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Technical Assistance to Fecal Sludge Management Services in Port Harcourt, Nigeria

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ASSESSMENT REPORT AND PROJECT DEVELOPMENT IN SELECTED PILOT AREAS

1 August 2017

aquaya

improving health through clean water innovation

P.O. Box 2207
San Anselmo, CA 94979
USA

Riara Corporate Suites, Suite #203
Riara Road, Kilimani Estate
Nairobi, Kenya

www.aquaya.org
info@aquaya.org
T +1 415 306 7593
F +1 415 306 7594

EXECUTIVE SUMMARY

The imperative for improving the collection, treatment, and disposal of human excreta is gaining increasing attention in international development efforts. Exposures to microbial pathogens transmitted in human waste are associated with diarrhea, helminth infections, and other infectious diseases (Pruss-Ustun, A. et al. 2014; Mara, D. et al. 2010). In addition, there is increasing evidence for links between unsafe sanitation practices, environmental enteric dysfunction (Lin, A. et al. 2013) and child growth faltering (Spears, D. et al. 2013). Nevertheless, in 2015, estimates indicated that over 2.4 billion people still lacked access to safe sanitation facilities, and the World Health Organization (WHO) has calculated that inadequate sanitation alone results in 280,000 deaths every year (WHO 2014). Poor sanitation also has social and economic consequences, and the returns on sanitation investments are estimated to be at least 5-fold (Hutton, G. et al. 2007).

Like most developing countries, Nigeria faces significant sanitation challenges: survey data indicates that as of 2015, only 29% of Nigerians were using sanitation facilities that are considered safe, or improved, by the WHO-UNICEF Joint Monitoring Program (JMP) for Water and Sanitation (WHO-UNICEF, 2015). In addition, other than in the capital city of Abuja, which has a piped sewer network that transports waste water to a treatment plant designed for approximately 700,000 inhabitants, public sewerage systems are nonexistent. The recognition that building sewerage infrastructure remains prohibitively expensive for many cities of the developing world has promoted growing interest in effective “Fecal Sludge Management” (FSM) systems that provide for the safe collection, transport, treatment, and disposal (or enduse) of fecal sludge (also called septage) from pit latrines, septic tanks, and other onsite sanitation facilities (Strande et al. 2014).

This report presents an assessment of current FSM practices in Port Harcourt, Nigeria, and discusses options for piloting improved FSM approaches. Port Harcourt is the capital of Rivers State and the center of Nigerian oil industry in the Niger River Delta. The Port Harcourt Water Corporation (PHWC) is currently implementing the Port Harcourt Water Supply and Sanitation Project (PHWSSP), which is supported by investments of USD 328 million from the African Development Bank, the World Bank, and the Rivers State Government. The primary objectives of the PHWSSP are to rehabilitate and expand the water supply system (production, treatment, transmission, storage, distribution and house connections) in the urban center of the Port Harcourt metropolis. However, the project also includes the development of sanitation facilities in public areas (markets and parks), and the implementation of FSM pilots in low-income communities that will inform the development of a sanitation master plan for the city.

Features of FSM in Port Harcourt

The sanitation landscape of Port Harcourt is characterized by four notable features, which are summarized below:

1. **High coverage of personal flush toilets connected to underground containment structures.** A representative survey of water supply, water quality, and sanitation in Port Harcourt that was commissioned by the World Bank in 2015 showed that 90.5% of surveyed locations (n=398) had cistern-flush or pour-flush toilets. The remainder relied on hanging latrines over waterways (5.3%) and pit latrines (1.8%). Among the locations with flush toilets, 93% reported underground containment structures, and the remainder reported direct drainage of waste to waterways. Residents of waterfront communities were more likely to dispose of fecal matter in waterways, whereas flush toilets linked to underground containment were common in the rest of the city.

   These findings were confirmed in the current analysis: 59% of households surveyed in low-income waterfront communities (n=92) and 84% of households in the low-income area of Diobu (n=41) reported using indoor cistern-flush or pour-flush toilets. Among low-income households with indoor toilets, 75% reported underground containment structures (n=330). The high prevalence of flush toilets and underground containment in Port Harcourt may reflect the relative prosperity of the oil-producing region. In addition, the former Rivers State Environmental Authority (RSESA) banned the use of pit latrines and bucket toilets in Port Harcourt in 1983.

2. **Robust industry of fecal sludge exhauster trucks.** Fecal sludge management services in Port Harcourt are dominated by private fecal sludge exhauster trucks (locally referred to as sewage trucks), which empty containment facilities at residences, businesses, institutions (churches, schools, hospitals) and government buildings. The Association of Exhauster truck Operators (ASTO) was established in 2008 and currently has approximately 57 members who, between them, manage over 100 trucks. The large size of this sector is likely a result of the high coverage of underground fecal sludge containment in Port Harcourt and the requirements for frequent emptying, due to both the use of flush toilets and infiltration by ground water.

3. **A dysfunctional treatment plant.** In 2010 the Rivers State Government began making a significant effort to establish Nigeria's first treatment plant. The Eagle Island plant, in Port Harcourt, was commissioned in 2013. However, it utilizes a 'Sequence Batch Reactor' (SBR) treatment technology, which is recommended for treating waste water, not fecal sludge. Our analysis of the influent characteristics of raw fecal sludge in Port Harcourt show that they exceed the design criteria for the SBR system. The capacity of the plant is limited to 1,000 m^3/day, which is not

sufficient for the city's treatment needs. Moreover there are five other informal/illegal dumpsites for fecal sludge in the surrounding region. Finally, PHWC, which currently operates the plant, does not have the financial resources to ensure proper maintenance.

4. **No regulatory framework for FSM.** Despite significant attention to water sector reforms in Rivers State, and the passage of a Water Sector Law in 2012, which created PHWC and the Rivers State Water Sector Regulatory Commission (RSWSRC), various aspects of the law have not been implemented, and institutional responsibilities have not been established for regulating either private sanitation infrastructure or the collection and disposal of fecal sludge by exhauster trucks.

Critical priorities for improving FSM in Port Harcourt

In addition to piloting new FSM activities in Port Harcourt, broader considerations of the following issues will be important for achieving significant sanitation improvements:

1. **Developing treatment capacity.** Currently, almost all of the fecal sludge generated in Port Harcourt is dumped into surrounding waterways without treatment. Due to both location and limited capacity, the Eagle Island plant can only provide a fraction of the city's treatment requirements. Furthermore, it is doubtful that the plant can adequately treat fecal sludge, even under optimum operating conditions; this remains to be verified, since the plant was not operational during the period of this assignment.

   The development of treatment infrastructure for Port Harcourt will require extensive considerations of land-use plans, appropriate treatment plans, operational capacity, capital and operational resource requirements and the impacts of both piped water networks and population growth on treatment needs. This level of planning necessitates a multi-stakeholder process that drives the development of a sanitation master plan. It cannot occur through ad-hoc investigations, and until there is political will to undertake this process, developing other FSM activities that contribute to unsafe disposal of waste will be difficult to justify.

2. **Establishing a regulatory framework for FSM.** The limited implementation of the 2012 Water Sector Law has left the water sector in Port Harcourt in a remarkable state of disarray. Coordination committees and governing boards have not been established and operating budgets are frozen. Capacity at key institutions, including PHWC and RSWSRC, is weak, and uncertainty regarding the future of the PHWSSP is likely promoting low staff morale. At the same time, FSM

improvement programs in other countries only emphasize the need for strong regulatory and coordination functions to advance pilot projects to any significant scale.

For example, FSM programs for two low-income suburbs of Dakar (Pikine and Guediawaye) include the following activities (ONAS 2014):

- The development of a call center, which enables multiple exhauster truck operators to submit bids for providing emptying services in response to customer requests.
- A certification process for emptying companies.
- The delegation of the management of Dakar's fecal sludge treatment plants to the private sector through a public-private-partnership model.
- A guarantee fund that supports commercial lending to exhauster truck operators.
- A mobile money platform that facilitates payments to emptying companies.
- A communications network that promotes FSM information-sharing between all stakeholders: customers, private sector operators, and government agencies.

All of these initiatives are implemented and managed through ONAS (National Sanitation Office of Senegal). Many of the same activities will likely prove important for FSM improvements in Port Harcourt, but they will be difficult to execute in the absence of a supportive institutional framework.

Options for piloting FSM improvements in low-income communities

To initiate small-scale FSM improvements that, ideally, will inform wider sanitation planning for Port Harcourt, this report outlines possible interventions for two low-income areas of the city:

- Okrika Waterfront is a self-built settlement constructed on land reclaimed from the surrounding waterways. Consequently, water tables are high. A slight majority of the residents (59%) utilize indoor flush toilets that are either connected to underground cesspits or open drains. Most of the remaining residents rely on public or private hanging latrines, and a small fraction practice open defecation.

- Diobu is a low-income area that was formally planned by the city (as opposed to the informal developments in waterfront areas). It is predominantly comprised of upland areas with lower water tables than the waterfront communities. Households largely reside in compounds, or yards and most (84%) utilize indoor flush toilets connected to septic tanks or cesspits.

The contrasts in geography, existing sanitation facilities, and household structures between the Okrika Waterfront and Diobu suggest different FSM approaches. In the Okrika Waterfront, a large proportion of residents could be served by modern public toilets, possibly created by retrofitting shipping containers connected to above-ground septic tanks that are readily accessible to exhauster trucks. Consideration should be given to linking the public toilets to community spaces that provide other amenities and services, such as laundry facilities, small retail outlets and mobile charging stations. Connecting anaerobic digesters to the public toilets would also provide an opportunity for evaluating the potential for biogas generation. The high water table in the Okrika Waterfront presents a significant challenge to improving underground containment structures, which are predominantly cesspits. A more viable option may be to increase the frequency of emptying by establishing a scheduled emptying service that leverages the capacities of existing desludging businesses and is supported by a regular household fee.

In Diobu, the high prevalence of indoor toilets and the lower water table together suggest that FSM improvements should focus on improving containment infrastructure, possibly by promoting the installation of larger septic tanks that are shared by multiple households in a yard, and developing scheduled emptying services, as noted for the Okrika Waterfront.

Both the Okrika Waterfront and Diobu are relatively close to the Eagle Island Treatment Plant. However, as outlined in the report, an analysis of operating conditions is required to determine if the existing plant can treat waste generated from the pilot activities to acceptable safety levels. If not, pilot activities should not proceed until adequate treatment capacity has been developed.

In addition, the main sector challenges described above appear to stem from a shift in political priorities in 2015 which mean that in the near-term it is unlikely sector reform or project implementation will be driven forward by a significant supply of political will. Consequently, the success of FSM pilot programs in this context of a weak institutional environment will likely depend on the levels of community ownership and local financial sustainability that are built into the implementation process.

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ABBREVIATIONS AND ACRONYMS

AfDB	African Development Bank
ASTO	Association of Sewage Tanker Owners
bCOD	biodegradable Chemical Oxygen Demand
BOD	Biological Oxygen Demand
CAB	Community Ablution Block
CBO	Community Based Organization
CMAP	Collaborative Media Advocacy Platform
COD	Chemical Oxygen Demand
DEWATS	Decentralized Water Treatment System
FGD	Focus Group Discussion
FOG	Fats, Oils, and Grease
FSM	Fecal Sludge Management
GIS	Geographic Information Systems
ICRC	International Committee of the Red Cross
JMP	Joint Monitoring Program
KII	Key Informant Interview
LGA	Local Government Area
LGC	Local Government Council
MSF	Medecins Sans Frontieres
MWRRD	Ministry of Water Resources and Rural Development
₦	Naira
NDWQS	Nigerian Drinking Water Quality Standard
NECO	National Examination Council
NESREA	National Environmental Standards and Regulatory Enforcement Agency
NGO	Non-Governmental Organization
NPC	National Population Commission
ONAS	National Sanitation Office of Senegal
PHWC	Port Harcourt Water Corporation
PHWSSP	Port Harcourt Water Supply and Sanitation Project
PIU	Project Implementation Unit
PMC	Project Management Consultancy

PoC	Point of Contact
RSESA	Rivers State Environmental Authority
RSSTOWA	Rivers State Small Towns Water Supply and Sanitation Agency
RSWB	Rivers State Water Board
RSWSRC	Rivers State Water Services Regulatory Commission
RUWASSA	Rural Water Supply and Sanitation Agency
SBR	Sequencing Batch Reactor
SFD	Shit Flow Diagram
TCC	Total Coliform Count
TKN	Total Kieldahl Nitrogen
TN	Total Nitrogen
TOR	Terms of Reference
TP	Total Phosphorous
TS	Total Solids
TSS	Total Suspended Solids
UASB	Upflow Anaerobic Sludge-Blanket
UNDP	United Nations Development Program
UNICEF	United Nations International Children's Emergency Fund
USD	United States Dollar
VS	Volatile Solids
VSS	Volatile Suspended Solids
WAEC	West Africa Examination Council
WASH	Water, Sanitation, and Hygiene
WASHCOM	Water, Sanitation, and Hygiene Committee
WHO	World Health Organization
WSDP	Water Sector Development Plan
WSP	Water Service Provider

1. INTRODUCTION

1.1 Background

Poor sanitation and its associated impacts on public and environmental health are significant challenges for Port Harcourt, Nigeria. Although the majority of residents have access to flush or pour-flush toilets, piped sewer systems are non-existent (Kumpel et al. 2017). An established network of exhauster (vacuum) trucks provides emptying services for on-site waste containment facilities; however, most fecal sludge collected by the trucks is dumped without treatment at informal sites on the outskirts of the city. Manual emptying of septic tanks and cesspits is also prevalent in low-income areas, and waste is disposed of in adjacent rivers and streams. In low-income areas, toilets and cesspits also discharge into open drains, and residents without access to toilets rely on public hanging latrines built over waterways or defecate in the open. These practices adversely affect public health and local drinking water sources. Previous studies on groundwater quality have shown that drinking water supplies in Port Harcourt are vulnerable to fecal coliform contamination (Kumpel et al. 2017).

Given the need for improved fecal sludge management (FSM) practices in Port Harcourt, the World Bank commissioned this study to investigate and document the FSM value chain, current challenges, and potential institutional and technical opportunities. This analysis will support the development of pilot FSM projects that should inform an integrated sanitation master plan for the city.

1.2 Geographic Scope

Port Harcourt is the capital of Rivers State, Nigeria. It is located in the Niger Delta and situated along waterways of the Bonny Estuary. Over the past four decades, increasing urbanization and migration, motivated by the growth of the petroleum industry have resulted in significant population increases. Estimates suggest that the Greater Port Harcourt urban area currently has 1,450,000 inhabitants, which includes the Local Government Areas (LGAs) of Obio/Akpor and Port Harcourt (National Bureau of Statistics 2012).

The geographic scope of this assessment coincides with planned improvements in water supply infrastructure for the LGA of Port Harcourt, as well as the adjacent LGA of Obio/Akbor (Duret and Revell de Waal 2016). In 2010, a land use plan was developed to accommodate urban development in these areas, including the provision of water supply infrastructure. The land use plan envisions a three-phase approach to water supply infrastructure development, with the first phase of investment (Phase 1) benefiting 25% of the population of these two LGAs. These improvements will target the eight hydraulic zones identified in the "Phase 1 Outline" shown in **Figure 1**. The area of Eagle Island, which includes a sludge processing facility, will also be included via an extension of the distribution network in Hydraulic Zone 9.

Phase 1 is supported by investments from the African Development Bank (AfDB) and World Bank and funding from the Rivers State Government. The project was approved by Nigeria's Federal Executive Council and by both Banks in 2014 and implementation started in 2016.

