for hands, masks for the face [are] provided to them… staff have to use these items.*
>
> **ENGINEER, KUSHTIA MUNICIPALITY**

Kushtia FSTP workers removing rubbish from solid organic waste for co-composting purposes

Clogging of filters

Clogging of the dumping chamber for the drying bed filters has resulted in overflow challenges and mechanism failure on occasion. The FSTP is in operation 24 hours per day, but the operators only work from 8 am until 4 pm, and so at times the vacutug operators dump sludge without monitoring from the plant staff. As vacutug operators do not know how much sludge the treatment system can receive at any given time, overflow challenges and occasional clogging of the filter media treatment mechanism has occurred twice to date. To deal with the current high input issues, vacutug operators have been instructed to offload sludge into the trenches while the additional drying beds are constructed. Large perforated drums have been installed in the dumping chamber to address the filter clogging challenge.

Co-composting of treated sludge and organic waste

Kushtia FSTP worker sealing the co-composted fertiliser into bags (left) and the final fertiliser product (right)

Rainy season

Flooding concerns and the rainy season presented challenges during construction, and affected ongoing O&M. During construction, it was a priority for the designers to raise the drying beds above the flood level, which required significant earthworks. Previously, O&M was put under pressure during the rainy season as there were no sheds or covers for the drying beds, which meant that sludge could not be dried, thereby disrupting the treatment process. Significantly more effort from operators was required to treat the sludge in the rainy season as the drying beds needed emptying and cleaning. In the middle of 2018, the production manager informed the municipality of this ongoing challenge and requested for the construction of a shed to protect the drying beds from the rains.

Occupational Health and Safety (OHS) challenges

Due to the manual sorting of organic matter from solid waste for co-composting processes, staff have frequently been cut by metal scraps. Despite OHS-mandated measures, including the use of gumboots, gloves, face masks, uniforms, and handwashing with anti-bacterial soap, the production manager explained that staff did not always use protective clothing due to the discomfort of these clothes in hot weather. However, at present, staff have become habituated to using protective clothing, which minimises these OHS challenges. The municipal authority is always encouraging the cleaners to wear Personal Protective Equipment (PPE).

Opportunities for reuse

Co-composting – the controlled aerobic degradation of organics using more than one feedstock (faecal sludge and organic solid waste)[3] – occurs at the FSTP for the retail production of agricultural fertiliser. At the Kushtia FSTP, open composting occurs where the mixed sludge and organic solid waste is piled in heaps and left to decompose for a period of 45 to 50 days. These piles are periodically turned to provide oxygen and to ensure that all parts of the pile are subjected to the same heat treatment.[4]

Plant operators sort the organic waste to be mixed with the treated sludge. The fertiliser that is produced is then sold for agricultural use at the local market and in other districts (Dinajpur, Bogura, Chittagong, Dhaka, Jashore). Since 2018, two years after private sector involvement in the co-composting operation, the facility has been realising a profit.

[3] E. Tilley, L. Ulrich, C. Lüthi, Ph. Reymond and C. Zurbrügg, *Compendium of Sanitation Systems and Technologies*, 2nd Revised Edition, Dübendorf, Swiss Federal Institute of Aquatic Science and Technology (eawag), 2014, https://sswm.info/sites/default/files/reference_attachments/TILLEY%20et%20al%202014%20Compendium%20of%20Sanitation%20Systems%20and%20Technologies%202nd%20Revised%20Edition.pdf (accessed 5 November 2020).
[4] As part of SNV's support, compost was sent to the Bangladesh Agriculture Research Institute for testing in different agriculture products, and the Fisheries & Marine Resource Technology Discipline of Khulna University to analyse compost impact on pisciculture. Findings of both research were used to improve the quality of compost production. Read more here: https://snv.org/cms/sites/default/files/explore/download/snv_-_co-composting_of_faecal_sludge.pdf and https://snv.org/cms/sites/default/files/explore/download/snv_-_impact_of_treated_faecal_sludge_on_fish_growth.pdf

Informed choice considerations	Coco peat filter and reuse production in Kushtia, Bangladesh
Operating & design capacity	Design capacity = 8-9 m^3/day Operating capacity = 8-9 m^3/day
Operating costs	US$ 10,800 per year (salaries) + US$ 950 per year for facility lease
Energy requirements	Low energy demand
Input characteristics	Variability in both quality and quantity
Output characteristics	BOD = < 40 mg/L (discharge limit: 40 mg/L)
Reuse	Co-composting for retail agriculture fertiliser
Skills & human resources requirements	Seven staff
Technology/material (local) availability	Natural technologies were chosen for their low-cost and simple design in terms of construction, operation and maintenance

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S.R.O. No. 197-Law/97-Environment Conservation Rules (1997) Ministry of Environment and Forest, Government of Bangladesh

Tilley, E., Ulrich, L., Lüthi, C., Reymond, Ph. and Zurbrügg, C., *Compendium of Sanitation Systems and Technologies, 2nd Revised Edition*, Dübendorf, Swiss Federal Institute of Aquatic Science and Technology (eawag), 2014, https://sswm.info/sites/default/files/reference_attachments/TILLEY%20et%20al%202014%20Compendium%20of%20Sanitation%20Systems%20and%20Technologies%20-%202nd%20Revised%20Edition.pdf (accessed 5 November 2020).

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Photos: SNV

CASE STUDY 4

Briquette production as reuse

Nakuru,
Kenya

Background

Treatment selection and purpose

NAWASSCOAL produces and sells round-shaped carbonised briquettes made from treated sludge as an alternative fuel for domestic cooking and heating. NAWASSCOAL is a subsidiary of the Nakuru Water and Sanitation Services Company Ltd (NAWASSCO) and was established in 2018, after a pilot phase which began in 2013. NAWASSCO's conventional domestic water treatment plant was built in 1956 and rehabilitated in 2018 to enable compatibility and a well-functioning link to NAWASSCOAL's operations. Key considerations in selecting the NAWASSCOAL briquette production design included: (i) technological capability to process human waste into carbon concentrated material suitable for domestic briquette production; (ii) an ability to operate in various weather conditions, particularly during the rainy season; (iii) the need to fit within the available land area; and (iv) requirement to meet the environmental impact concerns of key stakeholders as the facility is located in a national park.

The briquette production facility was designed locally by a range of stakeholders under the Nakuru County Sanitation Programme (NCSP) (2013-2018). NAWASSCO implemented the NCSP with support of Vitens Evides International (VEI), SNV, Umande Trust, and the Nakuru County Government. The programme formed a steering committee with representatives of key departments in the NAWASSCO water utility as well as project partners and government representatives, who were involved through sub-committees in designing the facility and sourcing the technologies. Recommendations from the steering committee informed the final decision made by the programme and donor. The decision was also informed by the piloting of potential reuse products, e.g., different types of bio-fertilisers and biomass fuels through a partnership with Egerton University and other project partners. The pilot included product development and market studies, a feasibility and business model, a community pilot, and field trials.

> *The community trial with households in Nakuru's low-income areas confirmed people's willingness to use fuel produced from faecal sludge, as long as it would meet their cooking needs and [it was] affordable. The trials provided key insights for further product development and marketing, distribution, and sales strategies.*
>
> **WASH ADVISOR, SNV IN KENYA**

NAWASSCOAL briquette production facility

Agglomerator in operation using a rotating drum

Round-shaped carbonised briquettes in drying beds

Round-shaped carbonised briquettes used as an alternative fuel source

Description of the system

The NAWASSCO treatment plant is designed to receive any type of domestic wastewater, with the treated sludge used for the production of the briquettes by NAWASSCOAL. NAWASSCO receives greywater and blackwater through sewer lines and sludge from vacuum trucks or pit-emptying technologies. The NAWASSCO treatment plant receives an estimated 2,800 m^3/day of wastewater, which undergoes a screening process to remove sand and grit. This is followed by thickening in a primary clarifier to reduce the sludge moisture content, resulting in 1,020 m^3/day of sludge. The sludge is then pumped from the NAWASSCO treatment plant, through a newly built connection pipe, to NAWASSCOAL's briquette production site for further drying to 20% moisture content using open-air drying beds and a solar drier, or a combination of the two. This process results in approximately 200 m^3 or 140 t/day of sludge for processing into briquettes. The carbonisation technology used at the facility was designed to accommodate a wide range of biomass waste (any organic waste, including sawdust, rice husks, bagasse, and any type of human waste). Therefore, waste can be taken from the conventional treatment plant as well as directly from vacuum trucks.

The briquette production design has been optimised to ensure the required physical and combustion properties of the briquettes. Figure 1 (on next page) outlines the NAWASSCOAL production process, which includes a holding tank, open-air drying beds, a solar dryer, a carbonisation unit, hammer mills, a batch mixer, and a rotating drum or agglomerator. The briquettes are made of a combination of dried and carbonised sawdust (50%) and human waste/sludge (50%) by volume. The agglomerator works by tumbling the sludge and sawdust in a rotating drum, in the presence of a binding agent such as molasses, followed by drying of the briquettes on beds for up to four days. Testing showed that briquettes exhibited the positive attributes for moisture content (7.3%), volatile matter (34.5%), ash content (36.4%), and calorific value (22.001 MJ/kg), with molasses-bonded briquettes having a lower calorific value than faecal matter-bonded briquettes.[1]

[1] M.J. Mbuba, D.M. Nyaanga, P.A. Kabok and R. Eppinga, 'Effect of mix ratios and binders on physical and physical combustion characteristics of faecal matter – sawdust briquettes', *International Journal of Emerging Technology and Advanced Engineering*, vol. 7, issue 4, 2017.

Figure 1. Typical NAWASSCOAL briquette production process, including NAWASSCO treatment process (top of figure), drawn by SNV based on site visit

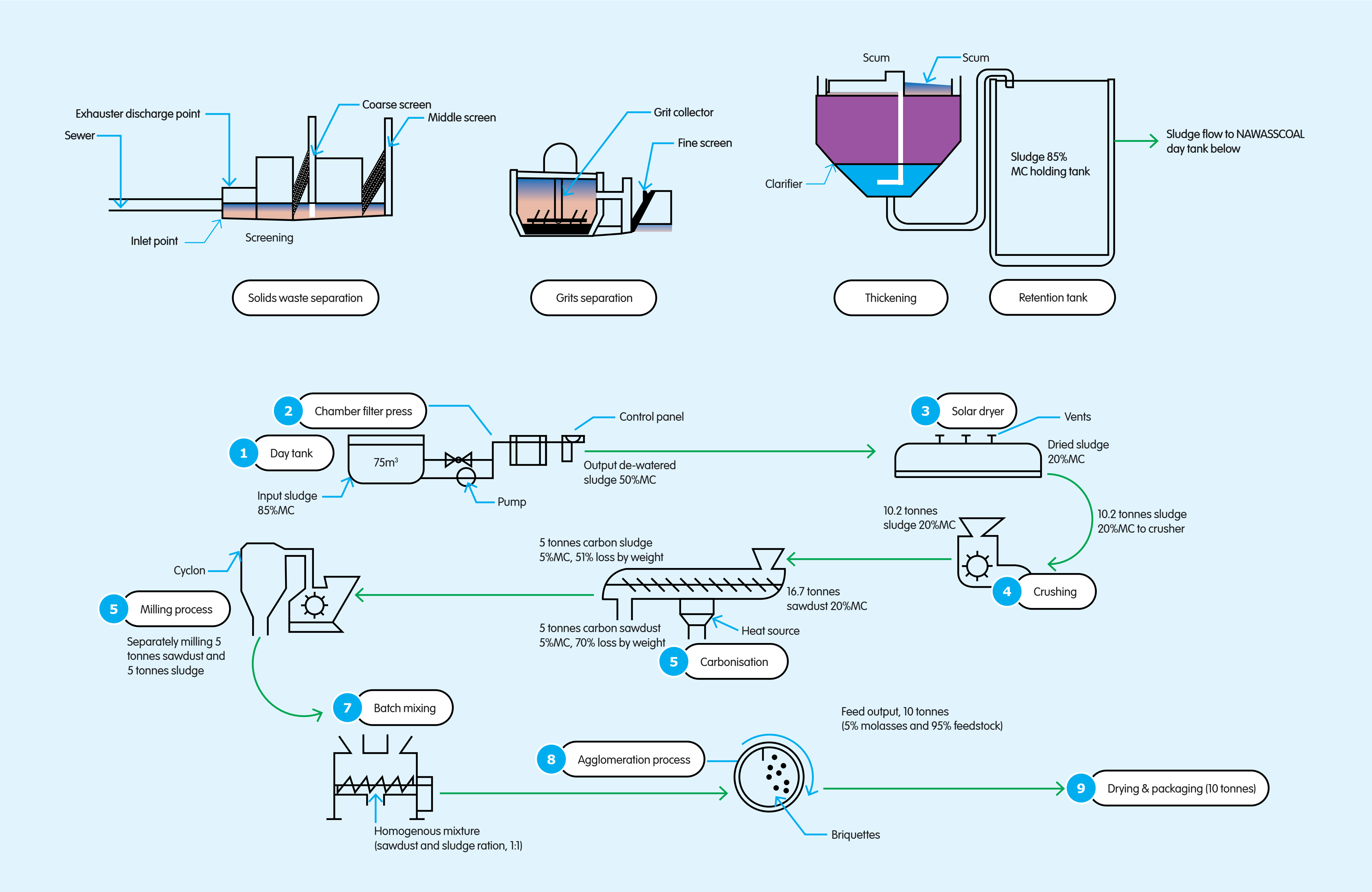


Table 1. Capacity and operating costs of the NAWASSCOAL treatment plan and briquette operations

	Conventional treatment plant	Briquette production for reuse
Design capacity	3,400 m^3/day of wastewater	250 t/month
Operating capacity	2,800 m^3/day of wastewater	10 t/month
Costs Capital expenditure (CAPEX) Operational expenditure (OPEX)	CAPEX = US$ 366,497 OPEX for NAWASSCOAL = US$ 14,020 (year one) OPEX for NAWASSCOAL = US$ 1,473 (year two) OPEX for NAWASSCOAL = US$ 18,172 (year three, estimated) OPEX for NAWASSCOAL = US$ 55,640 (year four, estimated) OPEX for NAWASSCOAL = US$ 206,458 (year five, estimated)[2]	

Regulatory environment and compliance

Treated effluent standards set by the Kenyan Natural Environment Management Authority (NEMA) are followed and met by NAWASSCO. Effluent standards for the conventional treatment plant are BOD (Biochemical Oxygen Demand) < 50mg/L and COD (Chemical Oxygen Demand) < 30mg/L.[3] The liquid part of the waste is further treated through a rock filter and grass ponds, up to the required standard by NEMA, then released into Lake Nakuru. Prior to construction, approval from all relevant parties, including the Kenya Wildlife Service and the Nakuru County Government, were required to ensure that environmental standards are met due to the facility's sensitive location in a national park. Concerns expressed by some stakeholders were overcome through a comprehensive consultative process.