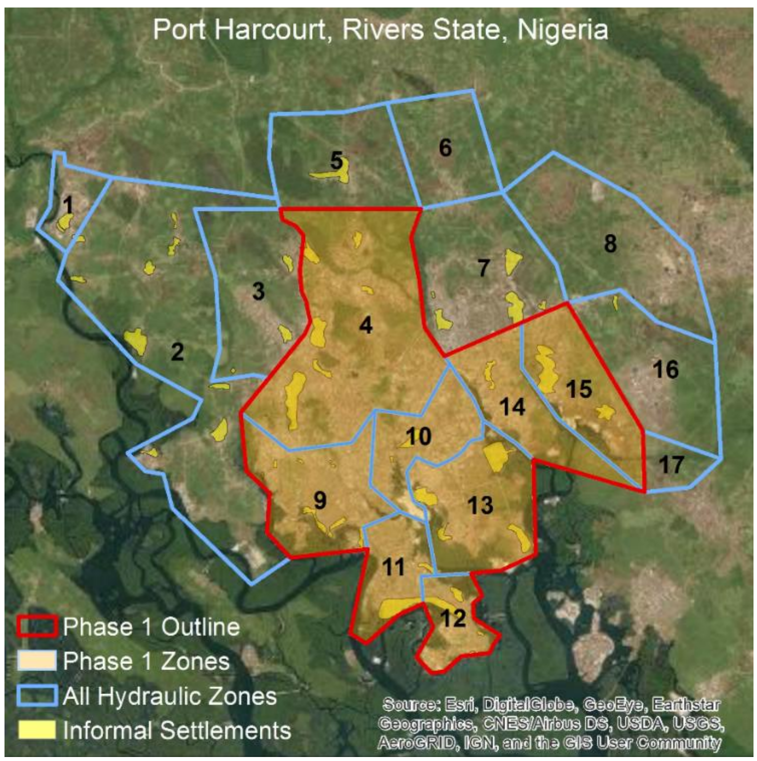


Figure 1: Hydraulic Zones of the Port Harcourt and Obio/Akpor Local Government Areas included in Phase 1 of the Port Harcourt Water Project

1.3 Data Sources and Research Methodology

Both quantitative and qualitative research methods were employed to explore FSM practices along the entire service chain of collection, transport, treatment, and safe enduse or disposal. Research tools developed by the World Bank were used in this study (Blackett and Hawkins 2016a, Blackett and Hawkins 2016b).

Table 1 provides an overview of the data collection instruments used to obtain quantitative and qualitative information.

Table 1: Quantitative and Qualitative Data Collection Instruments

	Instrument	Objective
Quantitative Methods	1. Household Survey	Collect information on household characteristics, water use, sanitation infrastructure, and on-site storage and emptying practices. Surveys were administered across the city, as well as specifically in informal settlements.
	2. Observation of Service Provider Practices	Observe containment, collection, transport, treatment, and enduse or disposal of fecal sludge
	3. Fecal Sludge Sample Analysis	Collect and analyze fecal sludge samples from exhauster trucks
	4. Fecal Sludge Private Providers Survey	Gather information on private provider characteristics, trucks operation, and the economics of fecal sludge exhauster truck services
	5. Transect Walks	Observe environmental and public health risks along specified routes throughout the community
Qualitative Methods	6. Key Informant Interviews	Obtain information from key stakeholders (e.g., government, service providers, etc.) on their roles and responsibilities throughout the FSM service chain, as well as their perspectives on challenges and opportunities for improving service delivery
	7. Focus Group Discussions	Gather information on household sanitation practices, people's understanding of risks associated with poor FSM services, and issues affecting the community, among other data
	8. Direct Observations	Direct observations and discussions with landlords, contractors, and farmers, as well as a technical assessment of the Eagle Island Treatment Plant

1.4 Geographic Distribution of Data Collection

Data on sanitation conditions was collected across the Phase 1 area, including communities with differing socio-economic levels. Sixty-five percent of household survey data was collected in low-income areas (n=509), and 28% of the surveyed households were located in waterfront communities, which are generally considered informal settlements (**Figure 2**).

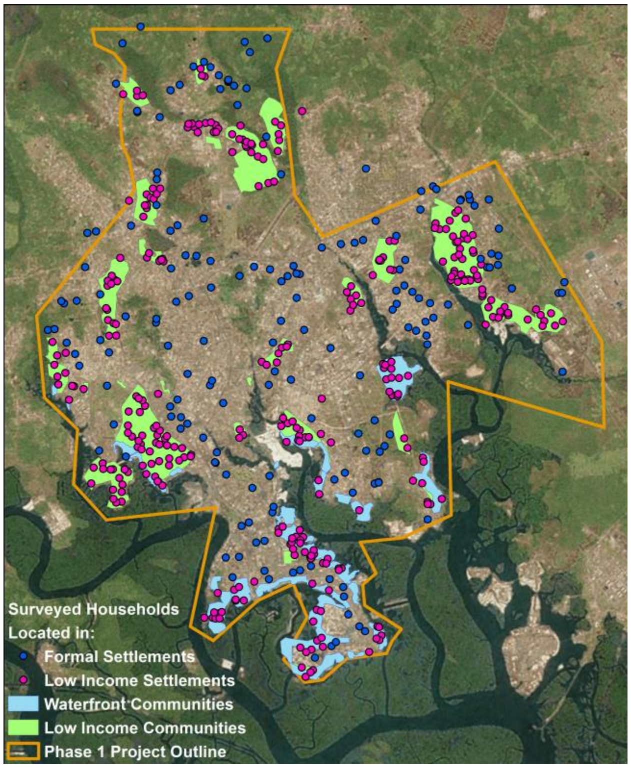


Figure 2: Surveyed households across the project area

Of the 15 transect walks and focus group discussions conducted across the project area, seven were conducted in low-income communities, six in middle-income communities, and two in high-income communities.

2 ASSESSMENT OF THE WATER AND SANITATION SECTOR

2.1 Sector Reforms of 2012

The Rivers State Water Sector Development Law, which reformed the State's water and sanitation sector, was passed by the State Assembly in January 2012 and signed into law by the State Governor on May 31, 2012 (Government of Rivers State of Nigeria 2012). Prior to this reform, the State Ministry of Water Resources and Rural Development (MWRRD), which is responsible for formulating state water and sanitation policies, oversaw the activities of two State agencies (Ministry of Water Resources and Rural Development 2012):

- The Rivers State Water Board (RSWB), which was responsible for providing water and sewage services; and
- The Rural Water Supply and Sanitation Agency (RUWASSA), which focused on rural water supply and sanitation: i.e., communities with less than 5,000 inhabitants.

In addition, various other institutions played a role in sector policy, resources management and services delivery:

- The Federal Ministry of Water Resources, involved with policy development and the implementation of water supply projects;
- The Niger Delta Development Authority, a Federal agency involved with the management of reservoirs, bulk water supplies and the implementation of water supply projects in partnership with the Federal Ministry of Water Resources;
- The Niger Delta Development Commission, a Federal agency dedicated to the development of the Niger Delta;
- Local Government Councils (LGCs), which administer Rivers State's Local Government Areas (LGAs) and shared responsibility for rural water supply and sanitation;
- The Rivers State Ministry of Health, which is mandated by the Nigerian Drinking Water Quality Standard (NDWQS) to conduct water quality surveillance; and
- The Rivers State Environmental Sanitation Authority (now known as the Rivers State Waste Management Agency), which is responsible for

regulating sanitation facilities and ensuring proper waste management, including solid waste.

The sector reforms were targeted towards separating and clarifying institutional responsibilities for three distinct activities:

1. policy formulation
2. regulation
3. service provision.

As a result, the Rivers State Water Sector Development Law of 2012 established the following institutional framework (Ministry of Water Resources and Rural Development 2012):

- Planning, policy formulation, and accountability is the responsibility of MWRRD, which is required to establish a Water Sector Coordination Committee and oversee the production and implementation of a Water Sector Development Plan (WSDP).
- Sector regulation is the responsibility of the newly created and autonomous Rivers State Water Services Regulatory Commission (RSWSRC), which is mandated to enforce State and Federal water laws and policies and to regulate wastewater and sewerage activities. RSWSRC also has the authority to license Water Services Providers (WSPs). All water and sanitation projects implemented in Rivers State, whether by Government agencies, companies, or non-profit organizations, must be approved by RSWSRC.
- Service Provision responsibilities fall to three institutions:
  - The newly created Port Harcourt Water Corporation (PHWC), which was given ownership of RWSB assets and charge for water and sanitation services provision in the State's urban center comprising Port Harcourt LGA and Obio-Akpor LGA. PHWC has the authority to contract with private service providers.
  - The newly created Rivers State Small Towns Water Supply and Sanitation Agency (RSSTOWA), which was given ownership of RSWB assets and charge for water and sanitation services provision in small towns (i.e., greater than 5,000 inhabitants) in all LGAs, except for Port Harcourt and Obio-Akor. RSSTOWA collaborates with LGCs, and has the authority to engage with private service providers and Water Consumer Associations (WCAs). Communities in small town are helped by RSSTOWA and Local Government Councils to form WCAs, which own, operate, and manage their water schemes[1].
  - RUWASSA, which was reformed to provide technical assistance and advisory services to rural communities that were given ownership of rural water supply and sanitation assets. Each LGC is required to form

[1] R.S.L.N. Law No. 7 of 2012 – Rivers State Water Sector Development Law, page A6, item (r).

a Rural Water Supply, Sanitation and Hygiene Department (WASH Department), which will liaise between RUWASSA and rural communities. Water Supply, Sanitation and Hygiene Committees (WASHCOMs) that are registered with LGCs will represent rural communities.

- A full list of institutional stakeholders is provided as Appendix A.

2.2 The Port Harcourt Water Supply and Sanitation Project: a State of Crisis

In conjunction with the sector reforms, MWRRD contracted an international consulting firm in 2011 to conduct feasibility studies and engineering designs for the rehabilitation and extension of water and sanitation infrastructure in the Port Harcourt metropolis (Azizi et al. 2014). This planning was the foundation for the Port Harcourt Water Supply and Sanitation Project (PHWSSP), which is envisioned as Phase 1 of a comprehensive infrastructure program for the Port Harcourt and Obio-Akpor LGAs. The Project addresses service improvements for the approximately 1.5 million people residing in the areas of Borokiri, Old Port-Harcourt Township, Diobu, Rumuola, Trans Amadi, Abuloma, Woji, and Elelenwo. The main project components include:

- Water supply and sanitation infrastructure - rehabilitation and expansion of water supply system (production, treatment, transmission, storage, distribution and house connections), environmental protection infrastructure, sanitation facilities in public places (markets, motor parks and some waterfronts), and the implementation of fecal sludge management (FSM) pilots that will inform the development of a sanitation master plan.
- Institutional support to the newly established Port Harcourt Water Corporation (PHWC).
- Hygiene, sanitation and environment improvements, including urban hygiene and the downstream prevention of environmental degradation such as pollution of the ground water resources and better hygienic behavior among school pupils and residents through hygiene and sanitation promotion and investment in the construction of hygienic toilets at the household level.
- Project management services to ensure the timely and successful implementation of the project.

The total costs of the project were estimated at USD 328 million, which was secured through development assistance loans from the AfDB (USD 200 million) and the World Bank (USD 80 million) to the Federal Government, as well as co-financing by the Rivers State Government (USD 48 million).

Approval of the project by the Nigerian Federal Executive Council and the two development banks was obtained in 2014. However, changes in the political leadership of Rivers State during the general elections of 2015 delayed the project, and the subsidiary loan from the Federal Government to the Rivers State Government was not approved until the 1st quarter of 2016. As a result, the project is facing serious time constraints since project activities funded by the World Bank are scheduled for completion by 30th June 2020, and activities funded by the AfDB are scheduled for completion by 30th April 2021.

In addition to delaying the approval of the subsidiary loan, the 2015 political changes in Rivers State have created significant additional challenges for the project. These challenges fall into three categories:

1. *Failure to complete the implementation of sector reforms:* The 2012 Water Sector Law requires MWRRD to establish a Water Sector Coordination Committee and oversee the production and implementation of a Water Sector Development Plan (WSDP). MWRRD has not formed this Committee and there is no WSDP for Rivers State. As a result, sector decisions are largely in the hands of the Governor, the Commissioner of MWRRD, and the State Executive Council.

   The lack of a Coordination Committee and WSDP has also created confusion over regulatory roles and hampers the creation and enforcement of new regulations. For example, both PHWC and RSWSRC claim responsibilities for regulating the quality of private water supplies and for issuing borehole licenses. Furthermore, it is not clear which agency should regulate private sanitation improvements and fecal sludge dumping by exhauster truck operators. In addition, MWRRD has not appointed a Board of Directors for PHWC. In the absence of a governing body, PHWC is currently operating without legally required oversight, and management decisions may be called into question.

2. *Failure to release operating budgets for sector agencies:* both PHWC and RSWSRC claim that they have not received State budget allocations since 2014, and the reasons behind these budget restrictions are not clear. RSWSRC has managed to operate by extending start-up funding received in 2014, by collecting fees from oil companies, and by participating in external activities such as the USAID SUWASA program. PHWC claims to be operating with start-up funds received in 2014, by testing water samples for private clients, and by obtaining operating loans (the sources of these loans were not specified). PHWC also charges exhauster trucks a dumping fee at the Eagle Island Fecal Sludge Treatment Plant, but these dumping fees do not cover the Plant operating costs. Recently, the Governor halted all revenue collection by agencies, which has limited regulatory fee collection by RSWSRC, though PHWC continues to charge for water testing and sludge dumping services.

3. *Suspension of Project Bank Accounts:* For reasons that are not clear, the Rivers State Executive Council (Heads of the various Ministries, including MWRRD) have frozen the project bank accounts. The current project activities are largely planning and capacity-building exercises implemented by the Project Management Consultancy (PMC), which is contracted to a consortium formed by the Danish consulting firm, Ramboll, and the Nigerian consulting firm, Hospitalia Consultaire. Work by the PMC continued until late June 2017 when the majority of the Port Harcourt-based team members were asked to disengage from the project and conserve their contracted project days until the bank account suspension is lifted. Moreover, at the time of this assignment, PHWC staff members working in the Project Implementation Unit (PIU) are not receiving the supplementary stipends that were committed for their project work. It is likely that the account freeze is also obstructing tendering and construction programs, which will place additional pressure on the project timeline.

In addition to the operational and financial stresses generated by both the lack of proper water sector governance structures and the seemingly arbitrary withholding of institutional budgets and project funds, these challenges are promoting uncertainty among employees in the various institutions. This is probably contributing to poor morale. Lack of capacity, particularly at PHWC, is already a major impediment to the overall success of the project. Unless strategies for addressing the politically driven challenges are implemented, staff turnover is likely to increase.

2.3 Strategic Considerations

The main sector challenges described above appear to stem from a shift in political priorities in 2015 which mean that in the near-term it is unlikely sector reform or project implementation will be driven forward by a significant supply of political will. Consequently, the success of fecal sludge management pilot programs in this context of a weak institutional environment will likely depend on the levels of community ownership and local financial sustainability that are built into the implementation process.

Planning should include a step-wise route to scale that relies as little as possible on centralized infrastructures and financial subsidies from the state. Moreover, if the pilots are to contribute to the broader and longer term success of PHWSSP, fecal sludge management programs should also entail capacity-development efforts for residents in the pilot sites that support their abilities to articulate sanitation priorities and initiate a more informed and engaged public conversation aimed at shifting political priorities and increasing accountability.

Building popular and articulate demand for effective service provision is critical, because, in the absence of strong supply-side WASH initiatives, an effective demand side-platform will be needed to drive efforts forward. Building popular and articulate demand entails designing and implementing facilities that are themselves popular articulations of local priorities. Therefore an imaginative design framework, broadly responsive to local needs, context and potential is critical.

In order to ensure such responsiveness, there needs to be sufficient resourcing for an iterative and participatory design process. There also needs to be commitment and resourcing to support a grass roots engagement and education drive, as well as a wide-ranging advocacy program. Importantly, the pilot should be configured to ensure the strategic and operational integration of these elements. Therefore, insulating the funding, procurement and implementation processes from political interference is also a critical requirement. This could be achieved by resourcing the pilots – at least the non-infrastructure components – directly through a technical assistance program. This would be a way to reinforce and safeguard investment.

In this regard, it will also be important to achieve a coherence of effort by non-state actors that are planning sanitation interventions. In addition to the project managed by PHWC, international non-governmental organizations, including the International Committee of the Red Cross (ICRC) and Medecins Sans Frontieres (MSF) are developing sanitation improvement programs in low-income areas of Port Harcourt. A planned UNDP/Cities Alliance GEF project on climate compatible urban development in Port Harcourt could offer further scope for broadening and deepening impact on the ground, while stimulating institutional reform.

Expansion of these efforts may promote the development of a parallel sanitation service sector and, in so doing, may not directly address issues of state institutional capacity. However, institutional reform is unlikely to take place absent of an organized and sustained demand for improvement. Given the urgency and depth of need for sanitation services, any efforts to concretely address this need, while demonstrating sector best practice and building the demand for institutional reform would be strategically valuable.

3 ASSESSMENT OF FSM SERVICES

To develop effective FSM pilot designs, it is important to document the existing FSM service chain in different areas of the city, including in low-income neighborhoods.

3.1 The FSM Value Chain

The FSM value chain describes each activity from production until disposal or enduse. Evaluations of existing FSM service chains are critical for designing service improvements (Lüthi et al. 2011).

- The user interface describes the initial capture of waste, including the types of facilities city residents use for defecation.
- Fecal sludge containment describes existing methods for storing waste, including the proportions of households and businesses connected to cesspits, septic tanks, and open drainage into the environment.
- Emptying and transport describes how fecal sludge is removed from containment structures and transported for treatment or disposal.
- Treatment describes existing processes for rendering fecal sludge harmless for disposal or enduse.