> *The public participation process, which included neighbouring community and school representatives as well as Kenya Wildlife, NEMA, and the Chief's offices ensured that all stakeholders were informed and have since supported the initiative.*
>
> **GENERAL MANAGER, NAWASSCOAL**

Carboniser plant

Operation and maintenance: realities, challenges, and opportunities

Realities of running the treatment plant

Optimising production through technological considerations

Treatment technologies, which optimised production processes were chosen when designing the NAWASSCOAL facility. The carboniser was chosen to enable large-scale carbonisation of dried faecal sludge and other biomass materials. The solar dryer was introduced to accelerate drying and to be used in combination with the open-air drying beds. Using UV-treated solar lag materials, the temperatures in the solar dryer can reach 50° Celsius and drying is not affected by weather conditions like rain.

Staffing, OHS, and operator training

Key considerations for operating the facility include ensuring that sufficient staff are employed, Occupational Health and Safety (OHS) measures are followed, and training requirements are fulfilled. Currently, there are four skilled staff including a general manager, a marketing officer, a business officer, and a production supervisor, as well as three unskilled production assistants

[2] Every year, capacity of the facility is increased. This will require an increase in operational costs and capital expenditure. Operational cost increases will be covered by additional profits from briquette production.
[3] *Environmental management and co-ordination (water quality) regulations (2006)* Kenyan Natural Environment Management Authority, https://www.nema.go.ke/images/Docs/water/water_quality_regulations.pdf (accessed 1 December 2020).

working at the NAWASSCOAL facility. Typical activities performed by the production assistants include briquetting, milling, mixing, feeding the carboniser, shredding raw materials in preparation for carbonisation, drying of final products, drying sludge, packaging, and distribution/sales.
To ensure OHS the company works to eliminate contact with raw untreated sludge as much as possible. Where contact occurs, wearing of protective gear and equipment is required as well as following proper training in handling untreated sludge. Ensuring that machines are constructed following rules and regulations as outlined in the Kenyan Occupational Safety and Health Act (OSHA) 2007 is also key.

On-the-job training and manuals outlining key procedures help upskill staff. NAWASSCOAL has a health and safety manual, a finance manual, a corporate and governance manual, a production manual, a human resource manual, and a standard operation and maintenance procedures manual which outlines proper operation procedures. Operators have been trained on the job by those able to operate the machinery, including by local and international suppliers of machinery used at the facility for Operations and Maintenance (O&M) and safety training.

> *A comprehensive assessment of the safety requirements was conducted and recommendations like inoculation of staff, use of safety equipment and First Aid and Fire Safety Trainings were put in place. A health and safety manual was developed to guide day-to-day operations. Signage, marking on the floors, insulation of hot pipes, among other safety procedures, have since been implemented.*
>
> **GENERAL MANAGER NAWASSCOAL**

Meeting market demand through facility expansion and improvements

Expansion of the NAWASSCOAL facility and continuous improvements are required to meet the increasing market demand for briquettes. With a population of 500,000 in Nakuru Town, the market study from the design phase indicated that the need for briquettes is greater than can be satisfied by the current scale of operations. Taking local government plans to extend sewer and treatment facilities for the town in the years to come into consideration, an additional US$ 115,134 has been invested in the NAWASSCOAL facility, with the company currently seeking extra funding to continue expansion as per their business plan.

Solar dryer in the NAWASSCOAL facility

The overall lifespan of the facility is between 5 and 20 years due to the different technologies in operation. The lifespan of some locally produced machinery is up to five years, while for larger imported machinery, it is between 15 and 20 years. To ensure that the machinery fulfils its intended lifespan, continuous improvement and maintenance are conducted. Examples of improvements made include insulation of the carboniser, improved floor durability of the solar drier using high quality materials (including reinforced concrete with a top layer of waterproof cement and concrete pillars between the sludge and the metal), and drying racks constructed from metal instead of wood. Key maintenance activities include repair of the hammer mills and rotating drum, which are easily done locally by staff.

Challenges of operation and maintenance

Key considerations in choosing the most appropriate technology

A key learning by the briquetting facility operators was in the type of technologies to use and not to use if scaling up operations is a priority. To increase production speed, a professional briquetting machine would have been preferred over the agglomerator machines currently in operation, which in the Kenyan case would need to be imported. It was also found that the carboniser requires fairly significant preparation work before it can be installed, and the dryer element may not be required. Preparatory work included ensuring there were sufficient water tanks and cooling tanks, building a framework for conveyors, building channels for the floor, installing the pillar required for the carboniser to sit on, and installing electricity cables. The dryer element is not required when there is sufficient sunlight and solar drying can be relied on. This saves significant amounts of energy. Finally, more professional hammermills that deal well with carbonised materials are also advisable if the plant moves to large-scale operations, as are dewatering devices. Generally, the suitability of various machines depends on the scale envisaged and the budget available.

> *We maximise the use of the sun to dry the raw materials as well as the final products. By utilising the natural heat from the sun, the company saves on electricity cost.*
>
> **GENERAL MANAGER NAWASSCOAL**

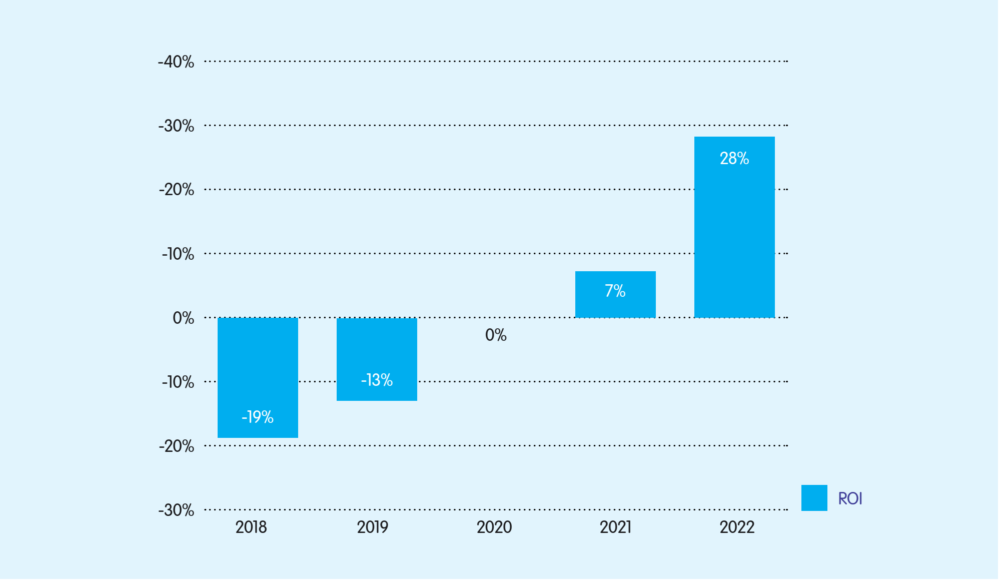
Absence of backup power supply

A key challenge faced by the NAWASSCOAL facility is the lack of a backup power supply. The facility relies on the electricity grid for power, which is one of the greatest costs, along with ongoing maintenance costs. Power outages can lead to delays in production of the briquettes. However, when there is no power, staff can work on other processes that do not rely on electricity. Even though the drying beds are covered, wet weather can also result in delays to drying of the sludge and the briquettes. NAWASSCOAL is currently proposing oven drying for the briquettes to prevent delays due to wet weather.

Ensuring financial sustainability

It was necessary for the company to break even within the first three years of operation to repay funds invested by NAWASSCO and to become financially sustainable. NAWASSCOAL inherited the capital investments made in the briquette facility through the NCSP EU co-funded programme and received loans from its mother company NAWASSCO (US$ 126,335) to cover operational expenditures for the first two years. This loan amount needs to be repaid at an interest rate of 5% once the company breaks even and begins making a profit, which is expected in the fourth year of operation, as shown in Figure 2. NAWASSCOAL plans to increase production capacity to 60 tonnes in the third year in order to cover operational costs and steadily increase production, allowing them to repay their loans and become financially sustainable.

Figure 2. NAWASSCOAL Return on Investment (ROI) prediction, based on conversation during site visit



Informed choice considerations	Briquette production as reuse in Nakuru, Kenya (NAWASSCOAL)
Operating & design capacity	Design capacity = 250t/month of briquettes Operating capacity = 10t/month of briquettes
Operating costs	CAPEX = US$ 366,497 OPEX for NAWASSCOAL = US$ 14,020 (year one) OPEX for NAWASSCOAL = US$ 1,473 (year two) OPEX for NAWASSCOAL = US$ 18,172 (year three, estimated) OPEX for NAWASSCOAL = US$ 55,640 (year four, estimated) OPEX for NAWASSCOAL = US$ 206,458 (year five, estimated)
Energy requirements	Grid electricity used for both single and three-phase machines using a 250KvA transformer, some natural processes including solar drying; per tonne of briquettes is US$ 20 for electricity
Input characteristics	Any type of sludge can be received by the NAWASSCO treatment plant (though not industrial sludge) or directly by the drying beds of NAWASSCOAL; to enable sludge to be used in the carboniser, moisture content needs to be less than 20% and particle size less than 5cm
Output characteristics	For the liquid effluent, BOD must be less than 50mg/L and COD less than 30mg/L, as per treated effluent standards set by NEMA; any pathogens in the solid part are completely eliminated during the carbonisation process
Reuse	Round-shaped carbonised briquettes (50% sludge/waste and 50% sawdust with molasses as a binder)
Land requirement	Land size for the facility is minimum of one acre; the current facility of NAWASSCOAL is built on 2.5 acres
Skills & human resources requirements	Seven staff in total: four skilled staff including a general manager, marketing officer, business officer, and production supervisor, as well as three unskilled production assistants; when scaled further, additional staff will be required
Technology/material (local) availability	Carbonisation unit was designed, piloted and imported from China; all other machines in operation were locally acquired and spare parts for all machines (including those from overseas) are locally available; over time some of this machinery was improved for safety and efficiency, in consultation with the fabricators

References

Environmental management and co-ordination (water quality) regulations (2006) Kenyan Natural Environment Management Authority, https://www.nema.go.ke/images/Docs/water/water_quality_regulations.pdf (accessed 1 December 2020).

Mbuba, M.J., Nyaanga, D.M., Kabok, P.A. and Eppinga, R., 'Effect of mix ratios and binders on physical and physical combustion characteristics of faecal matter – sawdust briquettes', *International Journal of Emerging Technology and Advanced Engineering*, vol. 7, issue 4, 2017.

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Photos: SNV

CASE STUDY 5

Anaerobic respiration for faecal sludge treatment and reuse

Lusaka,
Zambia

Background

Formal emptying and treatment of sludge collected from on-site sanitation facilities in Lusaka Zambia was established between 2012 and 2014 through the construction of two Faecal Sludge Treatment Plants (FSTPs) and the consequential development of pit emptying teams in two peri-urban compounds in the city, namely Kanyama in the South and Chazanga in the North. The FSTPs are owned by the Lusaka Water and Sanitation Company (LWSC) and managed by the Kanyama and Chazanga Water Trusts, which are community-based organisations (CBOs).

Treatment selection and purpose

The main objectives of the Kanyama and Chazanga FSTPs are sludge stabilisation through anaerobic digestion and (sludge) resource recovery: in the form of biogas as a fuel, and stabilised sludge as a soil conditioner. The FSTPs were financed by the Water and Sanitation for the Urban Poor (WSUP) through a Stone Family Foundation grant. The Kanyama FSTP was designed by the Bremen Overseas Research and Development Association (BORDA) in partnership with the Water and Sanitation Association of Zambia (WASAZA), with WSUP providing ongoing technical support. The Chazanga FSTP was a modification of the Kanyama FSTP approach. According to BORDA Zambia, the anaerobic system approach for the FSTP design was chosen for its high sludge stabilisation efficiency and low energy requirements for operations and maintenance (O&M). Obtaining biogas from the primary treatment process was a secondary motivation. Initially, the managers considered supplying biogas to nearby households as an alternative to fuel, but biogas is now reserved for use on-site.

> *The essence of the pilot project was to stabilise and dry the sludge. Natural gravity flow, low energy requirements, biogas for cooking were also part of the motivation.*
>
> **PROJECT ENGINEER, BORDA ZAMBIA**

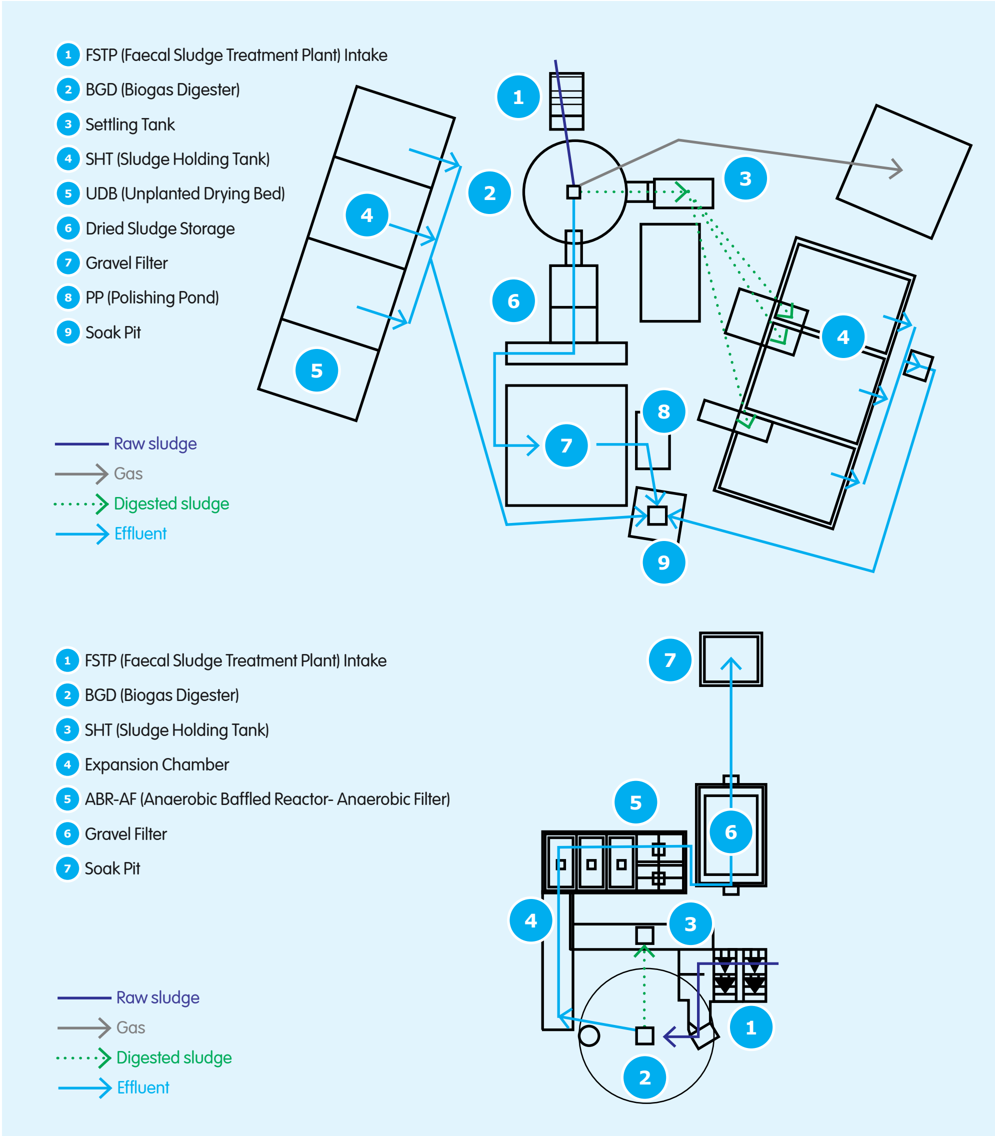
Chazanga biogas digester in construction

Kanyama FSTP worker emptying sludge

Description of the system

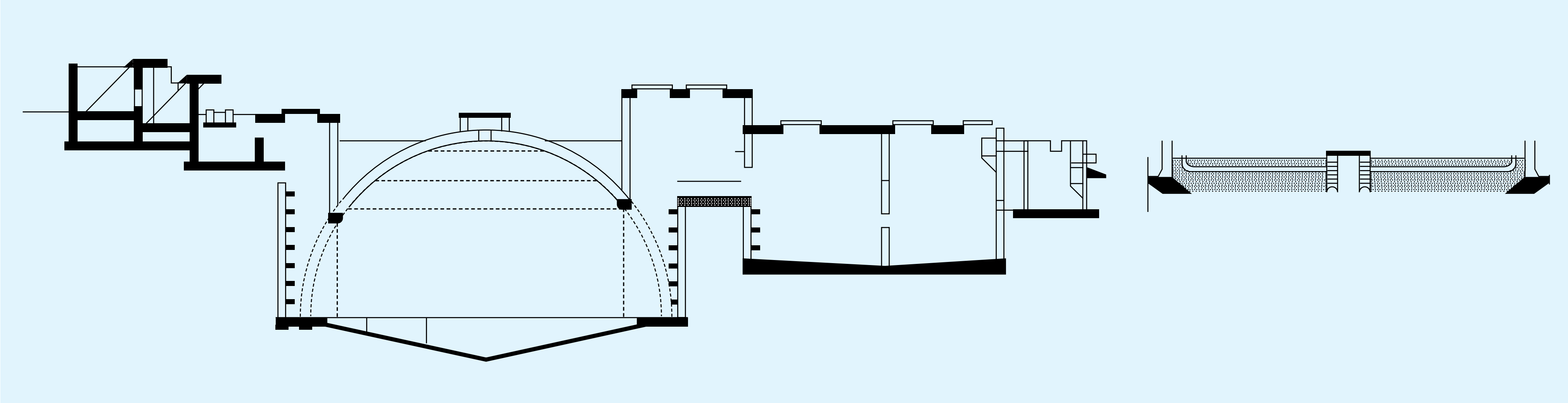
The Kanyama and Chazanga FSTPs have similar process flows, with key differences in the secondary treatment phase only. The FSTPs are designed solely for manually emptied pit latrine sludge. Sludge is transported to the facilities in 60L barrels and carried in open pickup trucks. At the FSTPs, the sludge in barrels is discharged into a series of chambers with the first two chambers having sloping floors and inclined bar screens for solid waste separation. The solid waste captured by the bar screens is placed on separate drying racks in preparation for its transportation to a landfill. The second chamber leads to a sand trap in which sand and grit from the sludge is retained to prevent it from flowing into the primary treatment unit, which is a fixed-dome Biogas Digester (BGD). Each facility has a fixed-dome biogas digester, with the Kanyama FSTP having a 58 m^3 dome and the Chazanga a 50 m^3 dome. The main purpose of the BGDs is to stabilise and digest the fresh and raw sludge. The sludge is homogenised inside the unit due to the turbulence created by changes in pressures during biogas production and consumption. The stabilised sludge then flows naturally by gravity and gas pressure into sludge holding tanks from which the sludge is pumped into tertiary stabilisation units before being sold for reuse. The incoming sludge and increasing gas pressure push the liquid from the BGD into the secondary treatment stage.

Figure 1. Presentation of Chazanga FSTP layout plan and flow diagram (top)[2] and Kanyama FSTP layout plan and flow diagram (bottom)[3] adapted by SNV



[1] A. Simwambi, S. Hibler, B. Pietruschka and P. Hawkins, 'Approaches to Faecal Sludge Management in Peri-Urban Areas: A Case Study in the City of Lusaka', in P. Hawkins and I. Blackett, eds., *FSM Innovation Overview and Analysis, Implementing FSM Services: Emerging Examples of Success*, Seattle, Bill & Melinda Gates Foundation, 2017.
[2] M. Klinger, A. Gueye, A. Manandhar Sherpa and L. Strande, 'Scoping Study: Faecal Sludge Treatment Plants in South-Asia and sub-Saharan Africa', *eFSTP Project Report*, Zurich, eawag, 2010, p.31, https://dqo52087pnd5x.cloudfront.net/posters/docs/gatesopenres-191067.pdf (accessed 9 November 2020).
[3] eawag, *eFSTP Phase I - Scoping study, Chazanga, Kanyama and Manchini (Lusaka)*, Zurich, eawag, 2019, p. 3.

Figure 2. Chazanga FSTP section plan with intake, BGD, settling tank, expansion chamber, and gravel filter[4] adapted by SNV



Secondary treatment of the liquid effluent from the BGDs differs in the Chazanga and Kanyama facilities. In Chazanga, two settling chambers and a rectangular expansion chamber separate the liquids and solids from the BGD. The liquid is pushed out of the treatment unit through a pipe towards the gravel filter, which is the next treatment component. The solids (sludge) remain to settle in the settling chambers as the liquid passes through the unit. The chambers are emptied at least twice a year, and the sludge is transferred into sludge drying beds or a sludge holding tank. In Kanyama, the BGD is connected to an expansion chamber and an anaerobic baffled reactor consisting of three chambers and one anaerobic filter with two chambers (ABR-AF). Anaerobic degradation of the effluent occurs in the ABR-AF, with the liquid effluent flowing to the gravel filter via an overflow pipe. Solid matter that settles in the three baffled chambers needs to be emptied regularly, with the frequency depending on incoming effluent characteristics. The removed sludge is transferred to off-site drying beds.

While both facilities utilise unplanted sludge drying beds (both covered and uncovered) for solid-liquid separation of the settled stabilised sludge, the drying beds are located onsite at the Chazanga facility, and off-site at the Kanyama facility as there is not enough land available for the latter. Sludge delivered at the Kanyama FSTP is stabilised in the biogas digester or holding tank (at another site) before being pumped out by a vacuum truck through the desludging tank and taken to the off-site drying beds. At the Chazanga FSTP, the BGD stabilised sludge is pumped out of the desludging tank using a trash pump and dried in on-site sludge drying beds.[1] The Chazanga FSTP has six operational sludge drying beds whose leachates drain through a sand and gravel filter media in layers. The leachate from the drying beds flows into a soak pit from which it drains into the environment. After the dewatering of the sludge, it is manually removed by the plant operators and stacked in the dried sludge storage space. The dried sludge is sold for reuse as a soil conditioner. In the case of Kanyama, sludge is transported to the Manchinchi Wastewater Treatment site for co-treatment or it is placed for direct drying on beds as there is fear of cross contamination of nearby boreholes at the Kanyama site.

Both facilities use a gravel filter and soak pit for final treatment of the liquid effluent. In Chazanga, the effluent then moves from the gravel filter to a polishing pond (shallow open tank) that stores the liquid before it goes to the soak pit. Through exposure to UV light, further treatment can occur. The treated effluent is used to dilute incoming faecal sludge to clean equipment and to water the facility gardens. The final stage of treatment is the soak pit, which is a covered, porous-walled chamber that is designed to discharge treated effluent into the surrounding soil.

[4] eawag, eFSTP Phase I – Scoping study, Chazanga, Kanyama and Manchinchi (Lusaka), 2019, p.3.

Roofed sludge drying beds at Kanyama FSTP

Lined but not roofed drying beds at Kanyama FSTP

Sorting and drying solid waste at Kanyama FSTP

Table 1. Capacity and operating costs of the Chazanga and Kanyama FSTPs

	Sludge drying beds
Design capacity	4 m³ of sludge/day
Operating capacity	5-7 m³ of sludge/day
Operating costs CAPEX (capital expenditure) OPEX (operational expenditure)	**Chazanga FSTP** CAPEX: US$ 166,500 OPEX: US$ 490-1,080/month (salaries, electricity, O&M) Revenue: US$ 366-975/month (emptying services and sale of biosolids) **Kanyama FSTP** CAPEX: US$ 70,000 OPEX: US$ 1,090-1,440/month (salaries, electricity, O&M) Revenue: US$ 1,058-1,480/month (emptying services and sale of biosolids)

Regulatory environment and compliance

National standards for faecal sludge effluent are in development due to the newness of the approach, with water pollution control regulations currently used for environmental compliance purposes. Several quality standards (limits) for effluent and wastewater are mentioned in the government regulation, 'Third Schedule Regulations 5(2) of The Water Pollution Control (Effluent and Waste Water)'.[5] These include for BOD to not exceed 50 mg/L, Total Dissolved Solids to not exceed 3000 mg/L, and Total Suspended Solids to not exceed 100 mg/L. Results of laboratory testing from the Chazanga and Kanyama facilities were not available.

[5] *The Environmental Protection and Pollution Control Act (1990)* Ministry of Legal Affairs, Government of the Republic of Zambia, http://www.parliament.gov.zm/sites/default/files/documents/acts/Environmental%20Protection%20and%20Pollution%20Control%20Act.pdf (accessed 5 November 2020).

Operation and maintenance: realities, challenges, and opportunities

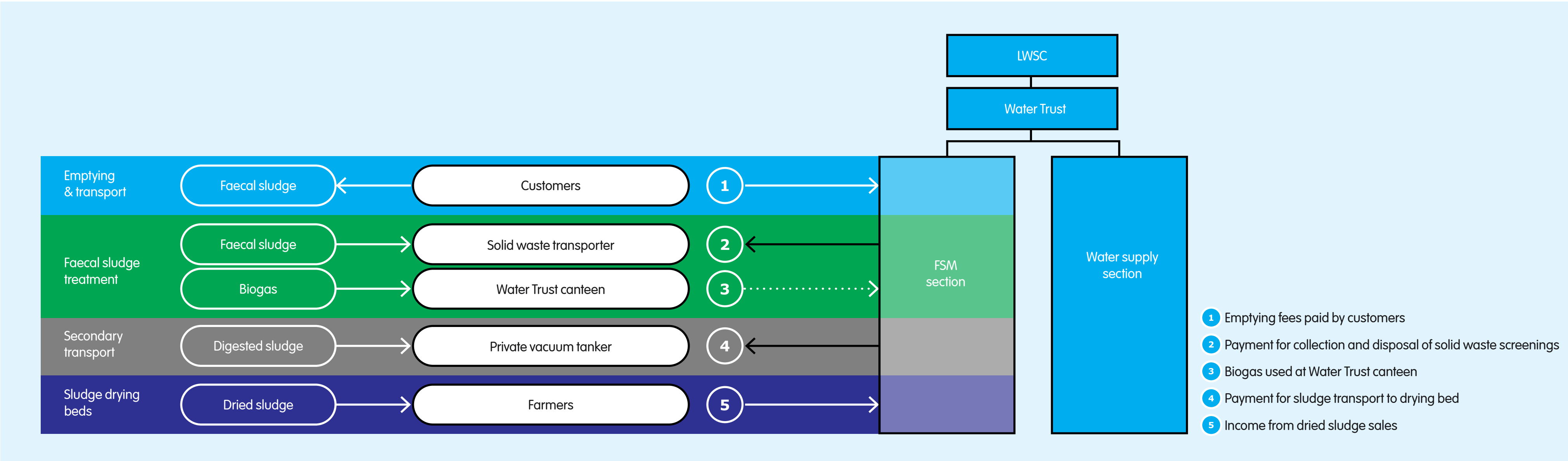
Realities of running the treatment plant

Governance, management, and revenue arrangements

The LWSC owns the FSTP facilities and is responsible for major capital investments, repairs, and providing expert input to the Water Trusts operators. The Kanyama and Chazanga Water Trusts are community-based enterprises owned by local residents, with community oversight by Ward Development Committees and the Lusaka City Council Area Councillor sitting as Water Trust Board Chair. These enterprises are responsible for the day-to-day operations of faecal sludge management services in their respective communities.[6] The Water Trusts employ community-based pit emptiers who are paid on a commission basis. The emptiers are paid 60% of the total FSM revenue and 40% is retained to pay maintenance costs such as management of screened solid waste, transportation of sludge to the drying beds, disinfectants, and purchase of safety equipment. Figure 3 outlines the FSM management by the Kanyama Water Trust, including an overview of revenue flows.