3.2 User Interfaces

Most households across the city use cistern flush or pour flush toilets, though the proportions of user interfaces between regions of the city differ significantly. (**Figure 3**). The high prevalence of indoor flush toilets is apparently due to regulations imposed in 1983 by the former Rivers State Environmental Authority (RSESA), which banned the use of pit latrines and toilets that emptied into buckets (Ocam Planters 2012). In the waterfront communities the proportion of households utilizing flush toilets is lower than in other areas of the city. However, it is still the predominant user interface **(Figure 3)**. The prevalence of flush toilets does vary across waterfront communities. In low-density, comparatively affluent areas, up to 80% of residents report using flush toilets. However, in “high-density multiple occupancy tenement” areas, “medium-density mixed development” areas, and areas comprising a 50/50 mix of these types, only 38% of residents report using flush toilets (Max Lock Consultancy Nigeria 2009). Eighty-five percent of the waterfront population live in the less affluent areas.

Of respondents using facilities (not open defecation), 32.3% use shared facilities (n=492). Of the shared facilities, 36.5% are public facilities (n=159). Private shared facilities serve, on average, 10.6 users (n=101), while public shared facilities serve, on average, 59.6 users (n=58).

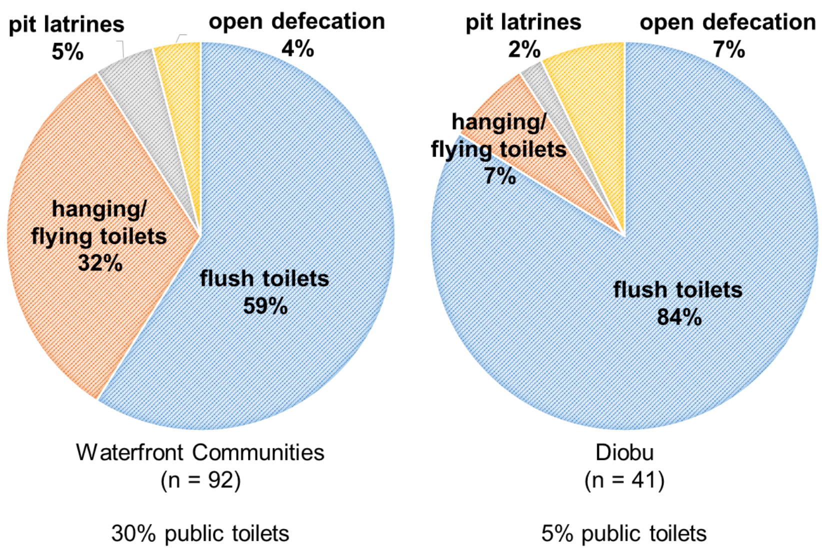


Figure 3: Proportion of users in waterfront communities (left) and Diobu (right) with primary access to the various types of user interface

Waterfront residents without access to household or shared toilets often reported using public toilet blocks, which are generally constructed as “hanging latrines” over the adjacent waterways. The Focus Group Discussions (FGDs), Transect Walks, and Key Informant Interviews (KIIs), however, indicated that these residents also resorted to defecating in plastic bags (flying toilets or ‘shot putting’ - which is the common local terminology) and buckets, particularly at night. In the low-income upland area of Diobu, the use of public toilets is lower, though households with a common courtyard or compound often share toilets.

3.3 Containment

Three-quarters of surveyed households with indoor toilets reported underground containment structures (**Figure 4**). However, understanding of containment systems was often poor. From observation, waste containment for households in formal settlements and higher-income areas are generally water-tight septic tanks linked to soakpits. In the waterfronts and other low-income areas, sealed septic tanks are rare. Most households construct cement-lined cesspits (locally referred to as soakaways) that are open on the bottom. The cesspits promote drainage and reduce the need for emptying. Cesspit overflow pipes that drain into street gutters are also common.

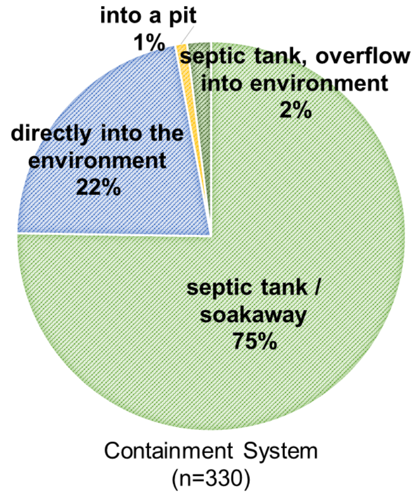


Figure 4: Containment systems for household survey respondents in low income areas

3.4 Emptying and Transport

3.4.1 Summary of the Exhauster Truck Industry

Fecal sludge management services in Port Harcourt are dominated by private fecal sludge exhauster trucks (locally referred to as exhauster trucks), which empty containment facilities at residences, businesses, institutions (churches, schools, hospitals) and government buildings. The Association of Exhauster truck Operators (ASTO) was established in 2008 and currently has approximately 57 members who, between them, manage over 100 trucks. The large size of this sector reflects the high coverage of underground fecal sludge containment in Port Harcourt and the requirements for frequent emptying due to both the use of flush toilets and infiltration by ground water.

Our estimates suggest that the treatment plant at Eagle Island only has capacity for 20% of the fecal sludge collected by sludge exhauster trucks. The remainder is dumped without treatment at a various other sites. The owner of one of these sites at Amadi Ama stated that he has a fecal sludge dumpsite permit from the Ministry of Environment. He reported that this permit is renewed annually for a cost of ₦100,000. He also reported that the Ministry of Environment specified regulations for the dumpsite, which include a discharge channel to the river, prohibition of the dumping of oil, and fumigation of the dumpsite every six months. We did not have time to verify the presence of the dumpsite permit, the reported annual fees, or the regulatory requirements.

On the first trip of the day to the Amadi Ama dumpsite, drivers pay a fee of ₦3,000. This includes ₦500 for the local government and ₦500 for state internal revenue. The rest goes to the dump owner. For subsequent trips on the same day, the dumping fee is ₦2,000, which is the reported dumping fee at the other informal dumpsites and at the Eagle Island Treatment Plant. These subsequent fees also go to the dump owner.

Regulatory requirements for the exhauster truck operators appear limited to the purchase of a series of annual operating stickers, including from the state government, the federal government, the Ministry of Environment, and Local Government Councils. In total there are about 15-20 stickers that are available as bulk purchases from “sticker vendors” for reported prices of ₦20,000 to 40,000 per truck.

Truck operators charge about ₦15,000 to 20,000 for emptying an underground containment structure. They prefer to establish long-term emptying contracts with businesses and institutions. However, these non-residential clients generally specify that fecal sludge can only be dumped at an operational treatment plant. Some truck operators reported servicing residential customers in waterfronts and other low-income neighborhoods. However, they add a billing surcharge for these clients due to security concerns and the need for longer hoses and additional vacuum pumps for emptying underground structures that are difficult to access from main streets.

3.4.2 Summary of Manual Emptying Sector

Manual emptiers of septic tanks and cesspits are most often employed in the waterfront communities. It is occasional work for young men who generally reported the work as a supplementary income source rather than their career focus. The emptiers in a particular neighborhood reported that they knew each other and refrain from competing on price. They stated that there are no formal manual emptying associations, and it is somewhat of a stigmatized profession. The emptiers may use gloves but do not employ any other protective equipment.

The cost of manually emptying a pit of 7ft x 12ft x 10 ft. was reported as ₦19,000, which is similar to the cost of hiring an exhauster truck. The process of manual emptying is complex and begins early in the morning by pouring kerosene (sometimes mixed with garlic) into the pit to reduce smells and kill maggots and insects. Sealed concrete covers are broken to gain access. In the evening emptiers working in pairs use 20 liter buckets to bail the pit, eventually climbing inside as levels drop. The buckets are emptied into nearby waterways, and emptying is usually timed with an incoming tide. Emptying continues until the bottom of the pit is free of sludge, which can take up to three hours. The manual emptier interviewed for this study reported excavating pits until he reached the sand bottom. He also reported that pits often contain substantial solid waste in addition to fecal sludge: apparently the solid waste is introduced through cracks in the concrete covers.

Mechanical evacuation with exhauster trucks often also involves an element of manual emptying to remove thick sludge, silt and solid waste from the bottom of tanks. This is usually performed by the mechanical evacuators, but occasionally households hire manual emptiers as a supplementary service.

3.4.3 Household Knowledge of Emptying Practices

Knowledge of emptying practices was limited among households surveyed, with only 55% of households able to report emptying frequencies, possibly due to high rates of renting (67%) and the likelihood that many respondents were not the heads of households. Despite high water tables, reported emptying frequencies were low among all households, especially those in formally planned and generally higher-income areas (**Figure 5**). The low rates of emptying may be related to the use of well-designed septic tanks connected to soakpits in high-income areas and the use of cesspits that promote drainage in low-income areas.

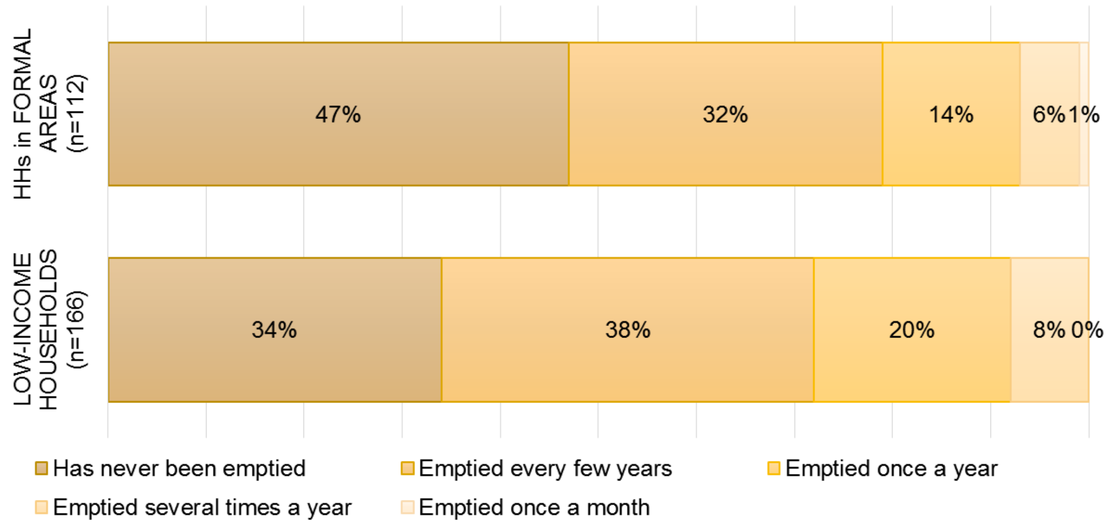


Figure 5: Emptying frequency among households surveyed

Among households who were familiar with the household's emptying practices, 15% reported paying for emptying services in the past year (n=278) (**Figure 5**). Households generally paid directly for emptying, often sharing the costs with their neighbors. (**Figure 6**).

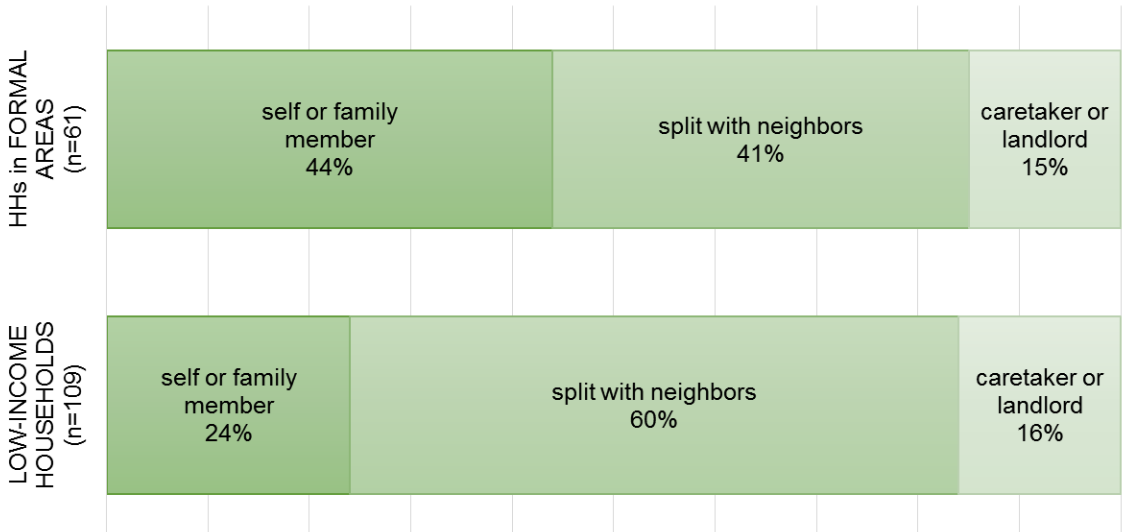


Figure 6: Distribution of emptying costs among households

Among households who reported that their containment facilities were emptied, 97% used fecal sludge exhauster trucks and paid ₦20,200 on average. Exhauster truck operators reported charging a median price of ₦18,000 (n=30). Only 25% of exhauster truck operators reported working in waterfront areas (n=32), citing poor physical access and the households' limited ability to pay as the main barriers. One truck driver cited security concerns as a reason for not working in waterfront communities.

3.5 Treatment

It is unlikely that any fecal sludge in Port Harcourt is sufficiently treated. Roughly 9% of sludge is transported to the Eagle Island Treatment Plant, but the effectiveness of treatment at the plant is unknown. (For detailed analysis of the treatment plant, see **Section 4**). The remaining fecal sludge that is collected by exhauster trucks is dumped directly into the environment at informal sites.

Shit Flow Diagrams (SFDs) were created for both the entire city and just the low-income settlements within the city (**Figures 7** and **8**). Blue arrows represent safely managed fecal sludge while red arrows represent unsafely managed fecal sludge. Values were calculated from household survey data collected as well as from exhauster truck survey data. Since treatment plant effectiveness is unknown, it has been assumed to be entering the environment only partially treated.