Biogas produced from the Kanyama BGD

Figure 3. Kanyama Water Trust FSM management,[7] adapted by SNV



[6] A. Simwambi, S. Hibler, B. Pietruschka and P. Hawkins, 'Approaches to Faecal Sludge Management in Peri-Urban Areas: A Case Study in the City of Lusaka', 2017.
[7] *eFSTP* Phase 1, 2019, p. 3.

Chazanga FSTP grit separation at influent discharge point

Construction considerations

During construction and rehabilitation of the Chazanga and Kanyama FSTPs key considerations included ensuring sufficient personnel were available, water proofing of the biogas digester, addressing concerns about flooding, and responding to community concerns. Identified pit emptiers who would later be working for the Water Trust partook in construction works so that they would gain familiarity with the FSTP technology. An external bricklayer, familiar with biogas digester construction, was hired to supervise and guide the local pit emptiers and bricklayers. Engineers from BORDA and WASAZA were also involved in training and supervising the construction process.

To ensure that the biogas digester was waterproof, it was lined with 6mm-thick dam lining materials and reinforced with steel and mortar to reduce the chances of groundwater contamination. For the Kanyama FSTP, flooding was one of the major considerations in facility design and construction. The compound is seated on a dolomite rock formation and prone to frequent flooding, which meant that the FSTP needed to be raised a little off the ground to avoid water ingress. Being a rocky subsurface, a lot of blasting was required. Community engagement processes before and during construction were facilitated to address any public objection risks.

> *Informal pit emptiers were engaged as construction workers so as to start inculcating aspects of system ownership in them.*
>
> **PROJECT ENGINEER, BORDA ZAMBIA**

Washing trough for cleaning barrels at the Kanyama FSTP

Staffing arrangements and OHS measures

At both the Kanyama and Chazanga FSTPs, staff are equipped with the necessary occupational health and safety (OHS) training and support measures. Eight semi-skilled staff are employed at each facility and are involved in pit latrine emptying as well as operation of the FSTPs.

All staff are provided with the necessary personal protective equipment. They have received on-the-job training in the following areas: OHS, Standard Operational Procedures (administrative and technical), O&M procedures for the treatment units, and emptying and desludging techniques. OHS measures that have been implemented at the facilities include construction of a ramp to the discharge point so that staff can easily roll the barrels full of faecal sludge for disposal rather than lifting them, and handwashing facilities for workers and provision to clean the barrels in a hygienic manner, while recovering the used water back into the system. All staff undergo periodic medical check-ups, are are provided with oral cholera, tetanus, and hepatitis B vaccines.

> *Community engagement processes included sensitisations and exposure visits to facilities using biogas digester technology.*
>
> **PROJECT ENGINEER, BORDA ZAMBIA**

Challenges of construction, and operation and maintenance

Clogging due to high sand and solid waste content

According to the system operators, the Chazanga and Kanyama FSTPs become blocked two to three times a year due to the high sand, sediment, and solid waste content from pit latrines and lack of regular maintenance. High solid waste content of the sludge (up to 20% solid waste) leads to blockages in the perforated distribution pipes of the BGD, the secondary settler chambers, and the sand traps. As the received sludge is very thick and the facilities have limited water access and water pressure, they encounter difficulties in diluting the sludge to achieve the required consistency for a good flow. This challenge resulted in the facilities being shut down for an average of three weeks (2-3 times per year), forcing the pit emptiers to undertake manual emptying using buckets. Extra funds from the Water Trusts are required to cover the pit emptiers' salaries while they undertake the work.

During normal operations, the solid waste is screened out from the sludge. But when the facilities need to be shut down 2-3 times per year, solid waste is dried and then periodically moved to the municipal landfill by a registered waste transporter at a cost of US$ 40/tonne.[8]

> *There were times when the system was overfed with too much sludge. The accumulation of sand from pits is another challenge, which makes the system fill faster and reduce the retention time.*
>
> **FSM BUSINESS DEVELOPMENT LEAD, LUSAKA WATER SUPPLY AND SANITATION COMPANY**

Inside the Chazanga biogas digester

Overloaded and non-operational drying beds

Currently, the Chazanga FSTP drying beds are overloaded with sludge, and the drying beds used for the Kanyama FSTP are non-operational. In Chazanga, capacity of the six drying beds is not sufficient for all the settled sludge processed at the facility. As a result, a temporary sludge receiving chamber was built in order to store the excess sludge, particularly when the BGD and settling chambers are being desludged. At the Kanyama facility, there are no drying beds onsite, and the 12 beds that were being used about three kilometres away have been decommissioned due to their close proximity to boreholes. Currently, all sludge collected by the Kanyama FSTP is taken to the decommissioned Manchinchi Wastewater Treatment Plant for storage in their sludge holding tanks. The construction of two new sludge drying beds has been proposed at a new site within the Kanyama settlement, about one kilometre from the Kanyama FSTP. Construction is planned for 2021.

> *Both facilities experience operational challenges with the sludge drying beds.*
>
> **FSM AND DESIGN ENGINEER, WSUP**

[8] A. Simwambi, S. Hibler, B. Pietruschka and P. Hawkins, 2017.

Kanyama FSTP decommissioned sludge drying beds

Dried sludge for sale

Pricing of services constrained by customers' willingness to pay and market competition

The pricing of FSM services offered by the Chanzanga and Kanyama facilities is based on estimated ongoing O&M costs but is constrained by customers' willingness to pay and the need to compete with informal service providers. The pricing model requires customers to pay US$ 34 for 12 sixty-litre barrels, US$ 48 for 24 barrels, and US$ 68 for 32 barrels.[9] This pricing model has not been sufficient to cover all O&M costs as not enough customers took up this service. The pricing model changed in 2020 with support from the Lusaka Sanitation Programme, which intends to increase uptake through price reduction and provision of incentives for private-sector vacuum operators to desludge pit latrines. This has resulted in a lower price for households of US$ 7/m^3. What is unclear is for how long this lower price can be sustained.

Opportunities for reuse

To generate revenue through resource recovery, it was planned for the dried sludge to be sold as a soil conditioner and for biogas to be sold to nearby households. At present, the processed and dried sludge is packaged and sold to landscapers as a soil conditioner. Within the initial design of the FSTP, the biogas produced by the BGD was intended to be piped for sale to nearby households at a value equivalent to that of charcoal. However, this failed as these houses were predominantly occupied by tenants who could not get consent from their landlords for the gas connections.[10] In addition, the price of the gas was higher than that of coal and electricity. The cost to connect only a few houses was not financially viable. The gas is therefore used by the Water Trusts themselves, for the workers' canteen in Kanyama and by the caretaker living at the Chazanga FSTP site. Gas production is approximately 12.5 m^3/d but is greatly dependent on the amount of sludge fed into the biodigester each day. The gas is mainly used for cooking, and the estimated consumption is about 4-6 m^3/d, with the excess gas burnt in the open air.

[9] A. Simwambi, S. Hibler, B. Pietruschka and P. Hawkins, 2017.
[10] A. Simwambi, S. Hibler, B. Pietruschka and P. Hawkins, 2017.

Informed choice considerations		Biogas digesters for treatment and reuse in Lusaka, Zambia (Lusaka Water and Sanitation Company)
	Operating & design capacity	Design capacity = 4 m^3/day of sludge Operating capacity = 5-7 m^3/day of sludge
	Operating costs	**Chazanga FSTP** CAPEX: US$ 115,000 (initial costs) + US$ 11,500 (additional works, e.g., extra drying beds) = US$ 166,500 OPEX: US$ 490-1,080/month OPEX (salaries, electricity, O&M) Revenue: US$ 366-975/month (emptying services and sale of biosolids) **Kanyama FSTP** CAPEX: US$ 125,000 OPEX: US$ 1,090-1,440/month (salaries, electricity, O&M) Revenue: US$ 1,058-1,480/month (emptying services and sale of biosolids)
	Energy requirements	Natural system, no energy requirements
	Input characteristics	Solid waste fraction of sludge up to 20%
	Land requirement	970 m^2 for Kanyama without drying beds, and Chazanga with drying beds on 1,400 m^2 plot
	Skills and human resources requirements	Eight semi-skilled staff are employed at each facility (Kanyama and Chazanga) and are involved in pit latrine emptying as well as operation of the FSTPs
	Technology/material local availability	Materials and manufacturing all locally available and managed

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Photos: WSUP

CASE STUDY 6

Black soldier fly (waste) treatment

Nairobi,
Kenya

Background

Treatment selection and purpose

Sanergy has been using Black Soldier Fly (BSF) systems to treat and upcycle organic waste into agricultural products and biomass briquettes. As a social enterprise, Sanergy was created in 2011 in response to the inadequate access to safe sanitation and waste management services experienced by Nairobi residents living in slums. Sanergy also saw an opportunity to develop agricultural inputs, such as insect-based protein for animal feed and organic fertiliser. Sanergy uses a full value chain approach, and the BSF technology was initially trialled in Kenya through a partnership with the Bill & Melinda Gates Foundation in 2013.

> *In Nairobi, 66% of all faecal waste generated ends up untreated back in the ecosystem, polluting the environment and harming public health. As Sanergy envisions to effect a systems change, we have developed an urban pit waste management service that aims to capture and contain manually emptied pit latrine waste in a formalised way.*
>
> **CO-FOUNDER, SANERGY**

Sanergy's black soldier fly (BSF) colony

Fresh Life container based, urine-diverting toilet

Description of the system

Sanergy utilises BSF larvae and thermophilic composting to treat and upcycle faecal sludge, agricultural waste, and market and kitchen food waste. Faecal sludge is contained in Fresh Life Toilets (a container-based system used for the storage of human waste) in Nairobi. These toilets are designed to reduce the moisture content of the sludge by separating urine and faeces. As of December 2019, Sanergy had installed a total of 3,247 Fresh Life Toilets in 11 informal settlements, serving over 80,000 urban residents. The containers, which hold the sludge, are double sealed and collected by operators with handcarts that transport the sludge to a decentralised collection point. Filled-up containers are replaced with clean empty containers in the Fresh Life Toilets. The containers are collected from the decentralised collection point and transported by vehicle to a transfer station, where the sludge is consolidated in large barrels and transported by truck to the treatment plant.

The BSF larvae break down organic material and return nutrients to the soil. The BSF system harnesses this process to convert organic materials – such as manure, agricultural waste, food waste, and human sludge – into usable by-products. In BSF processing facilities such as Sanergy's, the BSF larvae feed on decomposing organic material, and the larvae grow from a few millimetres to around 2.5 cm in 14 to 16 days, while reducing the wet weight of the waste by up to 80%.[1] The BSF larvae are 'harvested prior to the prepupal stage using a mechanical agitator to separate them from organic wastes.' Due to the high protein (approximately 35%) and fat (approximately 30%) content of the larvae, they can be used as animal feed. The frass residue (excrement from insect larvae) can be used as a soil conditioner but requires further treatment.[2] At Sanergy, the frass residue is mixed with carbon sources from plant waste in thermophilic composting windrows to produce organic fertiliser. Temperature, aeration, and moisture content are systematically measured to ensure a high-quality compost. Fuel briquettes are also produced from the frass residue through pyrolysis for use at the treatment facility. This helps reduce fossil fuel consumption and operating costs.

The Fresh Life Toilets ensure containment and separation of faeces and urine. Sanergy is also working with agricultural pack houses, markets, and restaurants to separate organic food waste from inorganic waste, plastics, and metals. The food waste is placed in dedicated containers that are collected and transported by Sanergy to other waste management and recycling companies. Sanergy is also exploring options to use pit latrine sludge by dewatering it first. While urine is currently safely disposed of, Sanergy is exploring options to reuse it.

Table 1. Capacity and operating costs of BSF treatment plant

	Conventional treatment plant
Design capacity	7t (current) and 200t (planned) of faecal sludge and organic waste/day
Operating capacity	7t (current) and 200t (planned) of faecal sludge and organic waste/day
Costs	Capital expenditure, CAPEX = US$ 7 million

[1] B.M.A. Dortmans, S. Diener, B.M. Verstappen and C. Zurbrügg, *Black soldier fly biowaste processing: a step-by-step guide*, Dübendorf: eawag, 2017, https://www.eawag.ch/fileadmin/Domain1/Abteilungen/sandec/publikationen/SWM/BSF/BSF_Biowaste_Processing_HR.pdf (accessed 8 April 2020).
[2] K. Tayler, *Faecal sludge and septage treatment: a guide for low- and middle-income countries*, Rugby, Practical Action Publishing, 2018, https://www.pseau.org/outils/ouvrages/practical_action_faecal_sludge_and_septage_treatment_a_guide_for_low_and_middle_income_countries_2018.pdf (accessed 25 April 2020), p. 332.

Emptiers removing sludge from Fresh Life toilets


BSF larvae ready for harvesting

Regulatory environment and compliance

Sanergy contracts third parties to test their end products to ensure compliance with international standards such as ISO 16649 and ISO 6579. Laboratories in operation at the treatment facility conduct testing of the sludge at various points in the process to ensure the BSF treatment removes pathogens from the end products including the fertiliser and animal feed, based on testing of E.coli. Independent testing by credible laboratories such as NAS-SERVAIR is conducted for comparison and to ensure the end products are free of pathogens.

Operation and maintenance: realities, challenges, and opportunities

Realities of running the treatment plant

Staffing and training

Sanergy has over 250 employees involved in waste collection, waste processing, distribution of agricultural inputs, strengthening the enabling environment (government regulation and policy), and research and development (R&D) activities. Regular training of all employees is conducted, particularly for emptying and treatment operators. Operators meet at forums for peer learning. Additionally, Sanergy has recently helped one group of 22 manual pit emptiers to become a formally registered community-based organisation (CBO) that is able to legally operate. Sanergy provides a waste transfer station for safe disposal of pit waste and helps emptiers to build professionalism in their work, through the use of personal protective gear, and by enhancing hygiene standards for themselves and their work.

Seed funding and financial sustainability

Sanergy financed the plant's initial set-up through seed funding and grants. Sanergy's growth has been supported by philanthropic partners and impact investors. To build the model's financial sustainability, Sanergy earns revenue from its for-profit arm, including through the sale of organic fertilisers and insect-based animal feed.

Challenges of operation and maintenance

Environmental conditions for BSF system

A key challenge faced by Sanergy was in establishing the correct environmental conditions to support BSF reproduction and growth cycles. Providing the right food source and climatic conditions to best mimic the natural habitat of the BSF for maximum output required a number of trials by the Sanergy R&D team. Regular monitoring of BSF reproduction and growth is required to ensure a reliable and steady supply of larvae to process waste. BSF reproduction and growth are sensitive to a number of environmental conditions including temperature, humidity, light, depth of organic waste, and ventilation.[3] To improve the food source of the BSF larvae, food and agricultural waste were mixed in with the faecal sludge. These measures assisted in scaling up the reproduction of BSFs and producing protein-rich insect-based animal feed.

Need for a strong enabling environment

Towards the beginning of production, Sanergy faced challenges in relation to land tenure for the toilet facilities in informal settlements, as well as in government policies that limited the manufacture and sale of waste-derived products. Policy changes were needed, and this was achieved by working in partnership with government, municipalities and other sanitation stakeholders. An enabling environment was created that supported the review and amendment of policies related to the treatment and reuse of waste to manufacture valuable products, and endorsement of container-based sanitation systems.

> *To realise our vision of providing safe sanitation to everyone and implement our circular economy approach to solve urban waste management challenges, Sanergy recognised that working with the government from the onset is very critical.*
>
> **CO-FOUNDER, SANERGY**

Lessons learnt

Investment and ongoing research required

Upfront investment and ongoing research are required to successfully treat and convert waste into agricultural inputs and alternative fuel products. Sanergy's recycling factory is the largest in East Africa. It has been adapted to use technologies developed in-house by Sanergy's team of engineers. All these have involved significant investment. In addition, investing in continuous research to improve product quality and standard operating procedures has been viewed as essential to improve the efficiency of the process and maximise revenue from the sale of high-quality products. Sanergy has partnered with various research organisations to support the continuous improvement process, and to promote the ongoing capacity building of the Sanergy staff.

Importance of understanding community needs

Sanergy has learnt that while marketing campaigns have a role to play in product and service promotion, they are particularly important for encouraging sanitation uptake and behaviour change. Personalised and targeted problem-led conversations with the different community members which address their needs have been found to be an effective way to ensure buy-in to Sanergy services and products. By directly addressing existing challenges, such as the agricultural and energy challenges faced by farmers and communities, buy-in for the products has been established.

Sanergy has also learnt that engaging with customers frequently and listening to what they value is central to providing a product or service that they actually use. In the case of the Fresh Life Toilet, Sanergy's team of engineers has continued to improve the toilet's design to incorporate customer feedback to solve any problems with toilet use. For example, version 3.0 of the Fresh Life Toilet, launched in 2015, includes a child- and woman-friendly squat plate, an interior with an easy-to-clean tile floor, and a squat-support to help people with disabilities to use the toilet.

> *In order to operate successfully, we have established an open and collaborative relationship with the communities where we work.*
>
> **CO-FOUNDER, SANERGY**

[3] K, Tayler, *Faecal sludge and septage treatment*, 2018.

Informed choice considerations	Black soldier fly treatment as reuse in Nairobi, Kenya (Sanergy)
Operating & design capacity	Design capacity = 7t (current) and 200t (planned) of waste per day Operating capacity = 7t (current) and 200t (planned) of waste per day
Operating costs	Capital expenditure, CAPEX = US$ 7 million
Energy requirements	Solar energy utilised: 350 MWh/month Mains (grid) electricity utilised: 87 MWh/month
Input characteristics	E. coli: $1.5x10^5$ to $2.0x10^5$ cfu/g*
Output characteristics	E.coli: <10 cfu/g
Land requirement	The area required for BSF processes is approximately 500-750 m^2 per tonne of dry solids processed per day with an additional 60 m^2 per tonne required for a waste receiving area and to accommodate a laboratory, office and storage space, and employee facilities[4]
Skills & human resources requirements	250 staff, ranging from semi-skilled (emptiers) to skilled (engineers, researchers with tertiary qualifications)
Technology/material (local) availability	Materials and manufacturing all locally available and managed, with some technologies internationally imported

*cfu - colony forming units i.e. number of bacteria/fungi

[4] B.M.A. Dortmans, S. Diener, B.M. Verstappen and C. Zurbrügg, *Black soldier fly biowaste processing*, 2017.

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CASE STUDY 7

Deep row entrenchment

Asia and Africa

Background

Treatment selection and purpose

Deep row entrenchment (DRE) can be used as a simple technology for the safe disposal, and in some cases, reuse of faecal sludge. This case study shares experiences from Malaysia, India, South Africa, and Benin in using and piloting DRE as an interim or longer-term solution. Across all four countries, DRE was chosen because of its low cost, and the simplicity of its design. In South Africa and Benin it was also chosen for its potential to provide opportunities for sludge reuse as soil conditioner in agroforestry.

In Malaysia and India, DRE was introduced as an interim solution to dispose of waste while awaiting the construction of faecal sludge and wastewater treatment facilities. In both countries, disposal of untreated sludge in deep trenches was not perceived as a desirable long-term strategy because of possible ground and surface water pollution through leaching. In Malaysia, DRE was introduced in 1994 by the Indah Water Konsortium (IWK), a government-owned company. A total of 26 trenching sites were created across the country, but almost all have now been phased out as Faecal Sludge Treatment Plants (FSTPs) and sewerage services have taken their place. In India, DRE is currently being used in the state of Odisha, with 84 trenching sites servicing 114 towns. The DRE sites are owned and operated by the local municipalities, with Ernst & Young providing technical support to towns transitioning towards FSTPs.

In South Africa, the Water Research Commission (WRC), in partnership with Partners in Development and the University of KwaZulu-Natal, has been investigating the potential of DRE through the evaluation of five separate experiments across the country since 2007. A pilot study is currently being set up in the community of Parakou in Benin to investigate the longer-term use of DRE as a disposal and reuse mechanism. The pilot has been set up to plant trees on top of covered trenches and is a key part of the Parakou Sanitation Plan.

Across all four countries, DRE was chosen because of its low cost and its simplicity of design.

It was also chosen in South Africa and Benin due to its potential to provide opportunities for reuse of sludge as a soil conditioner.


Emptying sludge into a trench at entrenchment site in Umlazi, South Africa

Description of the system

The construction and operation of deep trenches is simple, with site selection often the most complex aspect. In South Africa, site selection depended on whether a site was large enough to accommodate the volume of anticipated sludge over the tree growth cycle. The criteria used in making this assessment included: trench size, volume, size of the community being serviced, and the duration of the tree planting cycle. The tree planting cycle is relevant because the sites are tied up for 6-9 years. Other site selection criteria are, distance to sources of sludge, means of transport, and access to site for vehicles transporting sludge.[1] In India, guidelines developed by the Water Sanitation and Hygiene Institute (WASHi) stipulate that the selected land should be reasonably flat for easy operation and for desludging trucks to access the trenches. Waterlogged or flood prone areas should be avoided. A sufficient buffer distance to habitable properties is required (at least 200 m). Fencing around the site and warning signage should also be considered.[2]

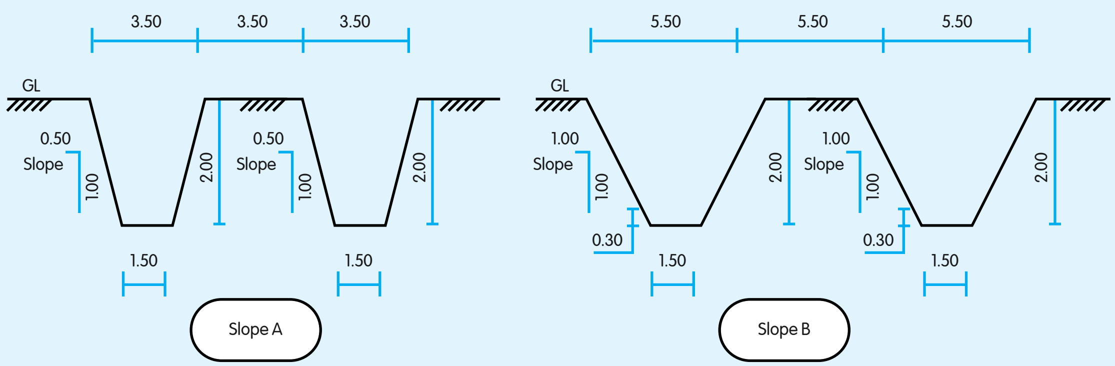
In selecting appropriate sites for the construction of deep trenches, several environmental considerations need to be taken into account. The site should not be close to surface, sub-surface or groundwater sources, and an investigation is required to evaluate the extent of separation between the base of the trench and the water table to prevent pollutant entry. An analysis of the characteristics of the soil and rock material and whether they allow rapid infiltration of polluted water is also required.[3 4]

The dimensions of the trench are one of the most important factors to consider in designing the trenching site. Dimensions can vary across sites, as shown in Table 1. Recommendations from the South African case study state that the optimal dimensions for trenches are 800mm deep and 600mm wide. The spacing between rows should take into consideration soil stability, with adequate space to accommodate the vehicles digging the trenches and those delivering the sludge.[5] Figure 1 provides a diagram of the recommended dimensions for deep trenches. The choice of slope dimensions will also depend on soil type and stability.

Table 1. Dimensions of deep trenches across the India, South Africa, and Benin case studies

Criteria	India (Odisha State DRE project and WASHi technical guidelines)	South Africa (Sappi Forest experiment)	Benin (to be piloted)
Depth	1.5 m	1.5 m	1.5 m
Length	10 m	20 m	50 m
Width	2.5 m-5.5 m (top width of trench) 1.5 m (bottom width of trench)	0.6 m	2.5 m
Distance between two trenches	3.5 m	3 m	1 m
Design capacity of trench	0.5m³ of sludge per m² of surface area	0.25m³ of sludge per m² of surface area	1m³ of sludge per m² of area

Figure 1. Model of normal deep trench adopted in India, adapted by SNV[6]



Length of the trench: 10m

Adopt any one of the slope based on the soil and site condition

Dimensions are to be read in metres

[1] WRC, *Entrenchment of pit latrine and wastewater sludges: An investigation of costs, benefits, risks and rewards,* Pretoria, Water Research Commission, 2015.
[2] WASHi, *Technical notes on shallow and deep trenches for faecal sludge/septage*, New Delhi, Water Sanitation and Hygiene Institute, 2020.
[3] WASHi, *Technical notes on shallow and deep trenches for faecal sludge/septage*, 2020.
[4] WRC, *Entrenchment of pit latrine and wastewater sludges*, 2015.
[5] WRC, 2015.
[6] WASHi, 2020, p. 26.

Household sludge buried in trenches is treated through natural biological processes. Once trenches have been filled with sludge, they can be covered with the excavated soil. Through dewatering and decomposition, the sludge becomes barely distinguishable from the surrounding soil after a few years. Trees that need large amounts of nitrogen can be planted in or alongside the trenches (as was the case in some of the South African experiments, and as is intended in the Benin pilot) or buried sludge can be left for up to four years to completely decompose. While most pathogens in sludge die off within 6-8 months, the ovum of Ascaris lumbricoides (roundworm) may survive for up to four years, and so roundworm is used as a marker organism to determine the degree to which sludge can be considered safe to handle. Therefore, it can be reasonably concluded that if there is a need to do so, buried sludge could be safely dug up after four years.[7] In terms of agroforestry, the average life cycle of trees is between 6 and 10 years before they can be harvested, which would leave sufficient time for any pathogens in the sludge to die off. It is, understandably, advised to avoid using the soil conditioner from DRE for annual or edible crops.

Regulatory environment and compliance

Ongoing monitoring of groundwater and soil on the DRE site is necessary to ensure that environmental and public health regulations and guidelines are being met. Baseline values of groundwater and soil should be established before sludge is entrenched at the site in order to provide a basis for assessing the impact of the entrenched sludge over time. India and South Africa, however, followed slightly different guidelines and monitoring.

Ongoing monitoring of groundwater and soil on the DRE site is necessary to ensure that environmental and public health regulations and guidelines are being met.

Umlazi planted trenches site in South Africa

Based on the South African experience, the WRC report outlines slightly different guidelines for the monitoring of groundwater and soil in DRE sites. Monitoring of water on the site should include faecal coliforms and E. coli. The following chemical attributes were also monitored in the South African case due to it being a research project: organic nitrogen, nitrate-nitrogen, ammonium nitrogen, chlorides, pH, COD, zinc, cadmium, copper, and specific conductivity. The frequency of monitoring will be determined by the depth of the groundwater table, clay content, the pH of the soil, and the water content of the sludge. Where the depth of the water table is less than 5 m, three-monthly monitoring processes for dry sludge, and monthly for liquid sludge during the rainy season are suggested. Less frequent monitoring may suffice if the clay content of soil on the DRE site is greater than 35%, i.e., if dewatered sludge is entrenched above a water table deeper than 10 m, or if liquid sludge is entrenched above a water table deeper than 20 m. In some cases, monitoring of groundwater may not be necessary due to the depth of the water table.