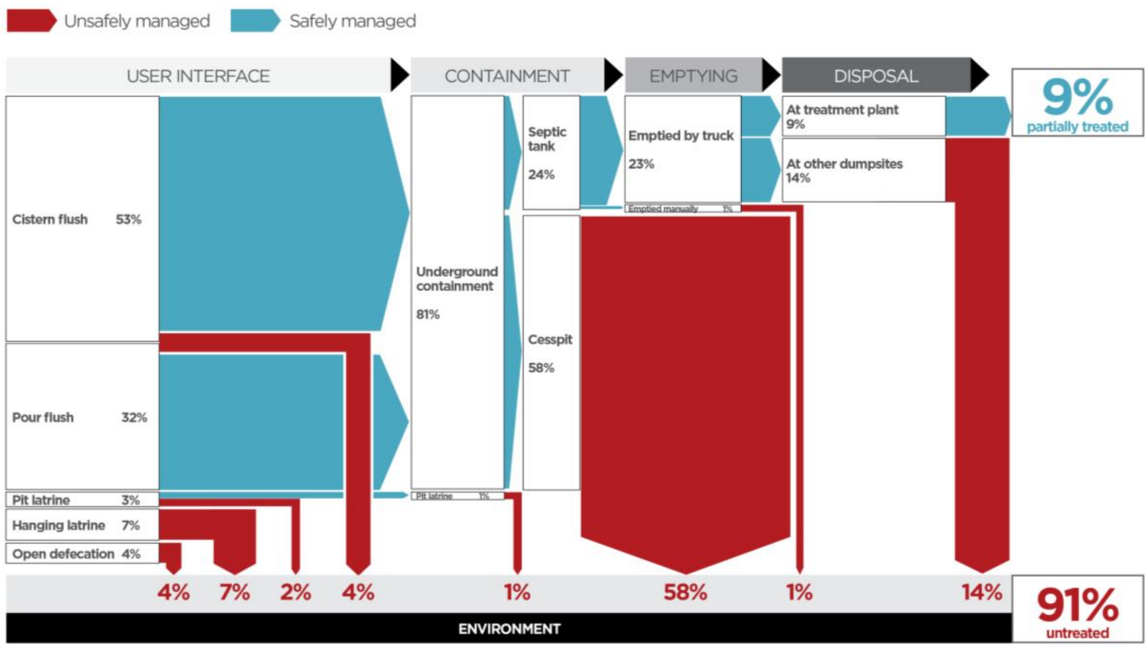


Figure 7: Shit Flow Diagram for entire city of Port Harcourt, Nigeria

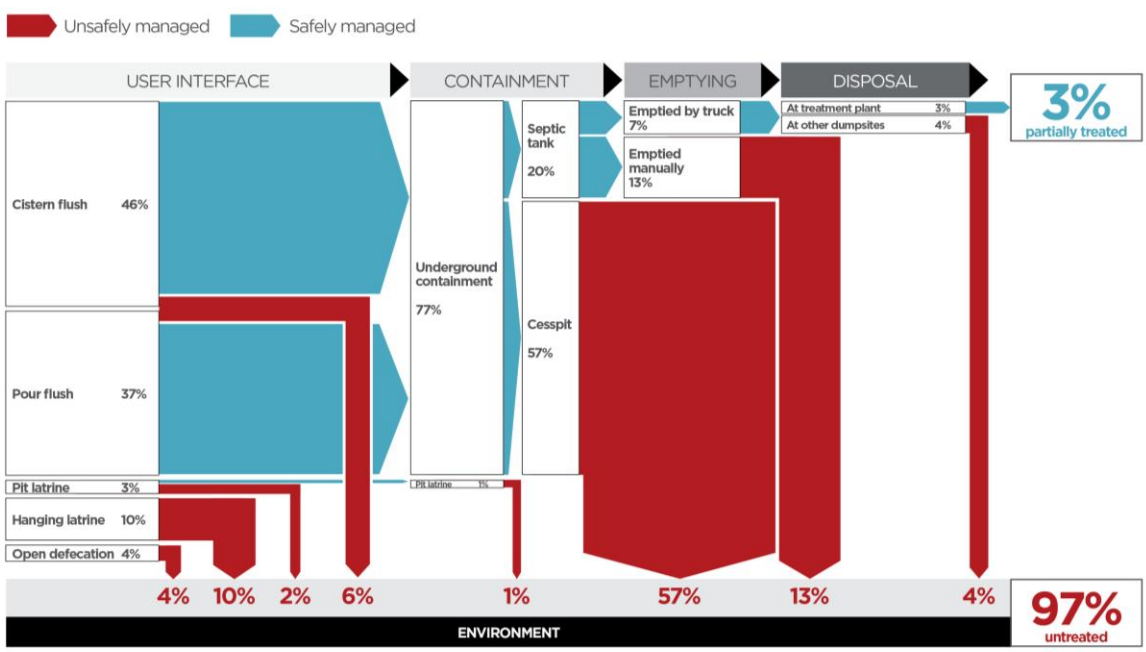


Figure 8: Shit Flow Diagram for low-income settlements in Port Harcourt, Nigeria

3.6 End Use and/or Disposal

Since operational challenges prevent the Eagle Island Treatment Plant from working at full capacity, there is no existing reuse of liquid or solid streams from the plant. Disposal at the plant is not closely monitored and the effluent safety is unknown. Dumping occurring at other sites is simply entering the environment without any treatment (**Figure 9**).

Figure 9: Exhauster truck emptying fecal sludge directly into the river at the Amadi Ama dumpsite

4 ASSESSMENT OF THE EAGLE ISLAND TREATMENT PLANT

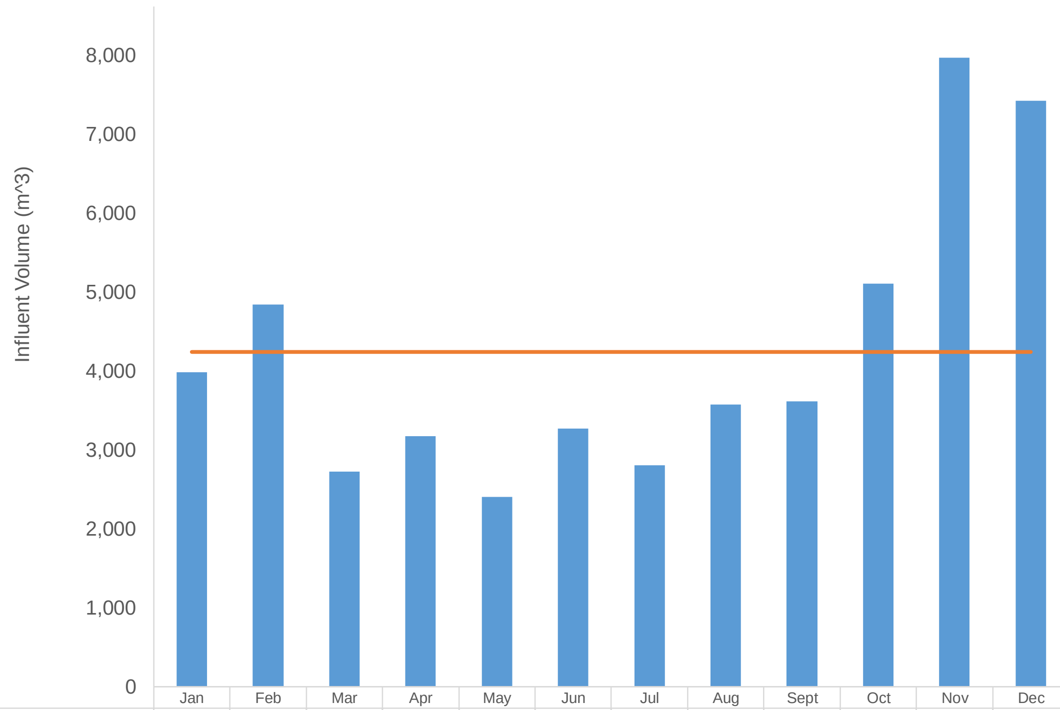
The Eagle Island Treatment Plant is the only facility currently processing domestic and commercial fecal sludge in the project area; it thus assumes an important role in the FSM service chain. The Plant is located in Port Harcourt and operated by the Port Harcourt Water Corporation (PHWC), which was formerly part of the Rivers State Water Board (RSWB). To construct the facility, the Rivers State Government selected the location for the plant and engaged JAM Services Company, LTD, based in Port Harcourt, to serve as the contractor responsible for civil construction. JAM Services engaged Tech Universal (U.K.) Ltd to complete the process design for the facility and to specify and procure the majority of the mechanical and electrical equipment. Construction commenced in 2010 and the facility was commissioned mid-2013.

4.1 Fecal Sludge Influent

4.1.1 Emptying Operations and Influent Volumes

Fecal sludge arrives at the Eagle Island Treatment Plant from exhauster trucks. It is removed from the trucks by gravity and emptied into a concrete basin. Once inside the basin, a submersible pump transfers the influent into a balance (equalization) tank.

Since the volume of influent varies substantially throughout the year, understanding historical flow patterns is important when evaluating the facility's performance. A typical influent flow analysis would rely upon measured, multi-year flow volumes. This information is not available for the Eagle Island Treatment Plant. As a result, historical flows have been estimated using financial records provided by PHWC and an estimate of the average capacity of trucks based on data obtained by Aquaya as part of the Fecal Sludge Private Providers' survey. PHWC reports that 4,496 trucks transported fecal sludge to the facility in 2016 (PHWC 2016a). Data collected from exhauster truck owners and operators indicates that the average capacity of an exhauster truck is 11,315 liters. Based on this information, influent flow volumes for 2016 have been estimated and are presented in **Figure 10**. On average, the facility received 4,239 m^3 of fecal sludge each month. Influent flows were above average in February, October, November and December.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Influent Volume (m^3)	3,983	4,843	2,727	3,168	2,399	3,270	2,806	3,575	3,609	5,103	7,965	7,422
Average (m^3)	4,239	4,239	4,239	4,239	4,239	4,239	4,239	4,239	4,239	4,239	4,239	4,239

Figure 10: Estimated Monthly Influent Flow Volumes (2016)

As noted by Niwagaba et al. (2014), the age, type, and quality of construction of containment units; emptying patterns; and inflow and infiltration can account for some of the fluctuation in fecal sludge influent volumes. In Port Harcourt, access to illegal dumpsites is also a contributing factor. Exhauster truck operators report that illegal dumpsites offer more convenient access for emptying than Eagle Island and thereby allow them to reduce fuel costs. In addition, illegal dumpsites are perceived as more reliable than the Eagle Island Treatment Plant due to the number of plant closures in 2016. The facility suspended operations several times due to mechanical failures; it also does not accept fecal sludge during public holidays or during the weekend.

Although influent volumes do not exceed the design capacity of the SBR tanks, they do exceed the capacity of the equalization tank (**Table 2**). The design capacity of the SBR tanks is listed as 1,000 m^3 per day. On average, only 24% of the SBR design capacity was used in 2016. However, average daily influent flow exceeded the capacity of the equalization tank throughout 2016.

Table 2: Average Daily Influent Volumes as Percent of SBR Tank Capacity and Equalization Tank Capacity

Month	Average Daily Influent Volume as Percent of SBR Tank Capacity	Average Daily Influent Volume as Percent of Equalization Tank Capacity
January 2016	22%	177%
February 2016	27%	215%
March 2016	15%	121%
April 2016	18%	141%
May 2016	13%	107%
June 2016	18%	145%
July 2016	16%	125%
August 2016	20%	159%
September 2016	20%	160%
October 2016	28%	227%
November 2016	44%	354%
December 2016	41%	330%

4.1.2 Influent Loads

Fecal sludge treatment is intended to protect human health, reduce excess nutrient levels, and prevent dissolved oxygen depletion in receiving waters. To achieve these goals, pathogens, nutrients, suspended solids, and Chemical Oxygen Demand (COD) are key parameters that should be measured and monitored at the intake facility and throughout the treatment process. Raw fecal sludge contains pathogenic organisms such as bacteria, viruses, protozoa and helminths, which carry infectious diseases and can adversely affect public health. Nutrients include nitrogen and phosphorous. Excess nitrogen in drinking water may increase the risk of birth defects in infants and the development of certain cancers in adults. Excess phosphorous can lead to eutrophication and algae bloom in receiving water streams and thus have negative impacts on recreational use of surface waters and drinking water production (Akpor 2011). Suspended solids have both organic and inorganic components and high concentrations of both can cause many problems for aquatic life and ecosystems. The organic portion, known as volatile suspended solids (VSS) contributes to oxygen consumption and biofouling. The inorganic components contribute to the formation of sludge deposits on water bodies. COD provides a means of measuring the pollutant strength of wastewater and fecal sludge; it is a measure of the total amount of oxygen required to oxidize all organic material into carbon dioxide and water.

To characterize raw fecal sludge in Port Harcourt, Aquaya collected and analyzed 31 fecal sludge samples during the emptying operations of exhauster trucks. The sludge was collected from households and businesses throughout the project area. It is important to note that no samples were collected from trucks emptying at the Eagle Island Treatment Plant, because the facility was not in operation during the time of sample collection. As a result, the samples were collected as exhauster trucks were emptying their tanks at illegal dumpsites.

The analysis parameters and results are summarized in **Table 3**. The results indicate high levels of COD, TP, TN, Ammonium, and TSS.

Table 3: Fecal Sludge Characteristics (n=31)

	Minimum	Maximum	Mean
pH	6.31	7.91	7.50
Chemical Oxygen Demand (COD)	2.29 g/L	53.70 g/L	19.64 g/L
Total Phosphorus (TP)	0.037 g/L	2.57 g/L	.498 g/L
Total Nitrogen (TN)	0.11 g/L	2.68 g/L	1.06 g/L
Ammonium	0.00 g/L	4.80 g/L	0.33 g/L
Total Solids (TS)	0.12%	9.78%	1.71%
Total Suspended Solids (TSS)	0.00 g/L	52.50 g/L	13.74 g/L
Volatile Solids (VS)	9%	64%	35%
Volatile Suspended Solids (VSS)	0%	100%	46%

4.2 End Use Goals and Treatment Objectives

4.2.1 Effluent Reuse and Discharge

Key stakeholders indicate that PHWC had originally expressed an interest in the production of reclaimed water for irrigation of golf courses and for use onsite at the plant. However, reclaimed water was not produced and the plant instead discharges effluent into an adjacent creek. PHWC has adopted a set of numeric targets for the quality of this effluent (**Table 4**).

Table 4: Eagle Island Effluent Discharge Targets (PHWC 2016b)

Parameter	Unit	Eagle Island Target	National Environmental Standards and Regulatory Enforcement Agency
pH		6.5 – 8.5	6.5 – 9.0
Biological Oxygen Demand (BOD)	mg/L	30	50
Chemical Oxygen Demand (COD)	mg/L	50	250
Total Suspended Solids (TSS)	mg/L	10	50
Total Kjeldahl Nitrogen (TKN)	mg/L	8	10
Total Phosphorous (TP)	mg/L	10	10
Total Coliform Count (TCC)	mpn/100ml	200	Not Specified

With regard to BOD, COD, TSS, and TKN, the facility's targets are more stringent than those of Nigeria's National Environmental Standards and Regulatory Enforcement Agency (NESREA).

4.2.2 Biosolids Disposal and Resource Recovery

Dried sludge is currently stored onsite following treatment. A biodigester was installed at the facility and was used initially for demonstration purposes. Key stakeholders also noted that chicken and cow manure were intended to be sourced locally and fed into the biodigester as a co-substrate. Unfortunately, key stakeholders could not provide documentation on the results of the pilot or were unsure why the biodigester was eventually abandoned.

4.3 Facility Overview

4.3.1 Utilization of SBR Systems: Literature Review

In 2010, Tech Universal (U.K.), LTD submitted an offer for the design of an activated sludge processing system featuring a Sequencing Batch Reactor (SBR). SBRs are commonly used for activated sludge treatment of domestic wastewater and high strength industrial wastewater; limited information is available on the extent of their use or effectiveness in treating fecal sludge. In SBR systems, aeration and sludge settlement occur in the same tank. The SBR process can be generally characterized by five phases: Fill, React, Settle, Decant, and Idle. The steps in the React phase can be adjusted to provide anaerobic, anoxic, or aerobic conditions necessary for biological nutrient removal.

Sirianuntapiboon et al. (2005) evaluated treatment efficiencies for milk industry wastewater using a conventional SBR and sequencing batch bio-film reactor system (an SBR with plastic media placed on the bottom of the reactor to increase system efficiency and bio-sludge quality). Milk industry wastewater contains high concentrations of COD, BOD_5, and TKN; the ranges used by Sirianuntapiboon et al. (2005) are summarized in **Table 5**. The COD, BOD_5, and TKN removal efficiencies of the sequencing batch reactor bio-film system under a high organic loading of 1340 BOD_5 were 89.3 ±0.1, 83.0 ±0.2, and 59.4 ±0.8 percent, respectively. For the conventional SBR system, the COD, BOD_5, and TKN removal efficiencies were 87.0 ±0.2, 79.9 ±0.3, and 48.7 ±1.7 percent, respectively. Further, the removal efficiencies of the system decreased, as organic loading increased (Sirianuntapiboon et al. 2005).

Table 5: Characteristics of Milk Industrial Wastewater (Sirianuntapiboon et al. 2005)

Parameter	Unit	Range	Average ± SD
COD	mg/L	5000 – 1000	7500 ±324
BOD_5	mg/L	3000 – 5000	4000 ±59
TS	mg/L	3000 – 7000	5000 ±46
Oil and Grease	mg/L	70 – 500	200 ±7.3
TKN	mg/L	50 – 150	120 ±2.8
TP	mg/L	50 – 70	60 ±0.41
pH		4.0 – 7.0	6.0 ±0.62
Temperature	°C	34 – 35	34.5 ±0.47

Sombatsompop et al. (2011) evaluated SBR effectiveness at treating piggery wastewater. Piggery wastewater consists of pig manure (urine and feces), food waste, and water from cleaning pig living quarters. Piggery wastewater contains a considerable amount of organic matter and a high ammonia nitrogen concentration. Its general characteristics are summarized in **Table 6**.

Table 6: Characteristics of Piggery Wastewater (Sombatsompop et al. 2011)

Parameter	Unit	Range
COD	mg/L	4700 – 5900
BOD_5	mg/L	1500 – 2300
TSS	mg/L	4000 – 8000
TKN	mg/L	300 – 500
Nitrogen-Ammonia	mg/L	210 – 380
pH		7.5 – 8.5

In study completed by Sombatsompop et al. (2011), the organic matter in piggery wastewater was initially treated using anaerobic digestion. Two SBRs, one conventional and the other a moving-bed SBR, were subsequently used to remove additional organic matter and reduce nitrogen through nitrification-denitrification. Both systems were operated with sludge retention times of 10 days. The results indicate that the BOD_5 removal efficiency was greater than 90% at organic loads of 1.18 – 2.36 kg COD/m3. The moving-bed SBR produced a TKN removal efficiency of 86-93%, while the conventional SBR system produced a removal efficiency of 75-87% at all organic loads.

4.3.2 Process Flow Diagram – Tech Universal (U.K.), LTD Offer

Figure 11 is a process flow diagram that depicts the system proposed by Tech Universal (U.K.), LTD.