[7] WRC, 2015.

Operation and maintenance: realities, challenges, and opportunities

Realities of running the treatment process

Sludge type, quality, and quantity

The type, quality, and quantity of sludge buried in the deep trenches are important considerations when managing a DRE site. In general, the four case study countries have only accepted household sludge, rejecting industrial, commercial, or toxic sludge. The untreated sludge generally comes from household pit latrines or septic tanks, with the exception of the Sappi Forest trial in South Africa, which received its sludge from a local wastewater treatment facility. In India, guidelines have been established to control the quantity of sludge received by keeping a record of the number of trucks entering, date of entry, quantity of sludge deposited, and time taken to fill each trench. Additionally, in South Africa, laboratory testing of the sludge is recommended if there is any reason to believe that it is contaminated with pollutants.

Sludge entrenchment costs

While DRE is an economical disposal option for sludge, some costs are still incurred in this approach. In South Africa, a cost of US$ 0.33/metre of trench was estimated, including the costs for digging the trench, maintaining the trench, and transporting the sludge (which is by far the largest proportion of the cost). Further costs are associated with establishing leachate and groundwater monitoring well points, with an estimated cost of US$ 546/hectare of trenching sites; assuming that one monitoring well will cover at least ten hectares.[8]

In the Benin pilot, the intention is to establish a partnership contract with the three desludging companies operating in the commune of Parakou. The desludging companies will be charged US$ 0.80/m^3 of sludge to empty into the deep trenches. In the Indian DRE project, the municipality does not charge desludging companies to empty sludge into the trenches because it wants to encourage them to use the trenches and not dump sludge into waterways. As DRE is seen as an interim solution to sludge disposal, the municipality absorbs costs for the time being.

In the Benin case, it has been calculated that if the desludging companies were to charge households US$ 7.50/m^3 of sludge removed, this could result in a potential profit for the companies of 30% per 10 m^3 of sludge (after taking into consideration all costs such as disposal charges, fuel, labour and vehicle costs). This billing rate would need to be agreed to by all the desludging companies. In other countries in Africa, this fee can sometimes be between 4-10 times than that quoted for Benin.

Testing soil quality

Testing of the impacts of sludge disposal on the soil characteristics is a necessary part of DRE monitoring processes. In South Africa, the Sappi Forest experiment reported spikes in nitrate and phosphate concentrations in the leachate, in the immediate proximity to the sludge. However, they observed no significant increases in nitrate or phosphate concentrations in any of the boreholes located between the sludge entrenchment sites and the nearest downslope streams. After three years there were no significant differences between the nitrogen and phosphate levels in the sludge and the soil surrounding the sludge. Similarly, in Malaysia in 2009, seven sites were chosen to assess the changes in nutrient and heavy metal concentrations in the soil due to DRE.[9] The sites were chosen based on the duration of trenching disposal activities, with a minimum of five years required. The soil sampling found slight improvements in nitrogen, phosphate, and potassium concentrations, and no significant increases in heavy metals. The study concluded that trenching can help to improve soil nutrient values, the rate of heavy metal accumulation is slow, and the observed chemical levels in trench samples were lower than the proposed limits.

OHS considerations

Due to the likelihood of variable pathogen concentrations in sludge, it should be handled as a hazardous waste and workers should be provided with the appropriate occupational health and safety (OHS) training and support, just as in other sludge treatment processes. Across the case study sites, OHS protocols for transporting and handling sludge were provided, along with associated training. This training included educating workers about pathogens, routes of transmission, and procedures to protect their health. Workers must wear protective gear while handling sludge to prevent infection by bacteria, viruses, or intestinal parasites. Parasitic eggs can become airborne when sludge is handled, making it important that workers wear masks, gloves, boots, and overalls. The rigorous OHS protocols prevent the transfer of pathogens out of the DRE site by ensuring that contaminated protective clothing is not worn outside of the DRE site or when driving vehicles. The OHS protocols also ensure that vehicle wheels do not become contaminated, carrying pathogens with them when they leave the site. Workers should also be provided with the means to disinfect their clothing before going home. Finally, it is recommended that workers are provided with regular health check-ups and deworming treatment if they regularly work with sludge.

[8] WRC, 2015.
[9] IWK, *National Environmental Health Action Plan (NEHAP): Effects of the reuse of sludge to environmental health*, Kuala Lumpur, Indah Water Konsortium, 2015.

Challenges of construction, and operation and maintenance

Accessibility considerations for desludging trucks

DRE sites should be designed and prepared in a way that allows access for heavy desludging trucks. Trenches should be dug parallel to the contours of the slope of the site, with trench spacing and dimensions dependent to some degree on the results of soil stability assessments, the natural ground slope, and the depth of the water table. Due to the anticipated frequent passage of desludging trucks, enough space must be left to accommodate the vehicles, and the backfill should be heaped beside the trench, without the trench collapsing.

Various solutions to prevent trenches from collapsing have been suggested and trialled across the case study countries. For the Benin pilot, the soil will be compacted at the point where trucks empty sludge into the trenches. In India, the walls of the trenches are cut at an incline to minimise the risk of collapse. In South Africa, the advice was for test trenches to ensure that the desired dimensions and spacing are adhered to in order for trucks to dispose of sludge without damaging the trench walls.

Environmental health concerns

Factors such as flooding, heavy rains, or encroachment of human settlement in DRE sites could alter the environmental impact of entrenchment during or after the period of use. In India, entrenchment has not been used in any areas that have issues with flooding or inundation, and trenches are not used during the monsoon season. Flooding or heavy rains may cause pollutants and contaminants in the sludge to rise to the surface or move further and more quickly (or in higher concentrations) through groundwater. Similarly, the encroachment of human settlement close to DRE sites may reduce buffer zones and may make water near the entrenchment site unsuitable for human consumption. Where DRE sites are affected by any of these factors, sludge entrenchment should be suspended until it is deemed safe to continue, or activities should be suspended indefinitely. In worst case scenarios, the sludge should be dug up and safely disposed of elsewhere.

Factors such as flooding, heavy rains or encroachment of human settlement to DRE sites could alter the environmental impact of entrenchment during or after the period of use.

Decomposed sudge after 3.5 years at the Umlazi site in South Africa

Opportunities for beneficial use

While DRE is primarily used as a sludge disposal mechanism, opportunities for beneficial use are possible in the form of agroforestry. Trees can be planted on top of or alongside filled trenches, and the nutrients in the sludge will improve growth rates and increase timber volumes. In the South African Sappi Forests experiment, sludge that was buried close to eucalyptus trees increased total timber volume by up to 50%. This additional timber volume was assessed as being able to offset the cost of the entrenchment process by as much as a third or even a half. This is less than the cost of entrenching the site but does offset the cost of the sludge disposal to a certain degree. In Benin, the community of Parakou intends to plant Gmelina Arborea trees on the filled trenches during the rainy season, at least 3-6 weeks after the trenches have been filled. The waiting time will allow for stabilisation of the sludge. Once the trees have matured, the community will either preserve the area as an artificial urban forest or harvest the trees for commercial sale after a period of ten years.

Informed choice considerations

Deep row entrenchment across Benin, India and South Africa

Design capacity	18-200 m^3 of sludge (depending on dimensions of trenches and land area available)
Operating costs	US$ 18/m^3 for trench excavation, backfill, and transportation of sludge US$ 900/ha for ongoing groundwater monitoring (estimates based on the South African experience)
Energy requirements	Natural system, no energy requirements except for fuel to power the excavator when preparing the trenches
Input characteristics	Household sludge from pit latrines and septic tanks
Output characteristics	After four years, the sludge is difficult to distinguish from the surrounding soil
Skills & human resources requirements	Minimal staff required: desludging truck operators (the most important staff), as well as staff to dig trenches or manage the site
Technology/material (local) availability	Low technology requirements; materials and manufacturing all locally available

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Photos: David Still

CASE STUDY 8

Use of rotating biological contactors

Banjarmasin, Indonesia

Background

Treatment selection and purpose

The Pekapuran Raya Waste Water Treatment Plant (WWTP) is one of seven WWTPs in Banjarmasin city that uses rotating biological contactors (RBCs) for the treatment of wastewater. The Pekapuran Raya plant has been in operation since 2008. All seven WWTPs in Banjarmasin city are owned by central government but are operated and maintained by PD PAL Banjarmasin, an independent government-owned company.

Several stakeholders were involved in selecting and designing the RBC technology and facility, including the local Public Works and Housing Office representatives, the provincial technical team of the Ministry of Public Works and Housing, the Director of PD PAL Banjarmasin, and a local consultant who designed the facility. The final decision on the technology and facility design was made by the Public Works and Housing Office in Banjarmasin. The decision was based on ease of operation, land area requirements, operational cost, and ability to meet the required effluent standards. The RBC technology requires operators to have mechanical maintenance skills, but no process control function skills. The technology does not require a large land area, which made it suitable for Banjarmasin city as it is densely populated and available land is scarce. The RBC requires electricity to operate, but compared to other mechanical technologies, the electricity requirements, and therefore operational costs, are lower.

> *The RBC technology was chosen because it is easy to operate, [it] does not need special skills to operate, and it does not require a big area. Land availability is quite an issue in Banjarmasin.*
>
> **HEAD OF TECHNICAL DIVISION, PD PAL BANJARMASIN**

Rotating Biological Contactor (RBC) Unit

Description of the system

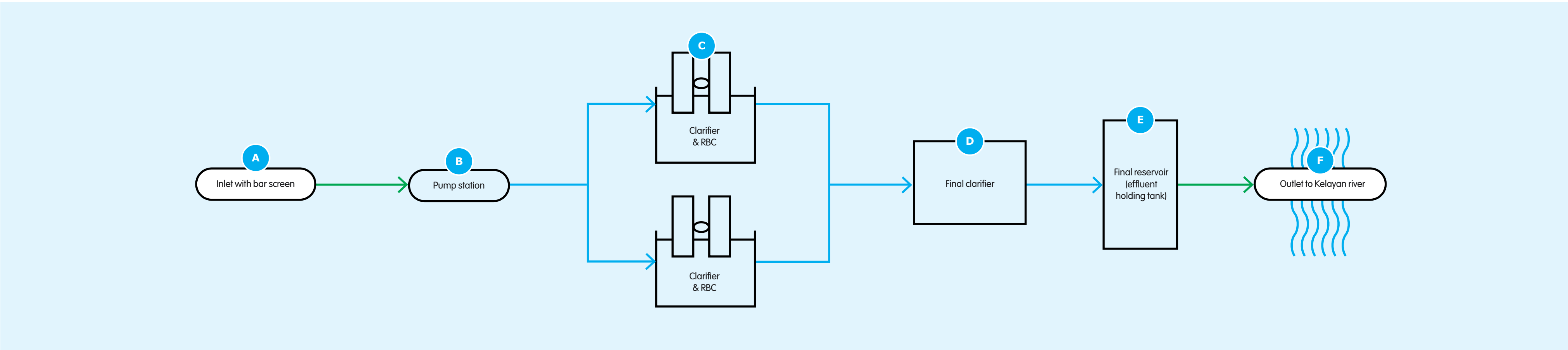
The wastewater at the Pekapuran Raya WWTP is treated using a biological treatment process, which relies on the RBCs for secondary treatment. The wastewater, which includes greywater and blackwater from households, hotels, restaurants, and offices, is delivered to the facility via a piped network. The treatment process is outlined in Figure 1.

As shown in Figure 1 the treatment process starts with step A, which is the inlet from the main sewer pipe delivering wastewater to the facility. Step B is the sewage pump station, which pumps the wastewater from seven metres below the ground to the processing unit. A bar screen before the pump station unit screens solid waste from the wastewater as part of the primary treatment process. In Step C, two clarifiers and two RBC units (8.15m long) are used for secondary treatment of the wastewater. The RBC consists of a series of closely spaced, parallel discs mounted on a rotating shaft, which is supported just above the surface of the wastewater. Microorganisms grow on the surface of the discs where biological degradation of the wastewater pollutants takes place. The rotating packs of disks, known as the media, are placed in a tank and rotate at 2-5 revolutions per minute. The shaft is aligned so that the discs rotate at right angles to the wastewater flow, with approximately 40% of the disc area immersed in the wastewater.[1]

Bar screen with submersible pump

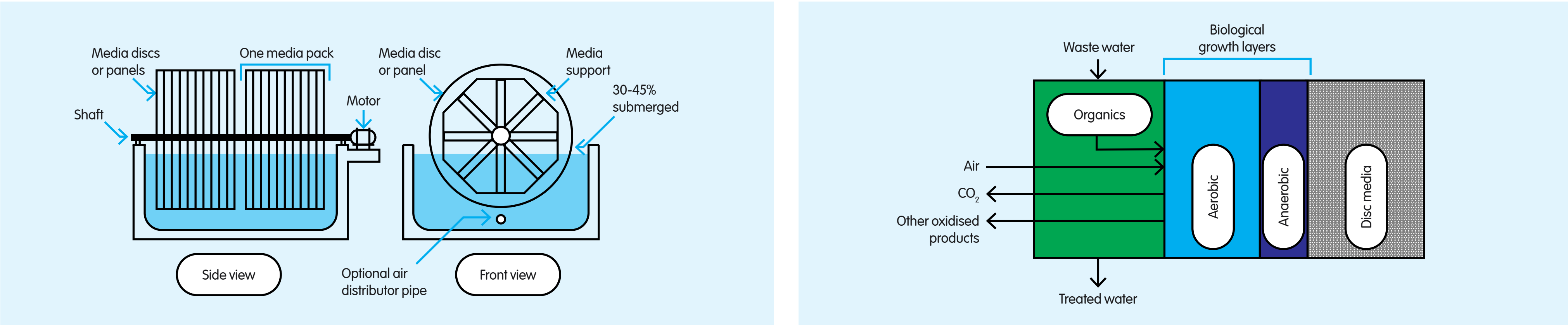
Raw sewage pump station

Figure 1. Treatment process at the Pekapuran Raya WWTP,[2] adapted by SNV



[1] R.L. Antonie, *Fixed biological surfaces – wastewater treatment: the rotating biological contractor*, CRC Press, 2018, https://doi.org/10.1201/9781351072045 (accessed 25 November 2020).
[2] Schematic diagram of treatment process based on SNV's site visit in 2019.