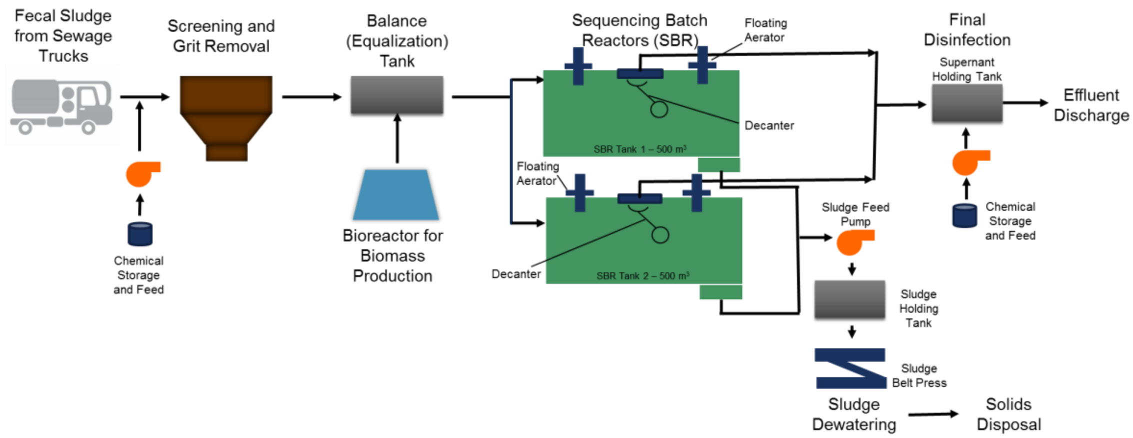


Figure 11: Process Flow Diagram – Tech Universal (U.K.), LTD Offer

4.3.3 System Description: Intended versus Actual

Eagle Island's SBR system has undergone several modifications since the original concept was circulated by Tech Universal. **Table 7** provides information on the plant's current system and how it differs from the original design intent.

Table 7: Intended versus Actual System Description

Ref.	Element	Intended	Actual
1	Inlet Flow management	Fecal sludge provided by exhauster trucks; closed pipe inlets, with a pumped manifold to the Hüber fine screen	A low-level concrete basin, for gravity discharge by tankers, with one inlet submersible pump lifting influent to the balance tank
2	Screens	Hüber fine screen, with chute for screening waste	A vertical 'screen wall' within inlet basin
3	Fats, Oils, and Grease Removal	None planned	Hanging baffle for scum removal, within inlet basin
4	Influent Balance Tank	One elevated tank with two (2) submersible pumps (duty/standby) feeding one manifold to either SBR. Used for staging biomass for use in the SBR process.	Used to store and balance influent flows prior to SBR
5	SBR Tanks	Two, elevated tanks with inlet and outlet pipework from each tank	Two, elevated tanks with inlet and outlet pipework from each tank. Only one SBR tank is used each day.
6	Final Effluent Piping and Collection	Final effluent was to be collected in a treated water tank for chlorine disinfection, then pumped directly into tankers for irrigation of a golf course, or for on-site process usage.	Final effluent is collected in a treated water tank and chlorine is added. Final effluent is subsequently drained by gravity to creek after each batch.
7	Solids Processing and Disposal	Sludge is pumped out of the SBRs by 1 of 2 (duty/standby) progressive cavity pumps to a sludge holding tank directly above a sludge belt press. Transportation from the SBR tanks to the holding tanks takes approximately 12 minutes at the end of the SBR batch process.	Approximately 100m3 of sludge is produced after decanting of each SBR. This sludge is pumped to a sludge holding tank which may take many hours to process, thus paralyzing the entire treatment process. The volumetric capacity of the sludge belt press severely limits the amount of solids that can be processed. Plant operators

Ref.	Element	Intended	Actual
			indicate that approximately 100 m^3 of 'sludge' is produced after decanting of each SBR; however, the sludge belt press only has a capacity to handle up to 3 m^3 per hour.
8	Biodigester	A concrete biodigester, with associated concrete chambers for biogas storage, as well as a (long-defunct) plastic biogas storage bag. An additional sludge belt press was installed for biodigester sludge management. Chicken and cow manure were expected to be locally sourced and fed into the biodigester as a co-substrate by which to augment biogas production.	The biodigester apparently worked at the beginning, but has not worked for a long time. Biogas usage devices were installed in the garage on the site for demonstration purposes: • Cooking stove • Pressure cooker • Lights
9	Odor Control	None	Hydrogen peroxide is periodically sprayed to control odor
10	Automation and Control	A central control room with an MCC cabinet, computer, and video screens was intended to be installed to observe the SBR process.	Since the facility was not in operation during the scheduled site visit, Aquaya was unable to verify automation and controls in place. Typically, automation is a key component of SBR operation. It is our understanding that the automation is limited and the entire SBR operation is run in manual. Based on interviews with key stakeholders, it is our understanding that there is an additional manual control system for trucks arriving at the site, and generator usage.
11	Wash Water	Unable to confirm	A borehole and wash water main provides wash water for the site.
12	Energy	Facility was intended to rely on power from municipal sources	The site is completely reliant upon one diesel generator. Power from the city grid is unreliable and is generally not used to power on-site equipment.
13	Medical Incinerator	None	A medical incinerator was installed in the corner of the site and apparently used "just once".

4.4 Key Challenges

The Eagle Island Treatment Plant has a number of key challenges. These are briefly summarized below.

Influent Discharge and Preliminary Treatment. As mentioned above, the influent equalization tank is significantly undersized and not providing uniform flow into the SBR tanks.

In addition, key stakeholders report that the effectiveness of the screening system and skimmers is limited. As a result, large objects and grease flow into downstream processes and adversely affect plant piping, equipment, and subsequent treatment processes. During interviews, several stakeholders noted:

- High Sediment Content – Due to the nature of the containment technologies in Port Harcourt, the influent has high sand content.
- Fats, Oils, and Grease (FOG) – Exhauster trucks reportedly transport FOG from local restaurants, as well as fecal sludge resulting in significant FOG in the influent. In addition, oil is often added to containment/septic tanks prior to emptying to reduce smells.
- Solid Waste – Influent often contains significant plastics (e.g., condoms, sachets) and rags that clog the screening system. These require manual removal.

Primary Treatment. Primary settling tanks are often used to achieve this separation, although septic tanks (to some degree), Imhoff tanks, upflow anaerobic sludge-blanket (UASB) reactors, and anaerobic ponds also serve the same purpose (Jimenez et al. 2010). The Eagle Island Treatment Plant does not have a method for primary sedimentation. However, quite often, SBR facilities often do not include primary treatment, if sludge retention times are high (i.e., more than 20 days). For this facility, historical documents do not indicate what factors, if any, influenced the determination that primary treatment was not necessary.

Secondary Treatment. Eagle Island's SBR system is intended to provide biological treatment and liquid-solid separation. However, its effectiveness is limited, because actual influent characteristics of raw fecal sludge exceed the design criteria for the SBR system (**Table 8**).

Table 8: Design Criteria versus Actual Influent Characteristics

Property	Design Criteria Max	Actual Influent Characteristic
Influent Volume (m^3)	1,000	200 – 250
TSS (mg/L)	10,000	0 – 52,500
TN (mg/L)	20	110 – 2,680
TP (mg/L)	Not specified	37 – 2,570
Source	Tech Universal (2010)	Aquaya (2017)

Further, the duration of aeration has been reduced significantly, even though aerators have malfunctioned and/or been removed. Plant operators note that they reduce aeration times to 4 hours during the rainy season when influent is very dilute. They also acknowledge that at least one aerator was removed from an SBR tank and never replaced.

The bioreactor originally installed for growing a stable population of microorganisms was only used for a short time. Anecdotal information suggests that its use was suspended, because it consumes a lot of energy.

Tertiary Treatment. Chlorine is applied to the liquid effluent prior to final discharge. Given the limited data available, we are unable to assess final effluent quality. However, it is likely that chlorine does not effectively disinfect the liquid effluent from the SBR, because of its high organic content.

Operations and Maintenance. Since it was not possible to visit the plant while it was operating, a detailed assessment of operations and maintenance could not be performed. However, information collected during stakeholder interviews suggests that Eagle Island is faced with several operations and maintenance challenges. The most significant are:

- Limited Use of Data for Monitoring, Evaluation, or Operational Control - SBRs require constant monitoring and evaluation to operate effectively. At Eagle Island, plant operations are impeded, because no sampling or laboratory analyses are performed for operational control (e.g. dissolved oxygen in the SBR tanks). Sampling apparatus and reagents are generally not available; as a result, treatment performance cannot be reliably or consistently determined by operators (**Figure 12**).

Wastewater Treatment Performance Indicators

Influent			Effluent					
Parameters	Unit	Actual	Parameters	Unit	Actual	PHWC Target	NESREA	World Bank Group
pH		7.52	pH		7.61	6.5 – 8.0	6.5 – 9	6 - 9
BOD	mg/l		BOD	mg/l		30	50	30
COD	mg/l		COD	mg/l		50	250	125
TSS	mg/l		TSS	mg/l		10	50	50
TDS	mg/l	1869	TDS	mg/l	1281			
TKN	mg/l		TKN	mg/l		8	10	10
TP	mg/l	27.00	TP	mg/l	10.72	2	2	2
EC	uS/cm	3329	EC	uS/cm	2003			
TCC	mpn/100ml		TCC	mpn/100ml		200		400
RCL	mg/l		RCL	mg/l				

Notes should be made for any disparity between actual and target

N:B *The disparity in Effluent TP observed is based on lack of air bubbling system in the SBR Tanks which is supposedly to function as a mixer. The blank spaces are as a result of No Laboratory reagents and apparatuses.*

Page **1** of **1**

MONTHLY REPORT Wastewater Treatment Plant

No Data

Figure 12: Eagle Island Monthly Monitoring Report

- Limited Equipment Repair or Replacement – As noted above, key stakeholders indicate that at least one of the SBR aerators was removed and never replaced. The decanters frequently detach from their hoses; this suspends the SBR batch process, because the supernatant cannot be removed.

-

Finance and Administration. The financial autonomy of the Eagle Island Treatment Plant is an important goal for PHWC. However, in 2016, the plant achieved a monthly average of 56% of its revenue target.

The plant charges a discharge fee of ₦2000 per discharge, regardless of the fecal sludge volume or strength being discharged. PHWC has set its monthly revenue projection at ₦1,200,000, a figure that assumes an average of 30 trucks discharge at the facility per month. This figure is less than the monthly operating expenditure (**Table 9**). However, PHWC is hesitant to raise fees, because they are concerned that an increase would encourage exhauster trucks to simply use illegal dump sites more.

Table 9: 2016 Operating Expenditure for Eagle Island Treatment Plant (TP)

	Costs in Naira		
Eagle Island TP Costs:	**per Batch [₦]**	**per week [=3*₦]**	**per month [=3*4*₦]**
Chemicals	15,500.00	46,500.00	186,000.00
Laboratory	15,000.00	45,000.00	180,000.00
Energy	32,000.00	96,000.00	384,000.00
Personnel	21,000.00	63,000.00	252,000.00
O&M	21,200.00	63,600.00	254,400.00
Site administration	3,000.00	9,000.00	36,000.00
Other Misc.	7,000.00	21,000.00	84,000.00
TOTAL COST	**114,700.00**	**344,100.00**	**1,376,400.00**
5% Profit Margin	**5,735.00**	**17,205.00**	**68,820.00**
TOTAL COST + 5% PROFIT	**120,435.00**	**361,305.00**	**1,445,220.00**

5 OPTIONS FOR IMPROVING FSM IN LOW-INCOME AREAS

5.1 User Interface

Currently the majority of households in Port Harcourt, including in low-income areas, use cistern or pour flush toilets (see section 3.2). As a result, introducing new user interfaces such the container-based systems that are being deployed in other settings (e.g. Sanergy in Kenya, Bohner et al. 2016; and SOIL in Haiti, Remington et al. 2016) will likely prove difficult due to perceptions that these interfaces are inferior to flush toilets. In addition, container-based systems have significant management requirements, which are challenging to develop in the absence of an organization (or champion) with a strong vested interest. Households that lack the resources to build private flush toilets either share facilities with their neighbors, use public hanging latrines, or practice open defecation. Comparisons of the attributes of user interface options indicate that public toilet blocks providing flush toilets and flush toilets shared by households should be considered to address the needs of this low-income household segment (**Table 10**).

Table 10: Comparisons of user interface options in low income areas

	Pay per use Public toilet block	Pay per use Single toilet	Shared Flush Toilets	In home Container-based toilet	In home Flush Toilet
Upfront cost for household	None	None	Moderate	Moderate	High
Ongoing cost for household	Moderate	Moderate	Low	Low	Low
User acceptance	High	Unknown	High	Low	High
Space requirements	High	Moderate	Low	Moderate	Moderate
Emptying access	Good	Good	Variable	Good	Variable

5.2 Containment

Taking into account the high prevalence of household flush toilets, strategies for household-level containment in low-income communities of Port Harcourt are evaluated below (**Table 11**). Container-based systems and other user interface technologies that provide additional containment options are not considered due to the poor likelihood of acceptance by the residents of Port Harcourt, and the requirements for a dedicated organization to develop, promote, and manage container-based sanitation systems, as discussed in section 5.1.

Table 11: Comparisons of fecal sludge containment options for low-income neighborhoods

Evaluation Factors	Small-scale condominial sewerage	Above-ground household septic tanks (water-tight, cement)	Underground sealed household septic tanks (plastic/ metal/ cement)	Shared septic tanks for multiple households
Infrastructure requirements	High	High	High	Moderate
Location	Below ground	Above-ground	Below ground	Below ground
Infrastructure Costs	High	High	High	High
Above-ground space requirement	Moderate	High	Low	Low
Below-ground space requirement	High	None	High	Moderate
Emptying requirements	None	High	Moderate	Moderate
Toilet requirements	Water flush	Water flush	Water flush	Water flush
Maintenance requirements	Low	Moderate	Moderate	Moderate
Cultural acceptance	High	Low	High	High
Public health considerations	Safe	Safe	Safe	Safe
Other considerations	Requires decentralized wastewater treatment system	Requires re-building of toilets on top of the aboveground tank.	Technically challenging in areas with high water tables.	Technically challenging in areas with high water tables.

As presented in **Table 11**, options for improving underground containment infrastructure, either by upgrading individual household/business/institutional septic tanks and cesspits or by constructing shared septic tanks that capture waste from multiple households/businesses/institutions, are more appropriate for upland areas of Port Harcourt with lower water tables. In areas of Port Harcourt with high water tables, sealed septic tanks will be difficult to install, and the soils are likely too waterlogged for establishing functional leach fields (Stenström et al. 2011). In addition, high population densities, particularly in the waterfront communities, limit available space for leach fields. Placing toilets on top of above-ground septic tanks is another option for high water table areas, though converting existing toilet facilities to include above-ground septic systems is not a practical solution (Strande et al. 2014). Above-ground fecal sludge containment may be more appropriate for newly constructed public toilet blocks. Condominial sewage systems, comprised of local piped sewage networks that transfer fecal material to a decentralized wastewater treatment system (DEWATS) have been successfully applied in some settings, notably in Brazil (Melo 2005). These localized sewage networks provide another possibility for managing fecal waste in areas of Port Harcourt where high water tables render underground contaminant difficult. Nevertheless, constructing local sewer systems will entail significant public works efforts, and establishing DEWATS installations at multiple sites will require large space allocations and extensive management capacity (Gutterer et al. 2009).

Examples of shared septic tank systems are provided in **Appendix D**.

5.3 Emptying and Transport

As described in section 3.4.1, Port Harcourt has a robust fecal sludge exhauster truck industry, which reflects the high prevalence of household flush toilets and the requirements for frequent emptying of fecal waste containment structures in areas with high water tables. Currently, however, exhauster trucks provide limited services in low-income areas, particularly in waterfront communities. To address fecal sludge emptying needs in these communities, we have considered three aspects of emptying services (**Table 12**):

- Service type: manual emptying vs. mechanical emptying via exhauster truck
- Management structure: on-demand emptying vs. scheduled emptying
- Fecal sludge transport: fixed transfer stations vs. mobile transfer stations (i.e. trucks adapted to empty multiple septic tanks in areas with poor road access)

Manual emptying is a common, though informal, practice in low-income areas, as described in section 3.4.2, and the costs are similar to the fees charged by exhauster trucks. Multiple factors, however, render current practices highly undesirable:

- Emptiers are not aware of the health risks associated with fecal sludge and do not utilize protective equipment.
- Fecal sludge is dumped into the environment, i.e., rivers.
- The emptiers mix kerosene with the fecal sludge, which potentially hampers future treatment efforts.

Various programs could be established to address these concerns. For example, an association for manual emptiers could be developed to support training and equipment procurement. Another option is the creation of formal business models for manual emptying that attracts entrepreneurs willing to invest in improved practices. Illicit dumping could be managed by constructing fixed fecal sludge transfer stations within communities that provide safe dumping options and are easily accessible to exhauster trucks. However, despite frequent reference to fecal sludge transfer stations in FSM improvement programs, evidence for their successful implementation is limited (Boot 2008, Boot and Scott 2009, Hawkins and Muxímpua 2015, Strande et al. 2014). Furthermore, community feedback in Port Harcourt indicates resistance to placing fixed fecal sludge transfer stations in common areas. Alternatively, “Gulpers” developed for evacuating cesspits and pit latrines have been successfully piloted with manual emptiers in Kampala, Uganda (Schoebitz et al. 2017, Strande et al. 2014). The Gulpers are emptied into barrels, which are transported to a treatment plant using rented pick-up trucks. Ultimately, the current stigmas associated with manual emptying, and the effort required to introduce changes suggest that formalizing the sector could be a long and difficult process.

An alternative to formalizing the manual emptying sector is to leverage the existing capacity of the exhauster truck industry to provide regular emptying services in low-income communities. However, the following constraints must be addressed to promote the use of exhauster trucks in these areas:

- poor access to household containment facilities
- unwillingness of truck operators to service poor neighborhoods, often due to security concerns.

Other cities that are developing innovative FSM programs are addressing the technical challenges of emptying in densely populated regions by equipping exhauster trucks with extended vacuum hoses and additional pumps to evacuate containment structures that are difficult to access by road (Murungi and Pieter van Dijk 2014, Strande et al. 2014). In addition, mobile transfer stations, or exhauster trucks that are stationed in a community and provide emptying services until they are full, provide another interesting possibility for servicing multiple households in low-income areas (Strande et al. 2014, Strauss and Montangero 2002). The model of mobile transfer stations, however, has not been successfully demonstrated to date.

Reducing security concerns among truck operators will require engagement with community leaders to discuss actual and perceived risks and methods for addressing the risks. One strategy is to introduce scheduled emptying of containment structures at defined intervals, during which community leaders commit to providing safe access for truck operators. Scheduled emptying of fecal sludge is increasingly common, and is generally managed by public utilities or private institutions in partnerships with public utilities (Chowdry and Kone 2012, Peal et al. 2014). Generally, households are charged a flat rate monthly sanitation tax that covers scheduled emptying services, and they are not subject to additional fees upon emptying. Non-scheduled emptying services would require additional payments, probably paid directly to the exhauster truck operator.

In Malaysia, the Indah Water Konsortium established scheduled emptying and desludged households once every two years and billed households ₦470 monthly for the service (Narayana 2017). Program challenges included septic tank database management, variable conditions of exhauster tanker trucks, poor accessibility of containment structures, weak enforcement, and limited household awareness. Nevertheless, termination of the scheduled emptying program resulted in a large drop in sludge removal and a decline in river water quality.

In Indonesia, the USAID-funded Urban WASH-PLUS program established a tariff for regular and on-demand emptying services (Mardikanto et al. 2017). In this model, registered customers receive emptying services every 3-4 years and the fecal sludge is transported to a treatment plant. The monthly fees range from ₦205 to ₦315 per household and cover all direct operational costs of collection, treatment, and program management. Fees are collected with water bills or by door-to-door collection.

In South Africa, the municipality of eThekwini in Durban has implemented free scheduled emptying (Gounden and Alcock 2017). Emptying occurs every two years for urine-diverting toilets and every five years for VIP latrines. To support these free services, the municipality relies upon cross-subsidization from water and sewerage service charges in more affluent areas. The municipality also provides on-demand emptying services for fees of approximately ₦21,700-28,300.

Table 12: Comparisons of options for fecal sludge emptying in low income areas

	Manual Emptying to Fixed Stations On Demand	Manual Emptying to Fixed Stations Scheduled	Mechanical Emptying to Fixed Stations On Demand	Mechanical Emptying to Fixed Stations Scheduled	Mechanical Emptying to Mobile Stations On Demand	Mechanical Emptying to Mobile Stations Scheduled
Cost to user	Low	Moderate	Low	Moderate	Low	Moderate
Cost fluctuations	Moderate	Low	Moderate	Low	Moderate	Low
Community support for transfer station	Low	Low	Low	Low	High	High
Management requirements	Moderate	High	Moderate	High	Moderate	High
Equipment requirements	Moderate	Moderate	High	High	High	High
Cooperation requirements with truck association	N/A	N/A	High	High	High	High
Public health risks	High	High	Moderate	Low	Moderate	Low

5.4 Treatment and End Use/Disposal

5.4.1 Considerations

In developing options for improving FSM services in Port Harcourt, our analysis of the Eagle Island Treatment Plant has led us to consider the following issues for safe and sustainable treatment of fecal sludge:

- The Eagle Island Treatment Plant is the only facility currently processing household and commercial fecal sludge in the project area; it thus assumes an important role in the FSM service chain.
- The Plant's operations are sub-optimal. The Plant has exceeded its treatment capacity in several respects and suffers from ongoing equipment deficiencies.
- The Plant does not have sufficient financial resources to sustain operations.
- Considering the current volume of fecal sludge collected in Port Harcourt, as well as the projected population growth of the project area, more

treatment capacity is needed in the near term. In addition, a valid financial management plan for supporting both existing operations and expanded treatment capacity is essential.

With these considerations in mind, the following subsections provide a process for evaluating options for improving fecal sludge treatment. As a first step, we recommend that PHWC make a firm determination about the intended end use products. Subsequently, an appropriate treatment technology can be selected and the role of the existing SBR system can be determined.

5.4.2 Determine End Uses

Since the start of operations, PHWC has made several attempts at resource recovery and the promotion of end use products in the form of reclaimed water and biogas production. Limited information is available on why these initiatives were suspended. However, it is important that PHWC determine its resource recovery objectives, evaluate market potential for its end use products, and develop financial projections for the revenue and costs associated with each product. **Table 13** provides a summary of reuse options that PHWC may want to consider.

Table 13: Reuse and Disposal Options

Reuse Option	Description
Compost	Several key stakeholders expressed an interest in the production of compost. A representative from PHWC noted that there is an economic empowerment project, as part of the Water and Sanitation Program, which specifically relates to women's groups producing compost derived from fecal sludge.
Biogas	Biogas was also often quoted by stakeholders as being a preferred reuse option. As mentioned above, a biodigester was installed and piloted at the plant, however there was no documentation available about the pilot process.
Solid Fuel	Using dried fecal sludge as a fuel for households or industries (e.g. cement manufacture) is becoming a popular fecal sludge transformation strategy, especially as it has been shown to yield higher revenue than alternative enduse products. In contrast to compost, no nutrients are recycled in the production of FS solid fuel, and pathogen activation is not required as a treatment step because all pathogens and all nutrients are destroyed during heating.
Reclaimed Water	Following treatment, effluent can be reclaimed and used on-site for process water and cleaning. Use of reclaimed water could off-site the costs of water supplies and/or provide additional reliability, if adjacent groundwater wells are no longer productive.

Sludge Disposal at Solid Waste Landfills	Sludge disposal at solid waste sites should be considered, if no reuse options for biosolids are deemed feasible or advantageous.
Sludge Incineration	Sludge incineration is common in the U.S. and quite often used as a means to reduce the volume of dried sludge sent to landfills. Ashes remaining after incineration can either be disposed of or used as raw materials for the manufacture of construction materials.

5.4.3 Aligning Treatment Objectives and Available Technologies

Once enduse and/or disposal options have been selected, PHWC should review available technologies that can be employed to achieve the treatment objectives associated with each end use product. **Figure 13** provides an overview of treatment technologies recommended by Ronteltap et al (2014) specifically for fecal sludge treatment.

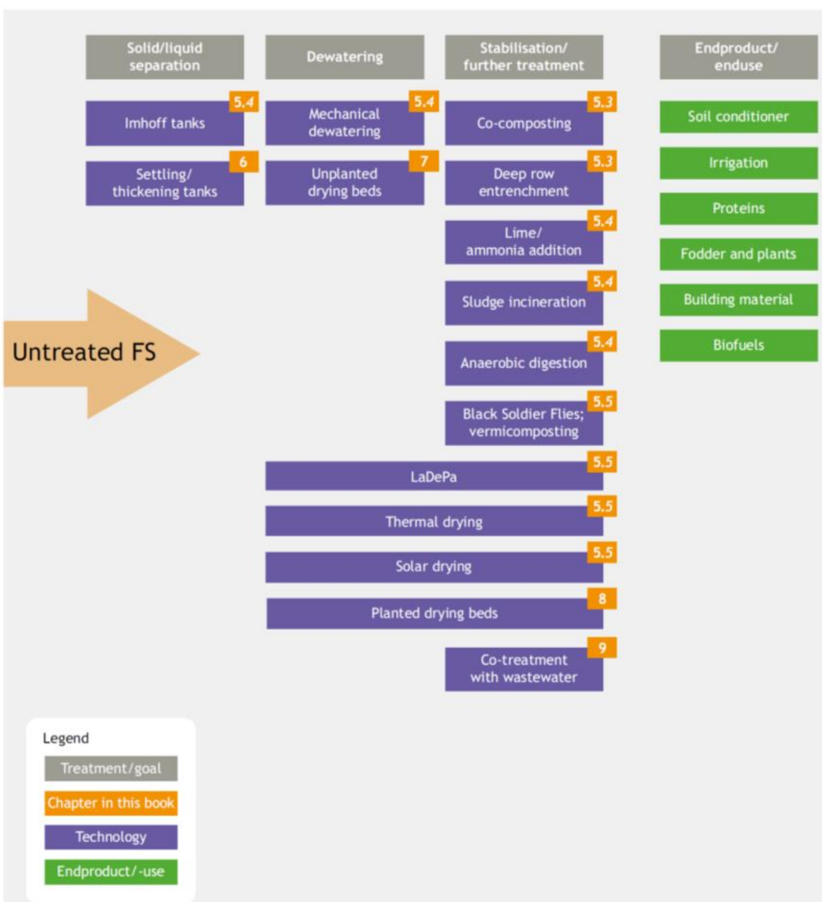


Figure 13: Fecal Sludge Treatment Technologies According to Treatment Objective (Ronteltap et al, 2014)

SBRs are not included in the list of proven fecal sludge treatment technologies, because no examples of their use or effectiveness with this application have been found. To provide some insight into their effectiveness, a preliminary modeling effort was performed to determine the SBR tank volumes, operational cycles and durations, and aeration requirements to treat fecal sludge influent with characteristics similar to those summarized in **Table 3**. It is important to note that the modeling relied upon a number of assumptions due to the limited amount of plant data available. A conventional SBR was evaluated and the modeling effort assumed that the SBR would be designed to achieve BOD removal and nitrification. This hypothetical SBR includes three, circular tanks. It was assumed that each SBR tank had decanters, mechanical mixers, aeration diffusers (coarse or fine bubble), aeration blowers, sludge removal pipes and tank drain trenches, and some instrumentation for basic process monitoring and control. Aeration was assumed to occur during the React phase, as well as a portion (25%) of the Fill phase.

Table 14: Preliminary Evaluation of SBR Sizing and Effectiveness

Item	Unit	Value
INPUTS		
Influent Flow Rate	m^3/d	250
Influent COD	g/m^3	19640
Influent BOD	g/m^3	9820
Influent TSS	g/m^3	13740
Influent TKN	g/m^3	1060
Influent TP	g/m^3	498
Number of Tanks		3
Settling Time	hours	0.5
Decant Time	hours	1.0
Idle Time	hours	2.0
Aerated Fraction of Fill Time	hours	25%
RESULTS		
SBR Tank Volume	m^3	1370
Total Cycle Time	hours	118
Aeration Time Required for Nitrification	hours	84
Average O_2 Required per Tank	kg/tank/day	915
BOD Removal Efficiency	percent	89%

The results suggest BOD removal could be achieved with an expansion in SBR tank capacity and a significant amount of aeration (**Table 14**). It is assumed that the biodegradable COD (bCOD) would be removed at approximately the same rate that BOD is removed. The aeration time is estimated to be 84 hours and the average daily oxygen requirement is 914 O_2/kg/day for each tank. This preliminary analysis suggests that the cost and impact of the aeration requirements on total cycle time makes conventional SBRs operationally ineffective at treating fecal sludge.

More comprehensive modeling of an SBR system should be performed. Given the wide variability in fecal sludge influent, further analysis should incorporate a wide range of influent flow volumes and loadings. The modeling should determine whether acceptable removal efficiencies can be achieved for all key parameters and the aeration requirements associated with each scenario. Further, the impact of the high solids loading on SBR operation should be evaluated.

If the modeling indicates that SBR systems are not appropriate for use in treating fecal sludge, continuing to operate the current SBR at the Eagle Island facility should not be included among the list of potential treatment options.
For the remaining technology alternatives, consideration should be given to their proven effectiveness in treating fecal sludge, operations and maintenance requirements, and cost, among other factors (see **Table 15**).

Table 15: Fecal Sludge Treatment Technology Comparison

Technology	Objective	Previously Used for Fecal Sludge Treatment	O&M Considerations	Operating Cost Considerations
Imhoff Tanks	Liquid-Solid Separation	Yes, Indonesia	Cleaning of flow paths and scum removal is routine, but relatively simple	Less costly than traditional activated sludge treatment
Settling/Thickening Tanks	Liquid-Solid Separation	Pilot Testing	Cleaning is routine, but relatively simple	Low operating cost
Mechanical Dewatering	Dewatering	Yes, Malaysia	Cleaning of mechanical equipment is routine, but relatively simple	Electricity comprises significant percentage of operating cost
Unplanted Drying Beds	Dewatering	Yes, Ghana	Minimal maintenance	Minimal operating cost
Co-composting	Stabilization	Yes, Ghana and Bangladesh	Skilled operators required	Labor comprises most of the operating cost
Deep Row Entrenchment	Stabilization	Yes, South Africa	Minimal maintenance	Low operating cost
Lime Addition	Stabilization	Pilot Testing	Caustic chemical; requires that skilled staff use protective equipment and adhere to health and safety procedures	Ongoing purchase of chemicals and protective equipment
Sludge Incineration	Stabilization	No	Skilled operators required; potential for emission of pollutants	High operating cost
Vermicomposting	Stabilization	Pilot Testing	Ongoing monitoring of earthworm feeding, oxygen, and temperature	Unknown
Latrine Dehydration and Pasteurization	Stabilization	Yes, South Africa		Less costly than traditional activated sludge treatment
Thermal Drying	Stabilization	Yes, Ghana	Specialized knowledge required for system maintenance and repair	Electricity comprises significant percentage of ongoing cost
Solar Drying	Stabilization	Pilot Testing	Minimal maintenance	Low operating cost
Co-treatment with Wastewater	Stabilization	Yes, South Africa and Philippines	Co-treatment can lead to significant operational problems, if fecal sludge influent volumes are not monitored and managed	Costs may be significant if fecal sludge disrupts existing treatment processes

5.4.4 Siting

Following the selection of an appropriate technology, consideration should be given siting. Several stakeholders have expressed concern about continued use of the Eagle Island site, as exhauster truck operators have indicated that emptying there is not convenient. In response to this feedback, discussions were held with the Rivers State Waste Management Authority to identify and evaluate five solid waste dumpsites for the possibility of using part of the dumpsite for fecal sludge treatment. In addition, the Amadi Ama dumpsite currently used for fecal sludge emptying was assessed. Factors considered with regard to siting included the status of operation, available space, road access, distance from the urban center, presence of neighbors, and availability of a receiving water body for treated effluent. The results of this analysis are summarized in **Table 16**.

Table 16: Site Appraisals for Additional Treatment Options

Name / GPS cords	Appraisal Criteria						Scope to receive FS?
	Status	Available Space?	Road Access	Distance to urban center	Neighbors' presence?	Water body for effluent?[1]	
Allu 4.93588 N 6.96441 E	Under proposal	Yes	Fair	Far	None	No	NO
Igurita 4.93559 N 7.03194 E	Operational	Yes, with community approval	Fair	Far	Yes	No	NO
Eliozu 4.88657 N 7.01325E	Operational	No	Poor	Within, and to the North	Yes	No	NO
Oyigbo 4.87793 N 7.12333 E	Closed	Yes	Fair	Far	Closed after complaints from neighbors.	2.5km distance	NO
Umuebulu 4.8954 N 7.11627 E	Closed	Yes	Fair	Far	Yes	3.5km distance	NO
Amadi 4.7973 N 7.0229 E	"Official" FS dumpsite	No[2]	Fair	Within urban center	Yes	Yes	YES

NOTES:

The appraisal was based upon a single site visit to each site, and does not constitute a full feasibility study.