Figure 2. Schematic diagram of a typical RBC (left) and a schematic cross-section of the contact face of the bed media in an RBC (right),[3] adapted by SNV



The treatment process continues with the final clarifier (Step D in Figure 2), which is a settling tank designed to separate solids from water by allowing heavy suspended solids to settle to the bottom and clarified water to overflow at the top. Powdered chlorine is added as a disinfectant. The sludge layer produced at the bottom of the clarifier is desludged and disposed of at the Basirih Faecal Sludge Treatment Plant (FSTP) in Banjarmasin. Step E of the treatment plant consists of the final reservoir where the processed wastewater is held for 3-6 hours before release into the Kelayan River (Step F). Samples of the effluent are tested for quality before final disposal. Some water from the outlet is reused to water plants at the WWTP. Water is collected through a separate pipe and filtered so that it meets suitable quality standards for watering non-edible plants.

Table 1. Capacity and operating costs of Pekapuran Raya WWTP

	Pekapuran Raya WWTP
Design capacity	2,500 m^3/day of greywater and blackwater
Operating capacity	250-500 m^3/day of greywater and blackwater
Operating costs	US$ 84,000 per year for all seven WWTPs operated by PD PAL Banjarmasin

Regulatory environment and compliance

National and regional government environmental standards for influent and effluent quality are followed at the Pekapuran Raya WWTP, with regular testing conducted to comply with these regulations. The influent and effluent quality are checked monthly against the Ministry of Environment Effluent Standard (Peraturan Menteri Lingkungan Hidup No. 68/2016) and the Regency of South Kalimantan Effluent Standard (Peraturan Gubernur Kalimantan Selatan No. 36 Tahun 2008). Some daily checks are undertaken, including pH, temperature, and Dissolved Oxygen (DO). Monthly testing is conducted by a City Environment Agency laboratory and the Provincial Environment Agency laboratory conducts random sampling of the facility's influent and effluent quality 2-3 times per year. The quality of waste inputs has been found to be quite consistent, with some occasional spikes in Biochemical Oxygen Demand (BOD). Further analysis to understand BOD spikes has not been conducted to date.

> *The performance of the treatment facilities is consistent in that the effluent quality is always below the regulated effluent standard. One time, before the current regulation was enacted in 2016, the number of E. coli spiked. However, since the new effluent standard only checks the total coliform parameter, the E. coli amount is not measured anymore. Currently, to ensure that the total coliform parameter is below effluent standard, the dosing of chlorine disinfectant is adjusted.*
>
> **SECTION HEAD OF PIPE NETWORKS DIVISION, PD PAL BANJARMASIN**

[3] M.R. Beychok, *Aqueous waste from petroleum and petrochemical plants, 1st edition*, John Wiley & Sons Ltd., 1967, p. 262.

Table 2. Influent and effluent quality for the Pekapuran Raya WWTP

Parameter	Input	Output	Ministry of Environment Effluent Standard (Permen LHK 68/2016)	Regency of South Kalimantan Effluent Standard (Pergub 36/2008)
Temperature (°C)	28.5	28.3	–	–
pH	7.06	7.53	6-9	6-9
Total Suspended Solid (TSS) (mg/l)	25	6	30	100
Biochemical Oxygen Demand (BOD) (mg/l)	45.48	9.74	30	100
Chemical Oxygen Demand (COD) (mg/l)	115.99	24.84	100	–
Grease and oil (mg/l)	1.3	0.5	5	10
Ammonia (mg/l)	26.19	10.58	10	–
Total coliform (MPN/100 ml sample)	2,940	2,400	3,000	–

Operation and maintenance: realities, challenges, and opportunities

Realities of running the treatment plant

Construction considerations

During the construction of the WWTPs the environmental impacts were assessed to ensure quality standards were met and public objections considered.

The city of Banjarmasin is relatively flat. It is crossed by many rivers and has numerous swamps. Due to changing river tides, flooding is common and the swampy conditions cause soft soils. Therefore, in building the seven WWTPs, all structures were constructed on strong and deep piles above ground to prevent flooding. The Provincial Technical Team from the Ministry of Public Works and Housing ensured that the planning and construction quality criteria were met, as stipulated in the Ministry of Public Works and Housing Regulation No. 4 2017 on Waste Water Management.

Generally, none of the WWTPs experienced any challenges during construction, except for the newest WWTP where there were public objections to its development. PD PAL Banjarmasin addressed their concerns through regular information sessions, explaining that the WWTP would improve cleanliness and lead to better health outcomes for the community. Since that time, PD PAL Banjarmasin has been able to obtain a land ownership certificate. The land has been cleared, the WWTP has been constructed, and it will begin operations shortly.

We have not faced any public rejection up until our last Sultan Adam WWTP that was built in 2012. The community around Sultan Adam WWTP refused to connect their household pipe to the main pipe network because they did not want the WWTP to be built close to their houses. They perceive[d] that WWTP [to be] dirty and will have a bad smell.

HEAD OF TECHNICAL DIVISION, PD PAL BANJARMASIN


Inlet automatic flowmeter

Outlet pipe


RBC bearing

Continuous operation and maintenance of the facility

Several typical operation and maintenance (O&M) activities are required to ensure the smooth and continuous functioning of the Pekapuran Raya WWTP. These activities include:

- daily bar screen cleaning to remove debris and effluent checks of pH, temperature and dissolved oxygen;
- monthly influent and effluent laboratory quality checks and maintaining RBC motor parts; and
- quarterly checks of clarifiers to assess desludging requirements.

Power failures of 2-3 hours are common in Banjarmasin, which requires the facility to have a diesel power generator to ensure continuous operation of the WWTP. The power generator in use has an 80-100kVa capacity, which is sufficient to manage all the WWTP operations during outages.

Staffing and training

A small operator team of five ensures the continued operation of the Pekapuran Raya WWTP. One operator is the team coordinator. As the operators also perform security functions for the facility, they are provided with accommodation on the facility grounds.

A standard operating and maintenance procedure was developed for the facility by the vendor, Enviro, who supplied the RBC technology. The operators received on-the-job training from Enviro when the WWTP began operation in 2008. Additional training for all WWTP operators in Indonesia was provided by the Ministry of Public Works and Housing. However, not all operators who currently work at the Pekapuran Raya WWTP were employed at that time. As such, on-the-job training is provided to new recruits by existing operators. The peer-learning training sessions focus on the mechanical and electrical O&M of the facility.

Challenges of operation and maintenance

Limitations in operating and maintaining the WWTP

Ensuring continuous O&M of the RBC technology is essential for the overall functioning of the WWTP. However, the operators have found that some of the tasks involved are challenging. Critical elements of the RBC technology, which must be maintained include the shaft that keeps the bacteria media intact, and the bearing that keeps the RBC rotating. For the current operator, changing or repairing the bearing of the RBC can take up to one month. The facility does not have the required budget to hire an RBC technical expert, who would, reportedly, do the job much more quickly. As a result, such tasks unnecessarily hinder operations. Further, the occasional cleaning and desludging of the RBC basin is necessary, which requires one of the RBC units and clarifiers to be switched off to allow access.

> *When it comes the time to clean the sludge generated in [the] RBC basin, the RBC needs to be stopped and lifted so that the workers can desludge and clean the sludge chamber. This requires quite a long time, though we can operate the other RBC pairs. But to have the sludge chamber redesigned to improve access for cleaning and desludging would be really nice.*
>
> **SECTION HEAD OF PIPE NETWORKS DIVISION, PD PAL BANJARMASIN**

Adjustments to the final clarifier and outlet flowmeter would optimise the treatment process. The final clarifier requires powdered chlorine to be added to ensure that the total coliform level meets the required effluent quality standards. However, powdered chlorine sometimes clogs the disinfectant tube, and manual dosing has led to inaccurate amounts being added. Switching to a liquid disinfectant could prevent clogging and inaccurate dosing. Within the outlet pipe, a mechanical flowmeter often gets clogged by sediment. Replacing this with a non-mechanical flowmeter could address this problem.

Occupational health and safety (OHS) considerations

While OHS measures are part of the Pekapuran Raya WWTP's standard operating guidelines, the extent to which they are upheld varies. Personal protective equipment such as safety jumpsuits, hard helmets, hard boots, and gloves are provided to facility staff, however many operators do not use these items due to the hot weather and inconvenience they experience in wearing them. To combat this problem, the management team of PD PAL Banjarmasin runs frequent awareness sessions about the importance of protective clothing. Some occupational hazards were also observed during the research field visit, such as the lack of a rigid railing around the RBC basin to prevent people from falling in. Such considerations do not appear to have been part of the facility's OHS design considerations.

Financial arrangements not yet covering all O&M costs

All capital expenditure (CAPEX) costs for the Pekapuran Raya WWTP were paid by the national government through the Ministry of Public Works and Housing. However, PD PAL Banjarmasin is currently unable to cover all of its O&M costs. The operational expenditure (OPEX) for each individual WWTP has never been calculated, but the combined cost for all seven WWTPs is US $84,000 per year. PD PAL Banjarmasin earns revenue from wastewater management services tariff paid by households and commercial businesses, which are approximately US$ 1 and US$ 6 per month, respectively. This revenue contributes to O&M costs. If customers also have a piped water connection, then their wastewater management tariff represents 25% of the water bill. The revenue recovered by PD PAL Banjarmasin is used to cover some O&M costs, including

Disinfectant dosing unit, with the final clarifier below the tiles pictured

laboratory testing, disinfectant procurement, electricity bills, desludging and sludge cleaning costs, as well as the cost of spare parts and oil for mechanical parts. At present, PD PAL Banjarmasin incurs a budget deficit of US$ 6,470 per month for the O&M costs of all seven WWTPs. The company is conducting awareness activities to inform the community of the benefits of connecting to the piped wastewater network, but further efforts are required to increase demand for wastewater services, which will in turn increase revenue.

Informed choice considerations	Pekapuran Raya WWTP in Indonesia (PD PAL Banjarmasin)
Operating & design capacity	Design capacity = 2,500 m^3/day of greywater and blackwater Operating capacity = 250-500m^3/day of greywater and blackwater
Costs and revenue	Capital expenditure, CAPEX = US$ 256,870 to build Pekapuran Raya WWTP and US$ 64,230 to build piped connections Operational expenditure, OPEX = US$ 84,000 per year for all seven WWTPs
Energy requirements	Mechanical system for RBC technology: energy supply is greatest OPEX
Input characteristics	Sludge with pH = 7.06; TSS 25 mg/L; BOD 45.48 mg/L; COD 115.99 mg/L; Total coliform 2940 MPN/100ml
Output characteristics	Effluent liquid quality (Effluent limit as per environmental compliance standard Peraturan Menteri Lingkungan Hidup No. 68 Tahun 2016): pH = 7.53 (*6-9*); TSS 6 mg/L (*30 mg/L*); BOD 9.74 mg/L (*30 mg/L*); COD 24.84 mg/L (*100 mg/L*); Total Coliform 2400 MPN/100ml (*3000 MPN/100ml*)
Land requirement	Land area was a constraint and therefore they chose a mechanical system with a small footprint
Reuse	Minimal reuse of treated water for facility gardening purposes only
Skills & human resources requirements	Five operators working in the facility who also perform security functions, and one operator acts as the coordinator
Technology/material local availability	The RBC bearing is locally available if it needs to be repaired or replaced, however the operator did not know if the RBC shaft was also locally available (may need to be imported); the contact media is not locally available and needs to be imported

References

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Beychok, M.R., *Aqueous waste from petroleum and petrochemical plants, 1st edition*, John Wiley & Sons Ltd., 1967, p. 262.

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Photos: SNV

CASE STUDY 9

Decentralised wastewater treatment system

Makassar, Indonesia

Background

Treatment selection and purpose

Community-managed anaerobic decentralised wastewater treatment systems (DEWATS) offer sanitation solutions in low-income, densely populated urban settlements. There are 147 DEWATS in Makassar registered to UPTD (Unit Pelaksana Teknis Daerah: Regional Technical Implementation Unit), an independent government unit under the Public Works and Housing Office. This unit provides monitoring of these simplified sewer systems. However, the daily operation and maintenance (O&M) of each DEWATS is managed by a local community group. Implementation and construction of DEWATS is supported by the national budget, international and local grants, and international loans. The Abbulo Sibatang DEWATS, which is the focus of this case study, was built through an Asian Development Bank-funded project in 2011.

The Abbulo Sibatang DEWATS technology was chosen based on community demand and limited land availability. Local government primarily constructed the DEWATS at the community's request, due to a lack of adequate sanitation. The community had seen the DEWATS in a neighbouring area and decided it would be suitable for their needs. A densely populated city, limited land availability was another key consideration. As such, a simplified DEWATS sewer system, which is constructed underground, was the preferred option.

Once the community demand was established in Abbulo Sibatang, UPTD and the Public Works and Housing City Office in Makassar assessed the proposal. This was followed by an open procurement process to select an independent vendor to design the facility, the pipe network, and the household connections. This is the standard procurement process followed for all DEWATS in Makassar. and the Head of the Wastewater Management Division in the Public Works and Housing City Office makes the final decisions on the selection of the vendor and the type of DEWATS.