1. Assessed on Google Earth. Receiving bodies considered if less than 5km from site. Effluent would require to be pumped in all cases.

2. Adjacent to waterfront, so possibility to reclaim land, as was done for Eagle Island.

6 RECOMMENDATIONS FOR PILOTING FSM SERVICES IN LOW-INCOME AREAS

Evaluations of FSM improvement programs in selected regions of Port Harcourt are critical for guiding the development of a sanitation plan for the entire urban metropolis (Duret and Revell de Waal 2016). In this section we discuss strategies for piloting FSM improvement efforts, with a focus on low-income areas of the city.

6.1 Pilot Objectives and Site Selection

Optimally, FSM pilot implementation in Port Harcourt should be based on collaborative design and technical cooperation between community sanitation committees, PHWC, which will implement the FSM pilots through the Port Harcourt Water Supply and Sanitation Project, and FSM experts with experience in implementing FSM improvement programs in other African cities.

Site selections for the FSM pilot programs prioritized regions of the city that are representative of low-income areas in Port Harcourt, which encompass both upland areas and waterfront communities. The old city of Port Harcourt is built on a laterite plateau along branches of the Bonny estuary in the Niger River delta. The waterways that edge the laterite plateau tend to be 5-10 meters below the plateau level with mangrove forests along their banks. Historically these waterways have been the location of small fishing camps and sites for loading and off-loading goods transported between the city markets and nearby riverine communities. Following the discovery of commercial oil in the region and the rapid expansion of Port Harcourt as the region's oil capital, the small waterfront settlements also began to grow.

Port Harcourt's waterfronts are largely self-built settlements, constructed on land reclaimed from the creeks by compacting dense fibrous soil (Chicoco mud) brought in by canoe from the surrounding mangrove forests (Max Lock Consultancy Nigeria 2009). Garbage from the city is often added to the mass of compacted Chicoco mud, which is again compressed and allowed to settle for a number of years. Some waterfront settlements are built on land that was reclaimed by government by sand filling, and then allocated to communities (Max Lock Consultancy Nigeria 2009).

Waterfront settlements tend to be lower lying than the 'upland' areas of the city. As they are built on natural drainage routes, refuse from upland parts of Port Harcourt are often carried into their waterways. Some of the settlements are prone to flooding. Like many other areas of the city, waterfront settlements tend to be densely populated and suffer from poor access. Though authorities have tolerated or actively enabled informal or semi-formal connection to the electricity grid, they remain almost entirely devoid of any other form of municipal provision (Max Lock Consultancy Nigeria 2009).

Building typologies and layouts differ significantly between the 49 or so waterfront settlements (Max Lock Consultancy Nigeria 2009). Some are constructed largely from non-durable and temporary materials and lack any consistent layout. Others, particularly those on sand-filled reclaimed land, are dominated by reinforced concrete and block structures up to three stories and follow community-imposed layouts and building regulations. All, however, lack infrastructural provision and security of tenure. In addition, the lack of adequate sanitation facilities results in pervasive environmental and health problems.

To pilot and evaluate FSM strategies for Port Harcourt, we selected the low-income areas of the Okrika Waterfront and the Diobu upland area (**Figures 14** and **15**). Their characteristics are described below.

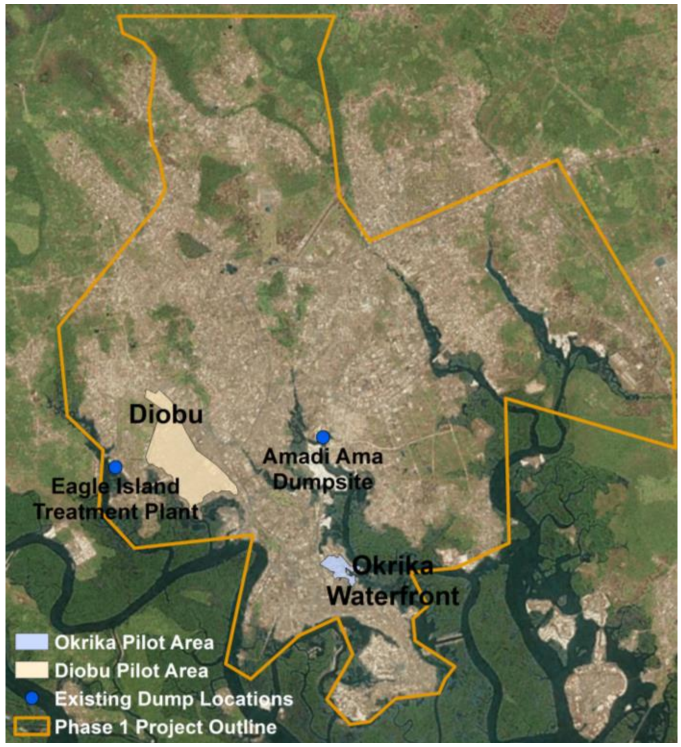


Figure 14: Locations of selected pilot communities within the greater project area

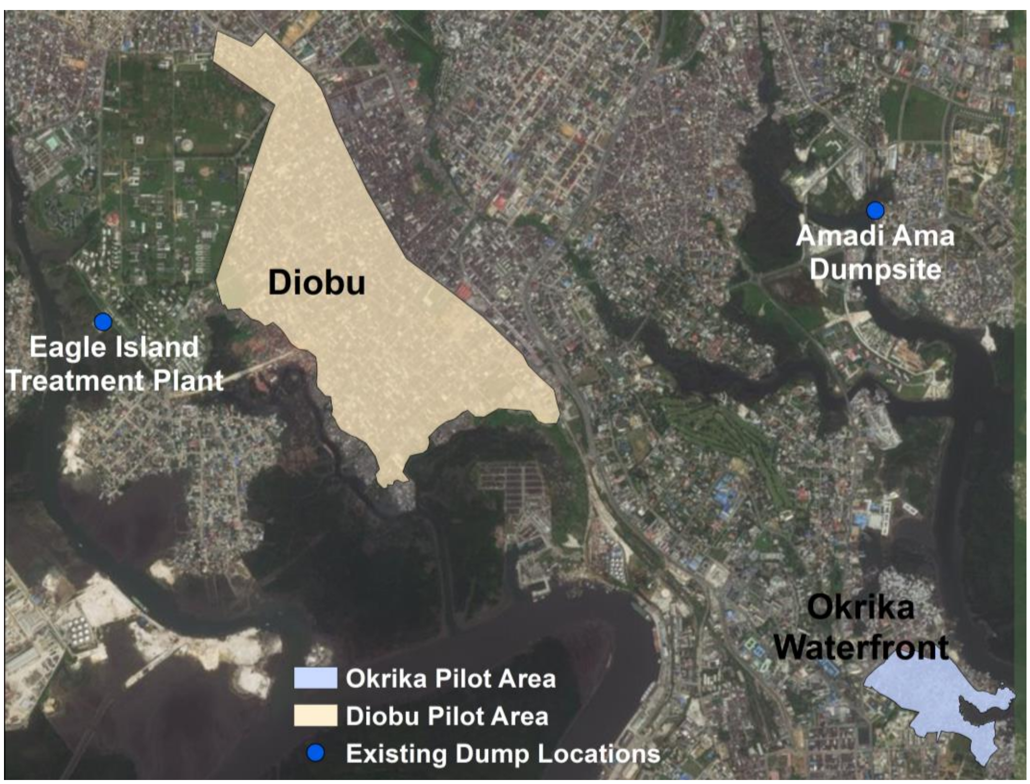


Figure 15: Locations of selected pilot communities in relation to existing dumping locations

Okrika Waterfront has a population of 29,500 over 35 hectares. Our previous experience with community projects (CMAP) indicates that Okrika Waterfront has a higher capacity to mobilize, organize, and implement improvements than many other waterfront communities. Local community governance is active and the Okrika Waterfront is also home to active community-based organizations (CBOs) that are managing successful community engagement programs. These CBOs have established partnerships with non-governmental organizations (NGOs) that could complement and add value to FSM pilot activities. There is an established sanitation committee and demonstrated capacity to manage and maintain public facilities.

Diobu is a larger low income area that was formally planned by the city (as opposed to the informal developments in waterfront areas). The upland area is bordered by waterfront settlements on its southern boundary, but they have not been included in the suggested pilot geography. Diobu encompasses 279 hectares, but there is no good population estimate. Households largely reside in compounds, or yards, many of which have storied structures, restricting the amount of aerial estimation possible. Calculating an accurate population figure will be a critical first step in pilot implementation.

Diobu has well-defined boundaries and is close to the Eagle Island Treatment Plant. The community has many permanent structures and long-term residents and poses fewer security risks compared to some other upland low income areas, particularly those on the outskirts of the city. Historically, households had communal courtyard bucket toilets coupled with a well-established manual emptying system. As described in section 3.2, a local government ordinance banned the use of bucket toilets in 1983.

Areas of public health risk were determined using GIS software (ArcGIS, Redlands, CA) to create a heat map based on fecal sludge containment data (**Figure 16**). Households where fecal sludge is directly emptying into the environment were ranked with the highest public health risk. Households where fecal sludge is contained in sealed and water-tight septic tanks with overflows to soakaways were ranked with the lowest public health risk. This analysis indicates that both the Okrika Waterfront and Diobu contain areas of high public health risk due to poor fecal sludge containment (**Figure 17**).

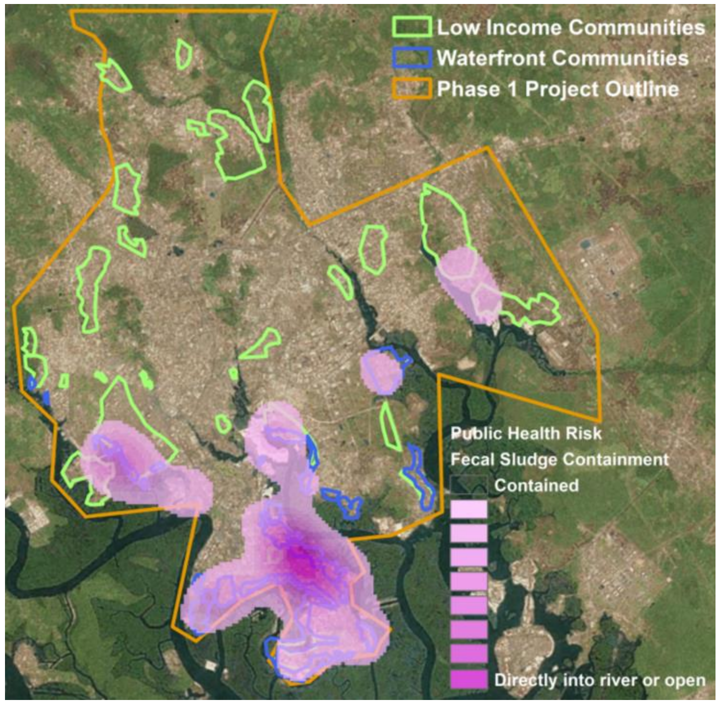


Figure 16: Heat map indicating areas of highest public health risk across the project area using data from the household surveys

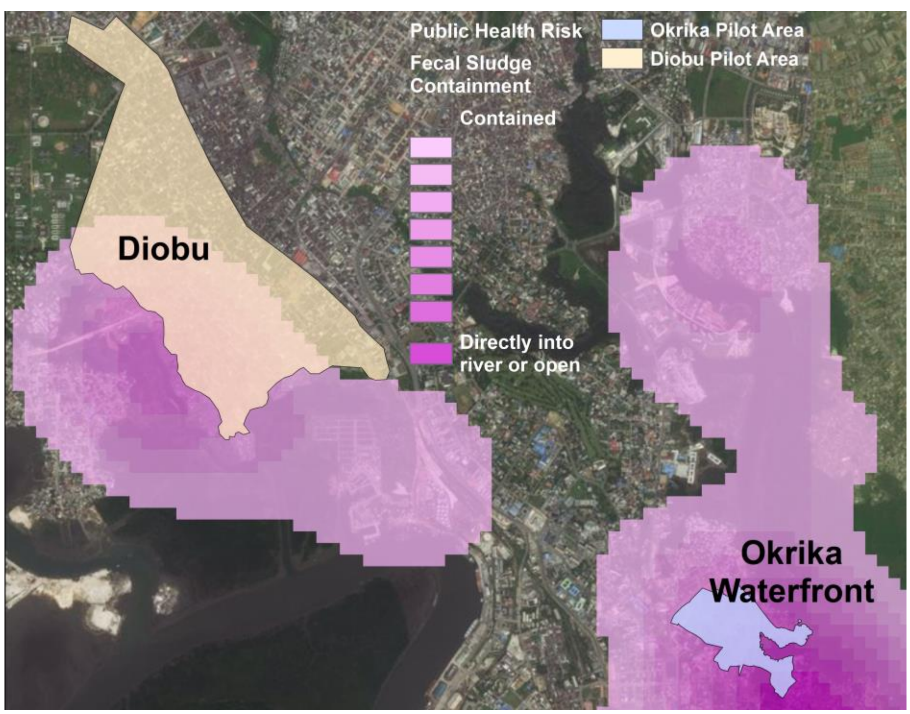


Figure 17: Areas of high public health risk falling within pilot areas

6.2 Public Toilet Facilities for Okrika Waterfront

Based on the analysis of FSM options for low-income areas of Port Harcourt, as described in Section 5, modern public toilet blocks with flush toilets and safe excreta containment systems provide a compelling option for the 36% of Okrika Waterfront residents who do not have access to private or shared toilet facilities and currently rely on public hanging latrines or practice open defecation. Waterfront communities accept public toilets, which can play an important social role in waterfront societies: even those who have a private household toilet will sometimes choose to use the public toilet, and residents report using their morning trip to the toilet as a way to catch up with friends and neighbors.

Various factors must be considered in the implementation of public toilet facilities. Renewable energy and waste reuse solutions should be core design features. Furthermore, establishing public toilet blocks as social spaces that contribute to the creation of diverse cultural and commercial opportunities, while responding creatively to issues of gender-based security and general hygiene concerns would improve their sustainability. Building on the existing social use of toilet facilities in the communities, the integration of a broader range of amenities and services, such as laundry and catering services, solid waste collection, sorting and recycling, mobile appliance charging stations, and public gathering and recreational space, would increase the use of the facility and have a broader impact on changing community norms around WASH issues. Clearly linked to sustainability are the roles of community organizations, private contractors, and PHWC in the management of public toilets. In addition, user fees and government budgets for operations and maintenance need to be considered. As noted in section 6.1, these factors should be considered through collaborative and iterative exercises between residents, technical experts, government and facilitating organizations with established community relationships or a long-term commitment to forging them. Considerations for guiding these collaborative design efforts are provided below.

In an effort to make public toilet blocks innovative, resourceful and functional public spaces, one option to consider is retrofitting shipping containers. There are many examples of converting shipping containers to public toilets and public spaces as outlined in **Appendix B**. There are also companies that specialize in retrofitting shipping containers and transporting them to desired locations.

In terms of cost, one guidepost is the budget for converting shipping containers into community ablution blocks (CABs) in the eThekwini Municipality of Durban, South Africa (Gounden and Alcock 2017). The costs for developing a CAB are approximately ₦20.46 million, which includes water provision for drinking water, showers, and a sewerage connection. Extrapolating from the budgets for CABs, suggests an estimate of ₦19.85 million each (**Table 17**) for two initial public toilet block prototypes for Okrika Waterfront. After addressing design issues by prototyping, the unit costs are predicted to decline (**Table 17**). These costs should be assessed in greater detail during pilot.

Table 17: Approximate financial requirements for simple shipping container retrofitting

Item Description	Amount (for first prototypes)	Amount (subsequent models)
Design costs (design fees, workshop costs and public engagement program)	₦5,500,000	₦750,000
1-20 ft. shipping container	₦1,500,000	₦1,500,000
Retrofitting shipping container	₦3,600,000	₦2,500,000
Scaffolding (above-ground)	₦900,000	₦900,000
Septic tank	₦1,200,000	₦600,000
Labor	₦1,050,000	₦1050,000
Construction management	₦1,500,000	₦1,000,000
Equipment hire	₦1,000,000	₦1,000,000
Shipping	₦3,600,000	₦1,800,000
Cost per public toilet	₦19,850,000	₦11,100,000

Table 18: Estimated monthly expenses and revenue for public toilet and community space

Expenses				
	Cost per unit	**No. of units**	**Unit Description**	**Total Cost**
Attendants	₦10,000	60	Person-days	₦600,000
Engineer/plumber	₦40,000	15	Person-days	₦600,000
Cleaning supplies, toilet paper	₦40,000	1	Monthly unit	₦40,000
Maintenance	₦80,000	1	Monthly unit	₦80,000
Total Expenses				₦1,320,000

The estimated monthly operating costs for public toilet blocks in the Okrika Waterfront are provided in **Table 18**. These fees do not include the costs for emptying excreta containment facilities, which is discussed in section 6.2.1 below. As noted earlier, there may be opportunities to offset at least some of these expenses through user fees, however, the roles of user fees and government budgets in maintaining public toilet blocks requires a stakeholder dialogue. User fees are often promoted as a revenue source for public facilities. However, they may also dissuade users, particularly among the lowest income groups who have the greatest need for improved sanitation conditions.