> *We received a programme from the Ministry of Public Works and Housing to build the DEWATS. They gave us the manual and the design for the technology they had decided on. We socialised the technology to the community and they perceive that DEWATS is quite a simple technology and does not need a big area, hence suitable to implement in here.*
>
> **INTERIM SECTION HEAD OF SANITATION AND CLEAN WATER DIVISION, CITY PUBLIC WORKS OFFICE**

Abbulo Sibatang DEWATS

Description of the system

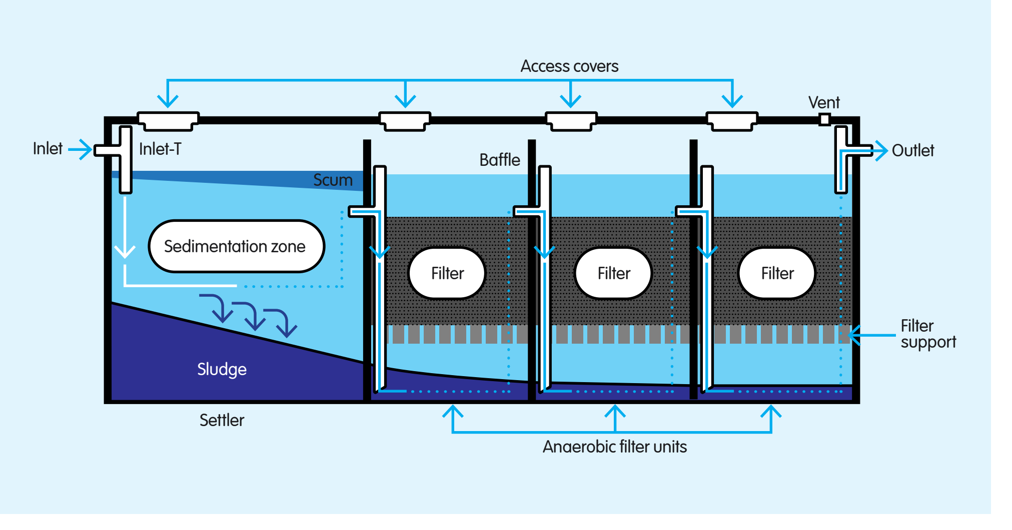
The Abbulo Sibatang DEWATS is a modular passive anaerobic treatment system designed to treat domestic wastewater, including greywater and blackwater. The wastewater comes from approximately 50 households and is delivered to the DEWATS via underground pipes.

The treatment process consists of four main steps beginning with sedimentation in a septic tank, labelled as Zona Pengendapan (sedimentation zone; step one) in Figure 1. Step two involves anaerobic digestion in anaerobic baffled reactors, where the removal of easily degradable organic solids is achieved by forcing the wastewater to flow through a series of chambers separated by baffles. The baffles provide resistance to the flow, thereby increasing contact time between the wastewater and the active biomass (sludge). The third step involves anaerobic decomposition and filtration through anaerobic filters, which dislodges degradable solids that are more difficult to remove. These chambers are filled with bioballs: plastic balls whose jagged shapes create increased surface contact between the organic pollutants and the organisms in the active sludge, resulting in organic digestion. The main function of the bioballs is not filtration, but rather to provide maximum surface contact. Because the bioballs are packed within the chamber (like a fixed-bed filter), they provide additional resistance to the particles containing organic matter and hence they also serve a filtration function. The fourth treatment step involves post-sedimentation and filtration. Here, the removal of digested solids and active bacteria mass occurs. Some DEWATS in Makassar use horizontal gravel filters for this process.

Installation of DEWATS technology

Comparison of concrete and lightweight iron cover for inspection chamber cover

Figure 1. Standard DEWATS treatment flow diagram,[1] adapted by SNV



[1] E. Tilley, L. Ulrich, C. Lüthi, Ph. Reymond, R. Schertenleib and C. Zurbrügg, *Compendium of sanitation systems and technologies*, 2nd revised edition, Dübendorf, eawag, 2014, p. 78.

The disposal of treated effluent and sludge is the final step in the treatment system. Treated wastewater moves to the filtration chamber, from where it is pumped via the outlet to the main city drainage. These open channels, which do not separate the sewerage and stormwater, flow to a nearby river downstream. The sludge generated from the DEWATS is removed and paid for by UPTD every three months and disposed of at the Makassar FSTP. Some of the treated effluent from the Abbulo Sibatang DEWATS is stored in local holding tanks and reused to water plants in the neighbourhood. However this is done without additional filtration or disinfection. Inspection chambers/manholes along the path of the treatment systems allow for access to perform bacteria seeding, repairs, desludging, and inspection of the DEWATS underground.

Table 1. Abbulo Sibatang DEWATS

	Abbulo Sibatang DEWATS
Design capacity	20 m^3/ day of greywater and blackwater
Operating capacity	9 m^3/ day of greywater and blackwater
Operating costs	US$ 2,090 per year (estimated at 5% of capital expenditure)

Table 2. Effluent quality for the Abbulo Sibatang DEWATS in 2019 as compared to quality standard

Parameter	Effluent quality	Standard (No. 68/2016)[2]
pH	7.3 pH	6-9 pH
Total suspended solids, TSS	24 mg/L	30 mg/L
Ammonia	2.0 mg/L	10 mg/L
Biochemical oxygen demand, BOD5	48 mg/L	30 mg/L
Chemical oxygen demand, COD	148 mg/L	100 mg/L
Grease and oil (mg/L)	<0.9 mg/L	5 mg/L
Total coliform (MPN/100 ml sample)	>160	3,000

[2] *Regulation of Ministry of Environment and Forestry of the Government of Indonesia* (2016) Permen LHK No. 68/2016

Regulatory environment and compliance

The UPTD ensures effluent quality is checked regularly, following the national Ministry of Environment and Forestry Effluent Standard (PermenLHK No. 68, year 2016). Due to the significant number of DEWATS in Makassar and budget limitations, effluent quality checks are conducted for approximately 60 of the 147 DEWATS in a year, resulting in each DEWAT being checked approximately every two years. Table 2 shows effluent quality for the Abbulo Sibatang DEWATS in 2019.

Generally, the waste input is quite homogenous as it comes from domestic households. However, there have been cases of home industries draining their contaminated wastewater into the DEWATS, which results in the treatment process breaking down. In this situation the UPTD requests these households not to drain their industrial or commercial wastewater into the DEWATS or the household connection is cut. No influent quality checks are conducted by UPTD as to the type and quality of wastewater from households (mostly kitchen, bathroom, and toilet). Furthermore, UPTD considers effluent quality checks to be more crucial, and UPTD's limited budget means both effluent and influent quality checks are not possible.

The waste input to the DEWATS is almost consistent since it comes from domestic household. But sometimes there is a home industry that discharges their wastewater to the DEWATS, which causes the DEWATS to not work properly. We can tell that from the unpleasant smell coming from the DEWATS' effluent.

CHIEF OF THE UPTD, MAKASSAR'S WASTEWATER UPTD

Operation and maintenance: realities and challenges

Realities of operation and maintenance

Financing mechanism

Household payments and the local city-allocated sanitation budget are used to operate and maintain the DEWATS. Operating costs and minor repairs are covered by the monthly household payments of US$ 1 per household, with collection and disbursements of the payments managed by the community committee treasurer. The exact amount charged is based on the agreement of all households.

Examples of continuous operating costs include monthly electricity bills, incentives for temporary technicians, and regular cleaning. Minor repairs cover the replacement of manholes or fixing broken pipes.

UPTD is responsible for major repairs, such as replacing any damaged infrastructure or flushing clogged pipes, with funding coming from the 2% of Makassar city's budget that is reserved for sanitation.

Inlet of the DEWATS

Community beneficiary group responsibilities and UPTD support

Each DEWATS location has a community management group with a working committee that is supported by UPTD to ensure the construction and continued O&M of the DEWATS. Each community management committee comprises a chief, secretary, treasurer, technician, and a campaigner (to socialise DEWATS related activities with the beneficiary group). In constructing the DEWATS, the community groups provide the labour, while the government provides all materials, expert technicians, and additional construction workers. While the community groups provide the labour, each community decides whether payment is provided or not. In the Abbulo Sibatang case, labour was paid for from the collected fees.

For the continued O&M of the DEWATS, the community technician is trained by UPTD. The UPTD receives support from IUWASH PLUS, a USAID-funded sanitation development project, in developing the training modules. Training covers the Standard Operating Procedures (SOPs) of the DEWATS, the Occupational Health and Safety (OHS) measures required, and sensitisation on the need to keep the DEWATS pipe network and manholes free of garbage, grease, and oil. The OHS measures include advice that personal protective clothing such as safety vests, gloves, hard helmets, hard boots, and masks should be worn. However, in reality the community group technician and workers do not follow this advice, perhaps because of discomfort due to hot weather conditions.

DEWATS tap for reused water in Abbulo Sibatang

The UPTD receives regular capacity development training from the Ministry of Public Works and Housing and the IUWASH PLUS expert team. This training includes comparative visits to other wastewater facilities and programmes. The training UPTD receives is then passed on to community groups.

Bi-monthly monitoring and evaluation of the DEWATS is also conducted by UPTD, with key activities including monitoring the condition of the manhole, the inspection chamber, and the physical quality of the wastewater input and output (colour, turbidity, smell, etc.).

> *The UPTD gives training to the community beneficiary group once a year, to every group in Makassar. The training encourages the group to maintain the DEWATS by not disposing any garbage to the manhole or disposing grease and oil to the sink that leads to the DEWATS. We advise them to put a grease trap in the inspection chamber.*
>
> **CHIEF OF THE UPTD, MAKASSAR'S WASTEWATER UPTD**

Challenges of operation and maintenance

Construction process objections and challenges

Community reservations about installing a DEWATS in their neighbourhood led to delays in construction and underutilisation of the Abbulo Sibatang DEWATS. Part-way through construction, community group members who had initially supported DEWATS connection decided against it. This is a common issue faced in constructing DEWATS, as many community members fear that the DEWATS will impede their access roads and that their houses may get damaged. As such, the Abbulo Sibatang DEWATS is only operating at 45% of its intended design capacity due to the significant number of households who pulled out after construction had begun.

Blockages and contaminated systems

Clogged manholes, pipes, and screens are some of the key maintenance challenges faced by the Abbulo Sibatang DEWATS. Clogging of manholes is a minor issue that many of the community groups are able to fix themselves. When they lack the technical skills needed, they call on the UPTD for support. Usually, community groups can also take the first steps in attempting to flush out clogged pipes. When this does not work, UPTD staff support is required to operate more sophisticated equipment. Clogged pipes are also often related to the iron bar screens becoming corroded and broken, which then allows solid waste to flow into the system.

> *Sometimes, the community groups ask UPTD to support the maintenance of clogged pipes, which requires us to use heavy equipment. We often faced difficulties in accessing the reported DEWATS when it is located in a narrow alley.*
>
> **UPTD STAFF**

Another key issue which can contaminate the system is breakage of the piped connections to the DEWATS. In several cases households who no longer wanted to be connected to the DEWATS due to clogging and perceptions of bad odours, decided to cut the pipes connecting their household to the sewer system. They did so without informing the community group or UPTD. This led to the DEWATS being contaminated with city drainage waste, as the inlet pipes were left exposed, resulting in a disruption to the DEWATS treatment process.

Personal protective equipment worn by UPTD workers when conducting field visits

DEWATS vs. household septic tanks

In some cases, operators felt that household septic tanks were a more effective sanitation solution in Makassar than DEWATS. Due to the densely populated urban setting of Makassar, finding sufficient land area to build DEWATS is challenging. In many cases the DEWATS are built underground (often under the road) to respond to this challenge. However, this type of construction is difficult as there are many other utilities underground, which need to be left undisturbed. Furthermore, if the reinstatement of the road after the DEWATS construction is deemed unsatisfactory by the local community, it leads to a public outcry with households sometimes cutting off their connection to the DEWATS or refusing to connect to the system due to a breakdown in communication and trust. In such cases, some operators have thought that until city-scale sewerage systems can be implemented, individual septic tanks could be a more cost-effective interim solution than a DEWATS.

Informed choice considerations		Abbulo Sibatang DEWATS, Indonesia (UPTD)
	Operating & design capacity	Design capacity = 2,500 m^3/day of greywater and blackwater Operating capacity = 250-500 m^3/day of greywater and blackwater
	Costs and revenue	Capital expenditure, CAPEX = US$ 41,870 Operational expenditure, OPEX = US$ 2,090
	Energy requirements	Passive system (using minimal to no energy) that uses gravity for the wastewater to flow through the system; some DEWATS require a pump if they are unable to use gravity and they need to pump some wastewater through the system
	Output characteristics	Effluent liquid quality (Effluent limit as per environmental compliance standard PermenLHK No. 68 year 2016): pH = 7.3 (6-9); TSS 24 mg/L (*30 mg/L*); BOD 48.32 mg/L (*30 mg/L*); COD 148.06 mg/L (*100 mg/L*); Total Coliform >160 MPN/100ml (*3000 MPN/100ml*)
	Land requirement	Land area was a constraint so they chose the DEWATS technology, which can be constructed underground, with total above-ground land area for 50 households: approximately 21 m^2
	Reuse	Minimal reuse of treated water for facility gardening purposes only
	Skills & human resources requirements	Each DEWATS daily O&M is assured by the community management group (total of 15 people, including chief, secretary, treasurer and technician) and more extensive O&M, as well as monitoring of the DEWATS, provided by UPTD (10 staff)
	Technology/material local availability	All equipment and materials locally available (in Makassar City or within Indonesia)

References

Regulation of Ministry of Environment and Forestry of the Government of Indonesia (2016) Permen LHK No. 68/2016

Tilley, E., Ulrich, L., Lüthi, C., Reymond, Ph., Schertenleib, R. and Zurbrügg, C., *Compendium of sanitation systems and technologies, 2nd revised edition*, Dübendorf, eawag, 2014.

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Photos: SNV

About the cover photo: Khulna City Corporation's Faecal Sludge Treatment Plant in Bangladesh is one of the largest constructed wetlands in operation today. The plant sits on a passive landfill site with loose and spongy landfill contents. In order to transform this land area, embankments with compacted soil were introduced, and geotextiles and HDPE sheets were laid over the entire top surface to hold ponding settlement and to build resistance against slope failure. (Photo: Rajeev Munankami/SNV)