6.2.1 Public Toilet Containment

As reviewed in section 5.2, sealed septic tanks that provide adequate containment of fecal waste will be difficult to install in Okrika Waterfront due to the high water table and the density of housing structures. Consequently, an important requirement for public toilet blocks that replace existing hanging latrine structures are connections to above-ground septic tanks that are designed to facilitate emptying by exhauster trucks.

An additional consideration is the evaluation of anaerobic digesters for producing biogas (Stenström et al. 2011). Though anaerobic digesters can be challenging to operate, successful implementation and resulting biogas production could support continuous lighting for the public toilets, which would promote safety and encourage nighttime toilet users. Anaerobic digestion would reduce volumes of fecal sludge thus reducing the need for sludge emptying. Examples of successful public toilet anaerobic digesters in developing countries are provided in **Appendix C**.

6.3 Containment for Households in Okrika Waterfront and Diobu

A striking aspect of the sanitation landscape in Port Harcourt is the high prevalence of flush toilets, even in low-income areas. During the household surveys, 59% of respondents in Okrika Waterfront and 84% of the respondents in Diobu reported access to flush toilets (**Figure 3**). Among households utilizing personal toilets, 75% reported underground containment structures, either septic tanks or cesspits (locally referred to as soakaways). The remaining 25% lacked underground containment. Addressing the containment requirements of these households will be critical, however the solutions will vary between Okrika Waterfront and Diobu.

In Okrika Waterfront, high water tables render it extremely difficult to construct sealed septic tanks underground, and it is likely that most of the existing underground containment in this area consists of cesspits. Above-ground septic tanks could address the challenge of the high water table, but the expense, space, and enforcement requirements for retrofitting households with above-ground septic tanks render this solution impractical. In the long run, condominial sewage systems + DEWATS may present promising solutions for managing household fecal waste in the waterfront communities (Ulrich et al. 2009). However, until these facilities are developed, pilot activities to increase the coverage of cesspits and to promote frequent and comprehensive emptying appear to be the two best options for reducing environmental contamination from household toilets in Okrika Waterfront. Pilot designs for emptying strategies are discussed in the next section.

In the upland areas of Diobu, high water tables are less of a concern for underground containment facilities. In addition, many families live in shared compounds, or yards. This setting favors the construction of shared underground septic tanks with leach fields that receive waste from multiple toilets. Efforts to develop local pre-cast septic tank construction for shared containment structures are currently underway in Abidjan, Ivory Coast (Sanitation Service Delivery Program 2017). Similar programs should be considered for FSM pilot activities in Port Harcourt. There are also a number of commercial suppliers of large, underground septic tank models (**Appendix D**). Though these will not be affordable for low-income households, they do provide safe containment solutions for apartment buildings and institutions such as schools, hospitals, and places of worship.

Ultimately, community participatory design and a full cost analysis will be necessary during the first phase of pilot implementation to confirm the best options for improving household containment in Diobu. It will be important to address concerns that landlords may raise for tenants with upgraded sanitation. Finally, any efforts to replace or repair containment facilities will require significant government regulation and enforcement. Subsidies may be needed to incentivize homeowners to improve underground containment structures, and building contractors may require training in septic tank construction techniques. One model to test during the pilot is the provision of discount vouchers to homeowners who use certified contractors to upgrade their containment facilities.

6.4 Emptying Services for Okrika Waterfront and Diobu

Data collection shows that mechanized emptying by exhauster trucks is not a common practice in Okrika Waterfront. More commonly, manual emptiers provide desludging services in waterfront areas, risking both their own health (they use little personal protective equipment) and community health (they dump directly into waterways or onto open ground). As presented in section 5.3, two options should be considered for piloting improved emptying services: 1) provision of small "Gulper" cesspit exhausters that can be used by manual emptiers to transfer fecal sludge to barrels, which are then transported to a treatment site (Schoebitz et al. 2017); and 2) the development of mobile fecal sludge transfer stations, which are exhauster trucks, equipped with long hoses, equipment for removing solid waste from containment structures, and additional pumps for sludge extraction over greater distances (Strande et al. 2014). Both of these options leverage existing actors, though the size of the exhauster truck industry and the existing association of truck operators (ASTO) provide clear benefits for developing pilot programs.

6.4.1 Scheduled Emptying

Piloting scheduled emptying in both Okrika Waterfront and Diobu, as described in section 5.3, will be useful for evaluating the feasibility for charging a regular fixed fee to households to promote regular emptying that reduces environmental contamination. Establishing contracts with emptying services (potentially a combination of manual emptiers equipped with vacuum trucks and exhauster truck operators) may also address the security concerns experienced by operators who service low-income areas on an ad-hoc basis. Details of establishing the emptying contracts, the household fees, and management of the emptying program will have to be developed in coordination with community representatives, private service providers, and PHWC, and other relevant government agencies.

6.5 Treatment: Pilot Operations at the Eagle Island Treatment Plant

6.5.1 Pilot Objectives

The pilot for the Eagle Island Treatment Plant has two objectives. First, it is intended to make the facility operational to support the treatment of fecal waste associated with the Waterfront Public Toilet Facility pilot. Second, it will facilitate the collection of data to evaluate the extent to which the SBR system should continue to be utilized for activated sludge treatment. Key questions to be addressed during the pilot phase: 1) What is the Plant's efficiency at treating fecal sludge?; 2) What is the Plant's sensitivity to changes in fecal sludge influent and upset conditions? As mentioned above, it is recommended that a determination of whether the SBR should continue to be used for fecal sludge treatment should be made following PHWC's reassessment of its end use objectives and review of appropriate treatment technologies for achieving those objectives.

6.5.2 Facility, Equipment, and Financial Resources

Pilot activities will require use of the existing treatment facility, but are not intended to adversely impact operations. Rather, they should help the facility become and remain operational in the short-term.

Numerous stakeholders have indicated that investment in the aeration system and decanters is necessary for the SBR system to operate. However, since an on-site assessment was unable to be completed while the facility was operational, additional equipment may also require repair and/or replacement. For the pilot, we recommend the identification and assessment of the condition of critical components and the subsidization of repair and/or replacement costs. Particular consideration would need to be given to the control system, since SBRs require reliable, automated controls. The pilot should not involve a complete control system upgrade; however, minor electrical and control system modifications may be necessary to facilitate basic operations.

In addition to mechanical and electrical equipment, an investment in analyzers and laboratory supplies is required to facilitate the collection of data. Use of external laboratories may also be necessary to facilitate sample analysis.

6.5.3 Technical Assistance and Capacity Building Needs

Assistance from PHWC staff is needed to effectively develop and execute the pilot. However, most staff would generally be required to fulfill typical duties, not assume new roles. Nonetheless, a capacity building plan will need to be developed and implemented.

6.5.4 Pilot Evaluation Protocol

During the pilot period, the SBR system should be evaluated for its removal performance, reliability, energy use, and sensitivity to changes in influent flow and other conditions.

More comprehensive modeling is also recommended for the Eagle Island Treatment Plant and can be performed concurrent with the market assessment for end use products. The modeling would assist PHWC in determining the effectiveness of conventional and modified SBRs at treating fecal sludge and their sensitivity to changes in fecal sludge influent and upset conditions.

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APPENDICES

APPENDIX A: Sector STAKEHOLDERS

LOCAL GOVERNMENT AUTHORITIES

- PHALGA - Port Harcourt City Local Government Area
- Obio-Akpor LGA

RIVERS STATE MINISTRIES

- RSG MWRRD - Ministry of Water Resources and Rural Development
    - Commissioner: Chief Ibibia Walter
    - Permanent Secretary
    - Communications
    - PoC: Emmanuel O. Amatemeso, Dir. Water Supply, Quality Control & Sanitation
- RSG MUD - Ministry of Urban Development and Physical Planning
    - Commissioner: Hon, Chinyere Igwe
    - Permanent Secretary
    - Communications
- RSG MoE - Ministry of Environment
    - Commissioner: Prof. Roseline Konya
    - Permanent Secretary
    - Communications
- RSG L&S - Lands and Survey
    - Surveyor Gen: Noel Elenwo
    - Data Manager: Dabotubo Siyefiema
    - Head of GIS: Brown Joshua
    - PoC: Noel Elenwo
- RSG MoA - Ministry of Agriculture
    - Commissioner: Barr (Mrs) Oinimim Jack
    - Permanent Secretary
    - Communications

RIVERS STATE GOVERNMENT AUTHORITIES AND COMMISSIONS

- RSWSRC - Rivers State Water Services Regulatory Commission
    - Director General: Christopher Obasiolu
- PHWC - Port Harcourt Water Corporation
    - Managing Director: Kenneth Anga
    - Project Manager: Emmanuel Idoniboye
- RSESA – Rivers State Environmental Sanitation Authority
    - TBD
- RIWAMA Rivers State Waste Management Authority
    - Sole Administrator: Bro. Felix Obuah
    - Director of Administration: Ian Abraham Gobo
    - PoC: Konakre
- GPHCDA - Greater Port Harcourt City Development Agency
    - Administrator: Desmond Akawor
    - Head of Department Projects: Chief Napoleon Ofik

FEDERAL GOVERNMENT MINISTRIES FGN MW - Federal Ministry of Water Resources

- Minister: Engr. Suleiman Hussaini Adamu
- Permanent Secretary: Rabi Jimeta
- Director Water Supply: Engr. B. A. Ajisegiri
- Director Water Quality Control and Sanitation: Emmmanuel Olusola Awe

- Third National Urban Water Reform Project (NUWSRP III)
    - Project Coordinator: Bode Fashoye

SANITATION SECTOR ASSOCIATIONS

- Association of Sewage Tank Owners
    - PoC- Chief Chris Onwuzurike, Chairman

PRIVATE SECTOR SERVICE PROVIDERS

- PoC- Chief Chris, Chairman of Association of Sewage Tank Owners

NGO IMPLEMENTERS AND ADVOCATES

- ICRC
    - PoC – Tim Ros, head of sub-delegation

APPENDIX B: EXAMPLES OF SHIPPING CONTAINER CONVERSIONS TO TOILETS

Many public toilets and public spaces have been constructed using shipping containers. Since shipping containers are modular, it is relatively easy to modify and add on to them compared to traditional building materials. There are many examples from both developed and developing countries.

1. Community Ablution Blocks (CABs) in eThekwini Municipality, Durban, South Africa (Gounden and Alcock 2017)

- Developed by eThekwini Water Services
- Each provides services to roughly 75 households within 200 meters
- Installation began in 2012. 2500 CABs were operational by 2016.

http://blogs.aecom.com/we-cant-wait-solving-the-worlds-sanitation-crisis-on-a-global-scale/

http://policytransfer.metropolis.org/case-studies/ ethekwini-communal-ablution-blocks-for-informal-settlements

CAB exterior design

http://informalcity.co.za/ethekwini

CAB interior design

2. Public Toilets in Sierra Leone (Strande et al. 2014)

- Large capacity modular and multi-functional transfer station
- Constructed by GOAL, 2012
- Fecal sludge disposal point, public toilet, and water point

Srande L, Ronteltap M, Brdjanovic D (2014) Fecal Sludge Management: Systems Approach for Implementation and Operation. IWA Publishing, London.

Exterior design

Srande L, Ronteltap M, Brdjanovic D (2014) Fecal Sludge Management: Systems Approach for Implementation and Operation. IWA Publishing, London.

Interior design

- 3. Shipping container 'parklets' in Montreal, Canada (Steeds 2014)



4. Solar-Powered Learning Lab, Cazuca, Colombia (Wang 2016)

- Solar-powered youth education center with internet connectivity
- Built in 2014
- Natural light and cross ventilation achieved through increased openings


APPENDIX C: EXAMPLES OF ANAEROBIC DIGESTERS USED AT PUBLIC TOILETS

Many studies have been conducted on the utility of anaerobic digestion in public toilets. Daisy and Kamaraj (2011) evaluated nine of these studies (Table 19).

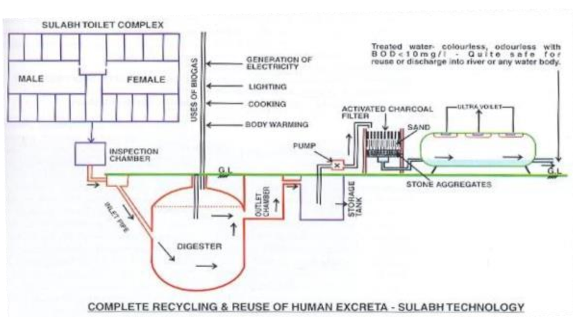
Table 19: Examples of public toilets using anaerobic digesters

Location	Design	Capacity (m^3)	HRT (days)	Source	Uses
India	Sulabh biogas plant (similar fixed dome)	30-60	30	Public toilet – 1.5/2 liters/person/day	Gas (cooking, electricity) Sludge (soil conditioning, fertilizer)
India	ANERT (similar fixed dome)	35	NP	Medical college, hospital campus, hospital – 1500/day	Gas (electricity) Sludge (soil conditioning, fertilizer)
Kenya	Water kiosk	54	5	Public toilet – 1000/day	Gas (cooking for café shop) Sludge (soil conditioning)
Nepal	Latrine-cum-biodigester	20 Gas 5.8”/day	70	School – 3010 students	Gas (cooking)
Eastern Nepal	Community toilet bio digester (fixed dome)	15	21	10 latrines – 250/day	Gas (household use) Sludge (compost)
Bangladesh	Fixed dome BCSIR	10” diameter	10-15	Public toilet – 200/day	Gas (cooking) Sludge (vegetable cultivation)
Maharastra, India	Malaprabha biogas plant	NP	45	Public toilet – 2.17 liters/person/day	Gas (cooking) Sludge (manure)
Delhi, India	Community toilet linked w/ biogas plant	1ft^2 gas, 1 person/ day	30	Public toilet – 1000/day	Gas (cooking, lighting, electricity)
Jebapur, India	KVIC	50	NP	School – 400 students	Gas (cooking) Sludge (maize crop)

HRT = Hydraulic Retention Time

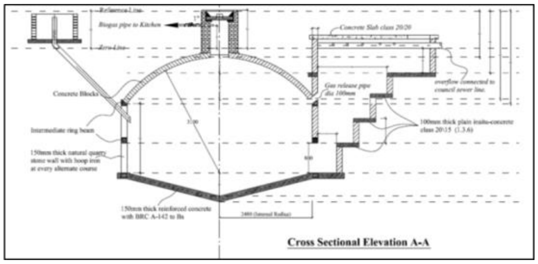
1. Sulabh International, India (Sulabh Int'l. 2017)

- Biogas generation in public toilets, pay per use
- Only uses human excreta and flush water, pour-flush
- 200 installations in India
- Additional on-site effluent treatment



2. Public toilet at bus depot, Naivasha, Kenya (Rieck and Onyango 2010)

- Biogas generation in public toilet at bus depot
- Pay per use, pour-flush toilets, ~300 users per day
- Water kiosk as well
- Use biogas for cooking (at a café next door)
- Biogas plant capacity 54 m^3

3. **Biocenters, Umande Trust, Kenya (Kushner 2016)**

- Biogas generation in public toilet, ~1000 users/day
- Pay per use, dozen toilets and cooking space in each BioCenter
- 76 BioCenters across Kenya as of 2016
- Weekly revenue of ₦24,500 from toilets/showers


APPENDIX D: EXAMPLES OF COMMUNE LEVEL CONTAINMENT

A number of cities across Africa use large septic tanks to serve apartment complexes or compounds.

1. KenyaCAST Products Ltd., Kenya (Kenyacastproducts.co.ke, accessed June 2017)

- Has tanks ranging from 1,000 liters (40 users) to 4,000 liters (400 users)
- Kitchen and shower/bathroom water is directed to soakpits to as is overflow from the tank
- The tank is specifically designed to biodegrade the sludge to eliminate pathogens



2. Bluetec Fiberglass, South Africa (Bluetec.co.za; accessed June 2017)

- Has tanks ranging from 600 liters (2 users) to 50,000 liters (250 users)
- Must be installed underground and can connect tanks in series to increase capacity